ESMAP

MINI GRIDS FOR HALF A BILLION PEOPLE

Market Outlook and Handbook for Decision Makers

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ESMAP's MISSION

The Energy Sector Management Assistance Program (ESMAP) is a partnership between the World Bank and 24 partners (https://esmap.org/donors) to help low- and middle-income countries reduce poverty and boost growth through sustainable energy solutions. ESMAP's analytical and advisory services are fully integrated within the World Bank's country financing and policy dialogue in the energy sector.

Through the World Bank Group, ESMAP works to accelerate the energy transition required to achieve Sustainable Development Goal 7 (SDG 7) (https://sdgs.un.org/goals/goal7) to ensure access to affordable, reliable, sustainable, and modern energy for all. It helps to shape WBG strategies and programs to achieve the World Bank Group's Climate Change Action Plan targets. Learn more at: https://esmap.org.

ESMAP reports are published to communicate the results of ESMAP's work to the development community. Some sources cited in this report may be informal documents not readily available.

A NOTE TO THE READER

This is a big book. It is packed with actionable information for decision-makers, and it is the World Bank's most comprehensive and authoritative publication on mini grids to date.

We intend this book as a reference guide to be consulted when important decisions about mini grids need to be made at the project, portfolio, or national program level. To that end, we have balanced cohesiveness among the chapters with each chapter's ability to stand on its own as a resource.

The book is structured as follows. The overview presents a global market outlook for mini grids and introduces the 10 building blocks that need to be in place if mini grids are to be scaled up in any country. These building blocks also represent the 10 frontiers for innovation for the sector, where, with disruptive digital solutions across all 10 frontiers, the services offered to end users can be raised to a level substantially better than what would be possible with alternatives. In the Handbook, the terms "building blocks" and "frontiers" are used interchangeably. Chapters 1–10 present the 10 building blocks in detail and answer the question *how do we scale up mini grid deployment to connect half a billion people by 2030?* Chapter 11 is our call to action.

This book is part of a comprehensive knowledge package that the World Bank has prepared on mini grids, which consists of the following elements, available online at www.esmap.org/mini_grids_for_half_a_billion_people:

- An executive summary, published separately in June 2019 (https://openknowledge.worldbank.org/handle/10986/31926).
- A volume of case studies on the history of mini grids in electric power systems, as well as mini grid regulations and subsidies in Bangladesh, Cambodia, India (Uttar Pradesh), Kenya, Nigeria, and Tanzania.
- Animations, infographics, and videos to present high-level findings to a wide audience.
- Briefs in the Live Wire series that can serve as quick reference guides for World Bank operations teams and other project implementation partners.
  - "Ensuring That Regulations Evolve as Mini Grids Mature" (https://openknowledge.worldbank.org/handle/10986/31773).
  - "Investing in Mini Grids Now, Integrating with the Main Grid Later: A Menu of Good Policy and Regulatory Options" (https://openknowledge.worldbank.org/handle/10986/31772).
- A roster of experts to provide rapid-response support for project implementation.

The objective of this comprehensive knowledge package is to present road-tested options and examples from the leading edge of mini grid development. Decision-makers can draw on these options and examples to scale up mini grid deployment in their own contexts. By acknowledging different national approaches to mini grids and providing context-specific considerations for implementation, this suite of knowledge products offers an adaptive approach to helping countries achieve their electrification targets.

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ACKNOWLEDGMENTS

This book is the result of a collaborative effort over more than four years to collect and synthesize the best research, data, and knowledge produced to date on the entire ecosystem that supports mini grids—regulations, financing, technology, training, gender, productive uses, geospatial planning, and more. We would like to acknowledge here those individuals and organizations that contributed to this project.

PARTNERSHIP AND FUNDING

This book is part of a much larger comprehensive knowledge package that was funded by World Bank/ESMAP and the Foreign, Commonwealth and Development Office of the United Kingdom as one of ESMAP's key donors in particular. This comprehensive knowledge package is the result of ESMAP's collaboration with a broad set of mini grid sector stakeholders, including mini grid developers, regulators and other government officials, financiers, technology providers, researchers, project implementation partners, development partners, and internationally recognized experts. We are particularly grateful to the following mini grid industry leaders who not only gave us their time but also helped ensure our work captured ground-level realities and frontier innovations accurately: Africa Minigrid Developers Association (AMDA), Engie, Havenhill, HOMER Energy, Husk Power Systems, INENSUS, Odyssey Energy Solutions, Power Corner, PowerGen, PowerHive, Techno Hill, and Trama TecnoAmbiental.

PROJECT MANAGEMENT AND AUTHORSHIP

This book was prepared by the Global Facility on Mini Grids team under the overall guidance of ESMAP's former and current practice managers, Rohit Khanna and Gabriela Elizondo Azuela, respectively. Jon Exel, Tatia Lemondzhava, Ashish Shrestha, and Dr. James Knuckles managed the project and oversaw the book's development, from inception to publication. Dr. Knuckles was the book's lead editor. The following individuals and organizations are this book's co-authors and contributors:

OVERVIEW: LEAD AUTHORS JON EXEL, JAMES KNUCKLES, AND TATIA LEMONDZHAVA

The chapter benefitted from expert inputs from Dr. Bernard Tenenbaum, Dr. Chris Greacen, and Peter Lilienthal (HOMER). The write-up on the first generation of mini grids is based on a report on the history of mini grids in electric power systems prepared by Morgan Bazilian (Colorado School of Mines), Francesco Fuso Nerini (KTH), Mark Howells (KTH), Alexandros Korkovelos (KTH), Lucille Langois (IAEA), Holger Rogner (IIASA), and Hisham Zerriffi (University of British Columbia), which is available on the companion website to this handbook: www.esmap.org/mini_grids_for_half_a_billion_people. Guidehouse (formerly Navigant Research) provided valuable assistance with initial data collection on the mini grid market in 2018, and we leveraged their global database as a starting point for our data set. We are grateful also to World Bank operations teams for helping us collect data on mini grids in their respective countries, and to Bloomberg New Energy Finance—in particular Itamar Orlandi—for answering our questions and helping us understand their earlier outlooks for the mini grid market. For the discussion on the Key Performance Indicators for the mini grid industry, we are grateful for contributions and guidance from the Africa Minigrid Developers Association's leadership team.

CHAPTER 1: LEAD AUTHORS CHRIS GREACEN AND JON EXEL

This chapter would not have been possible without the detailed data provided by mini grid developers. Detailed data on costs and designs are commercially sensitive. The authors thank all mini grid developers who recognized the importance of research on the evolution of mini grid costs and provided the data they could. For 32 mini grids in diverse countries across Africa and Asia, the firm Trama TecnoAmbiental S.L. (TTA) undertook the difficult work of requesting data and following up to iron out inconsistencies as they were discovered. Chris Purcell provided data for mini grids in Myanmar and Bangladesh; Sunita Chikkatur Dubey did the same for several mini grids in Ghana. The Odyssey team provided extensive data for hundreds of mini grids in Nigeria. The authors thank Andrew Pascale and Ziting Huang for their assistance and expertise in processing data and Mr. Pascale for his work on an early draft of this chapter. Marilena Lazopoulou and Pol Arranz Piera from TTA and Chris Purcell were generous and patient with our many questions.

CHAPTER 2: LEAD AUTHORS ASHISH SHRESTHA AND ALEXANDROS KORKOVELOS

The chapter benefitted from expert inputs from Philipp Blechinger (Reiner Lemoine Institut), Stewart Craine and Monty Craine (Village Infrastructure Angels), Reja Amatya (MIT), Xiangkun Li and Samuel Booth (NREL), Peter Lilienthal (HOMER), Rik Wuts (Powerhive), Ibrahim Abada (Engie), Emily McAteer (Odyssey Energy Solutions), Nabin Raj Gaihre, Philippe Raisin and Tobias Engelmeier (VIDA), and Frankie Eckersley-Carr, Imran Muhammad, Oliver Haas (Integration). The writeup on least-cost electrification planning was prepared with contributions from Chiara Odetta Rogate and Rhonda Lenai Jordan (World Bank). The spatial data analysis for Sub-Saharan Africa using GRID3 data was carried out by Christopher James Arderne.

CHAPTER 3: LEAD AUTHORS JULIETTE BESNARD, TATIA LEMONDZHAVA, JON EXEL, AND JAMES KNUCKLES

The chapter benefited from the support of Besnik Hyseni (World Bank), the Communities in Kisii and Nyamira Counties (Kenya), CLASP, Erika Lovin (CrossBoundary), Amanda DelCore (Factor[e]), GMG Facility Kenya, IDCOL, INENSUS and the World Bank RERED II team, Jon Leary, Ed Brown, and Simon Batchelor of Loughborough University, Pact/Smart Power Myanmar, Adriana Karpinska (Powerhive), SNV Netherlands Development Organisation, Barani Aung (Techno Hill), and Trama TecnoAmbiental.

CHAPTER 4: LEAD AUTHORS TATIA LEMONDZHAVA, WITH FELIX TER HEEGDE OF SNV

We are grateful to Rishabh Sachdeva of Quicksand and Elijah Siakpere of the World Bank office in Abuja, Nigeria, for additional contributions.

CHAPTER 5: LEAD AUTHORS RICKY BUCH, JON EXEL, JAMES KNUCKLES, AND TATIA LEMONDZHAVA

Kojo Adom Quagraine led the development of the database of investment deals featured in this chapter. Bryan Koo and Ziting Huang (World Bank) helped manage the nationally representative surveys of mini grid operators conducted by the World Bank and contributed to the chapter's analysis and writeup of survey results in Cambodia, Myanmar, and Nepal.

CHAPTER 6: LEAD AUTHORS INTERNATIONAL FINANCE CORPORATION, JAMES KNUCKLES, AND SUBODH MATHUR

We are grateful for feedback from David Ross of Statera Capital on earlier drafts of the chapter. Kojo Adom Quagraine led the development of the database of investment deals featured in this chapter. Dr. Chris Greacen and HOMER Energy conducted modeling and analysis for the section of this chapter on the impacts of performance-based grants on the cost of solar hybrid mini grid electricity. Yann Tanvez and Candice Lanoix provided a great deal of input from the International Finance Corporation.

CHAPTER 7: LEAD AUTHORS SUNITA DUBEY AND CASTALIA

We are grateful for contributions from the Institute of Electrical and Electronics Engineers and to GIZ, HOMER, and Trama TecnoAmbiental for their contributions as well.

CHAPTER 8: LEAD AUTHORS SUBODH MATHUR, WITH NICO PETERSCHMIDT AND JOANIS HOLZIGEL OF INENSUS

We are grateful to the International Finance Corporation for important inputs on this chapter, including the Investors' Perspective section on institutional frameworks for mini grids.

CHAPTER 9: LEAD AUTHORS CASTALIA AND JAMES KNUCKLES

This chapter draws on a research project conducted by ESMAP, Castalia, and Ecoligo, which included 11 field visits and 70 interviews, conducted between August and September 2017, with key mini grid sector stakeholders in Bangladesh, Cambodia, India (Uttar Pradesh), Kenya, Nigeria, and Tanzania. Stakeholders in each country included regulators, developers, rural electrification agencies, and consumers, as well as utilities and development partners, and we are very grateful for their time and insights. A full list of acknowledgments for each of the six countries is provided at the end of chapter 9. We also thank the International Finance Corporation for important inputs on this chapter, including the Investors' Perspective section on mini grid regulations.

CHAPTER 10. LEAD AUTHORS: JAMES KNUCKLES AND CASTALIA

Castalia developed sections of the chapter as part of a larger project it completed for ESMAP (see chapter 9), and Elijah Abiodun Siakpere contributed in major ways to the write-up of the standardized Environmental and Social Management System in Nigeria. Dr. Chris Greacen and Anastas Mbawala provided valuable comments on earlier drafts of the standardized asset transfer agreement. We are grateful to the International Finance Corporation for important inputs on this chapter as well, including the Investors' Perspective section on factors that make it easier (or harder) for mini grid developers to do business.

CHAPTER 11: LEAD AUTHORS JON EXEL AND JAMES KNUCKLES

KEY GENDER ASPECTS THROUGHOUT THE BOOK

Inka Schomer and Mary Dominic (World Bank) provided important contributions on the gender-related aspects of mini grid topics throughout the book, from access to finance to productive uses to community engagement and skills building, among others.

REVIEW AND CONSULTATION

This handbook underwent a formal World Bank Decision Review in February 2022, chaired by Demetrios Papathanasiou, Global Director for the Energy & Extractives Global Practice. The peer reviewers were Raihan Elahi (Lead Economist, World Bank), Dana Rysankova (Lead Energy Specialist and Global Lead for Energy Access, World Bank), Arsh Sharma (Senior Energy Specialist, World Bank), Patrick Thaddayos Balla (Senior Energy Specialist, World Bank), and Yann Tanvez (Energy Specialist, International Finance Corporation). In addition, the following experts carefully reviewed the book in whole or in part. For their time, expertise, and thoughtful comments we are exceptionally grateful. Dr. Bernard Tenenbaum, Castalia, INENSUS, the Rocky Mountain Institute, and Trama TecnoAmbiental reviewed the book in its entirety; their comments greatly elevated the quality of the final product. Gabriela Elizondo Azuela and Michael Toman (World Bank) provided provided invaluable input on the report's main findings that helped us convey comprehensive and impactful messages throughout the book. Comments from the United Kingdom's Foreign, Commonwealth and Development Office, the United States National Renewable Energy Laboratory, the Institute of Electrical and Electronics Engineers, and the Africa Minigrid Developers Association helped us transform several chapters throughout the book. The International Finance Corporation also provided extensive comments on several chapters, which strengthened the book as a whole. To all of these reviewers: thank you.

STAKEHOLDER ENGAGEMENT

Over the past five years, ESMAP has cohosted events and workshops on mini grids both virtually and in-person in Ethiopia, Ghana, Kenya, Myanmar, Nigeria, Spain, Tanzania, the United Kingdom, and the United States. We are particularly grateful for the host governments as well as the more than 2,000 participants at these events representing all mini grid stakeholder groups from more than 60 countries for their input, debate, and validation of the knowledge brought together in this report. The Global Facility on Mini Grids team would also like to express its gratitude to the ESMAP communications team, and especially to Lucie Blyth, Nansia Constantinou, Anita Rozowska, and Janice Tuten for their help in synthesizing and tailoring the main messages of this report for a wide audience, and their overall support in its preparation and dissemination.

EDITING, GRAPHIC DESIGN, AND OTHER CONTRIBUTORS

Our editors, Joan O'Callaghan and Steven Kennedy, require special praise. We are grateful to have been able to work with them. Naylor Design, Inc. typeset the manuscript and designed every table, chart, and figure in this book. The quality and consistency they brought to this report is a testament to their diligence and expertise.

The many people we interviewed or who reviewed this report were gracious with their time and knowledge. They were patient and accommodating with our requests under tight deadlines, and we are sincerely grateful. We alone are responsible for any errors of fact or interpretation.

ABBREVIATIONS

—	not available
A-B-C	Anchor-Business-Community
AC	alternating current
ACP-EU	Africa, Caribbean, and Pacific Group of States–European Union
ADB	Asian Development Bank
AFD	Agence Française de Développement (French Development Agency)
AfDB	African Development Bank
AGRITEX	Agricultural Technical and Extension Services
Ah	ampere-hour
AMADER	Agency for the Development of Domestic Energy and Rural Electrification
AMDA	Africa Minigrid Developers Association
ARE	Alliance for Rural Electrification
ATP	ability to pay
BAU	business as usual
BBBEE	Broad-Based Black Economic Empowerment Act of 2003
BERC	Bangladesh Energy Regulatory Commission
BLS	Bureau of Labor Statistics
BMZ	Federal Ministry for Economic Cooperation and Development
BNEF	Bloomberg New Energy Finance
BOO	build-own-operate
BRD	Development Bank of Rwanda
CAPEX	capital expenditure
CBS	Central Bureau of Statistics
CE	community engagement
CEDECAP	Centre of Demonstration and Qualification in Appropriate Technologies
CELAMeD	community engagement, load acquisition and micro-enterprise development
CIESIN	Center for International Earth Science Information Network
CO_2	carbon dioxide
cofin.	cofinanced
COGS	cost of goods sold
COP	Conference of the Parties
CPI	Climate Policy Initiative
CREDA	Chhattisgarh State Renewable Energy Development Agency
CSCs	customer service centers
DC	direct current

DISCO	distribution company
DRC	Democratic Republic of Congo
E4I	Energy4Impact
EAC	Electricity Authority of Cambodia
ECOWAS	Economic Community of West African States
ECREEE	ECOWAS Centre for Renewable Energy and Energy Efficiency
ECS	electricity consumer society
EDC	Electricité du Cambodge (Cambodia Electricity)
EDC	Enterprise Development Cambodia
EPC	engineering, procurement, and construction company
EEP	Energy and Environment Partnership
e-MPF	European Microfinance Platform
ERC	Energy Regulatory Commission
ESCO	energy service company
ESIA	Environmental and Social Impact Assessment
ESMAP	Energy Sector Management Assistance Program
ESMP	Environmental and Social Management Plan
ESMS	Environmental and Social Management System
EUEI PDF	European Union Energy Initiative Partnership Dialogue Facility
EWURA	Energy and Water Utilities Regulatory Authority
FCDO	Foreign, Commonwealth and Development Office
FCV	fragility, conflict, and violence
FDoE	Fiji Department of Energy
GEM	Global Entrepreneurship Monitor
GFMG	Global Facility on Mini Grids
GIS	geographic information system
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (German Society for International Cooperation)
GMG	Green Mini-Grid Help Desk
GoP	Government of Peru
GVE	Green Village Electric
GW	gigawatt
GWh	gigawatt-hours
GWp	gigawatts-peak
ha	hectare
HOMER	Hybrid Optimization of Multiple Energy Resources
HR	human resources
HRSL	High Resolution Settlement Layer
HV	high voltage
ICT	information and communications technology
IDCOL	Infrastructure Development Company Limited
IDS	Institute of Development Studies
IEA	International Energy Agency

IEEE	Institute of Electrical and Electronics Engineers
IEG	Independent Evaluation Group
IFC	International Finance Corporation
ILO	International Labour Organization
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IPP	independent power producer
IQR	interquartile range
IRENA	International Renewable Energy Agency
IUCN	International Union for Conservation of Nature
JPS	Jamaica Public Service Company
KBA	key biodiversity area
km	kilometer
KPI	key performance indicator
KPLC	Kenya Power and Lighting Company
kVA	kilovolts-ampere
kW	kilowatts
kW_{firm}	kilowatts of firm alternating current output
kWh	kilowatt-hour
kWp	kilowatts-peak
L	liter
LCOE	levelized cost of energy
LCOS	levelized cost of storage
LED	light-emitting diode
LF	load factor
LGA	local governmental area
li	lithium
LRP	Livelihood Restoration Plan
LV	low voltage
M	million
MAS	Multi-Agent System
MDG	Millennium Development Goal
MFD	Maximizing Finance for Development
MG	mini grid
MGA	Micro-Grid Academy
mi	mile
MIA	Microgrid Investment Accelerator
MIT	Massachusetts Institute of Technology
MLIP	Ministry of Labour, Immigration and Population
MOHP	Ministry of Health and Population
MOI	Ministry of Infrastructure
MRG	Minimum Revenue Guarantee

MTF	Multi-Tier Framework
MV	medium voltage
MW	megawatt
MWh	megawatt-hour
n.a.	not applicable
NAPTIN	National Power Training Institute of Nigeria
n.d.	no date
NEP	Nigeria Electrification Project
NERC	Nigerian Electric Regulatory Commission
NGO	nongovernmental organization
NIS	National Institute of Statistics
NPC-SPUG	National Power Corporation Small Power Utility Group
NREL	National Renewable Energy Laboratory (US)
O&M	operations and maintenance
ODI	Overseas Development Institute
OECD	Organisation for Economic Co-operation and Development
OEM	original equipment manufacturer
OPEX	operational expenditure
OSM	OpenStreetMap
OUR	Office of Utilities Regulation
P2PB	peer-to-peer business
PAYG	pay-as-you-go
PDR	(Lao) People's Democratic Republic
PFI	participating financial institution
PPA	power purchase agreement
PPP	public-private partnership
PRG	partial risk guarantee
PU	productive use
PUE	productive uses of energy
PV	photovoltaic
PwC	PricewaterhouseCoopers
RAP	Resettlement Action Plan
RE	renewable energy
REA	Rural Electrification Agency (Nigeria)
REA	Rural Energy Agency (Tanzania)
REAs	rural electrification/energy agencies
REF	Rural Electrification Fund (Cambodia)
REF	Renewable Energy Fund
REM	Reference Electrification Model
RENAC	Renewables Academy
REopt	Renewable Energy Integration and Optimization
RES4Africa	Renewable Energy Solutions for Africa

RISE	Regulatory Indicators for Sustainable Energy
RMI	Rocky Mountain Institute
RoE	return on equity
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SEforALL	Sustainable Energy for All
SDG	Sustainable Development Goal
SDG7	Sustainable Development Goal 7
SG&A	selling, general, and administrative
Sh	shilling
SI	system integrator
SIDA	Swedish International Development Cooperation Agency
SM	smart meter
SNV	Netherlands Development Organisation
SPD	small power distributor
SPI	Smart Power India
SPM	Smart Power Myanmar
SPP	small power producer
TANESCO	Tanganyika Electric Supply Company
TARA	Society for Technology and Action for Rural Development
TASF	Transaction Advisory Services Facility
TTA	Trama TechnoAmbiental
TWp	terawatts-peak
UCS	Union of Concerned Scientists
UN	United Nations
UNDP	United Nations Development Programme
UNIDO	United Nations Industrial Development Organization
UNOPS	United Nations Office for Project Services
USAID	United States Agency for International Development
USD	United States dollar
USDA	United States Department of Agriculture
US DOE	United States Department of Energy
USG	United States Government
VEC	Village Electrification Committee
VIA	Village Infrastructure Angels
W	watt
WB	World Bank
W_{firm}	watt of firm alternating current output
Wdc	watt of direct current
Wp	watts-peak
WTP	willingness to pay

All dollar amounts are US dollars unless otherwise indicated.

MINI GRIDS BY THE NUMBERS

Where we are today

48 million people connected to **21,500 mini grids,** of which half are solar PV, at an investment cost of **$29 billion**.

29,400 mini grids planned, 95 percent of them in Africa and South Asia, 99 percent solar PV, connecting more than 35 million people at an investment cost of **$9 billion.**

Where we need to be to reach universal access by 2030

490 million people served at least cost by **217,000 mini grids,** almost all solar-powered, requiring an investment of **$127 billion.**

To deploy mini grids at scale, countries must act on **10 Building Blocks**: (**1**) reducing costs and optimizing design & innovation for solar mini grids; (**2**) planning national strategies and developer portfolios with geospatial analysis and digital platforms; (**3**) transforming productive livelihoods and improving business viability; (**4**) engaging communities as valued customers; (**5**) delivering services through local and international companies and utilities; (**6**) financing solar mini grid portfolios and end user appliances; (**7**) attracting exceptional talent and scaling skills development; (**8**) supporting institutions, delivery models, and champions that create opportunities; (**9**) enacting regulations and policies that empower mini grid companies and customers; (**10**) cutting red tape for a dynamic business environment.

Regional mini grid trends from ESMAP's database of more than 50,000 mini grid projects in 138 countries

INSTALLED (mostly first- and second-generation mini grids)	PLANNED (mostly third-generation mini grids)
9,600 South Asia	**19,000** South Asia
7,200 East Asia and Pacific	**800** East Asia and Pacific
3,100 Africa	**9,000** Africa
1,200 OECD and Central Asia	**400** OECD and Central Asia
300 Other	**100** Other

Top 5 countries . . .

INSTALLED (mostly first- and second-generation mini grids)	PLANNED (mostly third-generation mini grids)
4,700 Afghanistan	**18,900** India
4,000 Myanmar	**2,700** Nigeria
3,200 India	**1,500** Tanzania
1,500 Nepal	**1,200** Senegal
1,200 China	**600** Ethiopia

Current financing

$29 billion—Cumulative global investment in mini grids to date

$9 billion—Cumulative global investment in Africa and South Asia in mini grids to date

$2.6 billion—Development Partners committed, including AFD, AfDB, FCDO, the Islamic Development Bank, GIZ and the World Bank, among others

$1.4 billion—World Bank commitment to mini grids in 31 countries through 2027

$500+ million—Private-sector investment in mini grid developers in low-income countries since 2013

25 percent—Average World Bank share of total mini grid investment (government, development partners, and private sector) in client countries

Top 3 private-sector developers *By installed and planned mini grids*

1. **Tata Power Renewable Microgrids** (10,000 / India)
2. **Husk Power** (5,000 / India & Africa)
3. **OMC Power** (5,000 / India)

Top 3 utilities *By installed and planned mini grids*

1. **RAO** (700 / Russia)
2. **PT Perusahaan Listrik Negara** (500 / Indonesia)
3. **NPC-SPUG** (300 / Philippines)

Private-sector opportunity

$3.3 billion annual profit potential for developers across all mini grids deployed through 2030

$5.8 billion net profit potential across all mini grid component and service suppliers in 2030 alone

Cost of a best-in-class solar-hybrid mini grid today . . .

$3,659/kW$_{firm}$ total capital expense

$596/kWp Solar PV Module

$297/kWh Lithium-ion batteries

. . . and by **2030**

<$2,500/kW$_{firm}$ total capital expense

$290/kWp Solar PV Module

$137/kWh Lithium-ion batteries

$265/kW battery inverter

Cost of unsubsidized electricity from a best-in-class solar hybrid mini grid . . .

$0.38/kWh (LCOE) baseline today

$0.28/kWh with income-generating machines to achieve 40 percent load factor

$0.20/kWh with income-generating machines and expected 2030 costs

. . . Compared with utilities in Africa

$0.27/kWh average across 39 utilities

2 of 39 utilities with cost-recovery tariffs

Income-generating machinery

< 12 months payback period
for more than 130 income-generating machines and other equipment available today

$3.6 billion microfinance needed for 3 million machines and other equipment connected to third-generation mini grids in 2030

3rd generation mini grid service . . .

99 percent uptime

Tier 4–5 access

84/100 customer satisfaction rate

. . . compared with typical utilities

40–50 percent uptime

Tier 3–4 access

41/100 customer satisfaction rate

Environmental impact

10–15 GW solar PV installed by 2030

50–110 GWh batteries mostly lithium-ion

60 percent energy savings from energy efficient appliances

1.2 billion tonnes of CO_2 emissions avoided

Typical third-generation mini grid

$0.5– $1.0 million investment

200–800 clients connected

800–4,000 people receiving electricity for the first time

50–100 kWp solar PV installed

200–500 kWh batteries installed

What is a mini grid?

Mini grids are electric power generation and distribution systems that provide electricity to just a few customers in a remote settlement or bring power to hundreds of thousands of customers in a town or city. They can be fully isolated from the main grid or connected to it but able to intentionally isolate ("island") themselves from the grid. Mini grids supply power to households, businesses, public institutions, and anchor clients, such as telecom towers and large agricultural processing facilities. They are designed to provide high-quality, reliable electricity. A new, "third generation" of mini grids has recently emerged. They incorporate the latest technologies, such as smart meters and remote monitoring systems; and are typically designed to interconnect with the main grid.

To be considered in our analysis in the context of this report, a mini grid had to serve multiple customers. Electricity systems that service a single hospital, industrial facility, military base, university campus, mine, or other single entity, were therefore not considered mini grids. We also do not define mini grids in terms of size, although in our detailed analysis of mini grid costs and in our global database of more than 50,000 mini grid projects, the vast majority (90 percent) ranged from 10 kW to 1 MW in installed capacity.

Sources and underlying analysis for the figures above are presented throughout the book.

Key performance indicators for the mini grid industry	2018	2021	2025*
Reducing cost (levelized cost of energy [$/kWh] of a best-in-class solar hybrid mini grid)	$0.55/kWh	$0.38/kWh	$0.30/kWh
Pace of deployment (mini grids built per key access-deficit country per year)	20–75 mini grids	150 mini grids	450 mini grids
Quality of service (industry-wide standard for reliability of electricity supply)	90–97 percent uptime	99 percent uptime	99 percent uptime
Access to finance for mini grids designed to boost access to energy (total cumulative investment)	$13 billion	$16 billion	$25 billion
Establish enabling environments (average RISE score for mini grids framework in top 20 electricity access-deficit countries)	59/100	64/100	75/100

Note: * projection with business-as-usual scenario.

Mini grid industry progress across all 10 frontiers / building blocks	2018	2021	2025*
Reducing costs and optimizing design and innovation for solar mini grids	yellow	light green	light green
Planning national strategies and developer portfolios with geospatial analysis and digital platforms	yellow	dark green	dark green
Transforming productive livelihoods and improving business viability	orange	yellow	light green
Engaging communities as valued customers	orange	yellow	light green
Delivering services through local and international companies and utilities	orange	light green	dark green
Financing solar mini grid portfolios and end user appliances	yellow	light green	light green
Attracting exceptional talent and scaling skills development	orange	yellow	light green
Supporting institutions, delivery models, and champions that create opportunities	orange	light green	dark green
Enacting regulations and policies that empower mini grid companies and customers	yellow	light green	dark green
Cutting red tape for a dynamic business environment	orange	yellow	light green

Note: * projection with business-as-usual scenario.

Dark green = magnitude change has been achieved; light green = irreversible progress towards magnitude change; yellow = needing attention; orange = no significant activities to date.

MAIN FINDINGS

THE NEW ELECTRICITY ACCESS LANDSCAPE

To achieve Sustainable Development Goal 7 (SDG 7), 930 million people will have to obtain an electricity connection between 2022 and 2030 (IEA 2021). In 2020, the global electrification rate reached 91 percent, with the number of people without access dropping to around 733 million—compared with around 1 billion people in 2016 and 1.2 billion in 2010 (IEA, World Bank, and others 2022). Nonetheless, the pace of electrification has slowed in recent years. Between 2010 and 2018, an average of 130 million people gained access to electricity annually. From 2018 to 2020, this number shrank to 109 million per year. While the slowdown is attributed in part to the difficulties in reaching the remotest and most vulnerable populations, it was compounded by the devastating effects of the COVID-19 pandemic. If current policies and efforts are not ramped up, only 260 million people are anticipated to be electrified between now and 2030 (IEA 2021), and an estimated 670 million people are projected to remain without access, with 9 out of 10 of them likely to live in Sub-Saharan Africa (IEA, World Bank, and others 2022).

In Sub-Saharan Africa, nearly 291,000 population clusters have profiles favoring the deployment of solar mini grids. That is, they are located more than 1km from the existing grid network and have a population density (>1,000 people/km^2) that favors decentralized system deployment. More specifically, analysis conducted internally by the World Bank team—based on spatial distribution of digitalized settlements (GRID3, CIESIN), grid network (Arderne C. et al—GridFinder) and population (WorldPop) over the region—shows that more than 177,000 settlements have a population of 100 to 500 people. These settlements could be powered by smaller solar mini grids of up to 20 kilowatts (kW) each. Nearly 96,000 settlements, each with populations of 500 to 2,500 people, could be powered by medium-sized solar mini grids of up to 80 kW. The larger solar mini grids, up to 200 kW, could power more than 15,000 settlements, each with 2,500 to 10,000 residents. Finally, for nearly 3,000 settlements, each with 10,000 to 100,000 people, custom sizing of mini grids might be more suitable.

Internal analysis by the World Bank team based on Multi-Tier Framework (MTF) data suggests that users in these load centers spend on average \$5–\$20 per month on alternative forms of energy such as candles, kerosene, dry-cell batteries, car batteries, and petrol and diesel fuel for stand-alone gensets. The introduction of innovative technologies in the marketplace (like solar home systems or mobile phones) has taught us that these new solutions need to be more than a little better than the current alternative. They need to be much better. Why else would consumers take the risk of changing their behaviors? For these clusters of clients, the service provided by the solar mini grids should be a reliable source for their consumptive activities like lighting, charging, and radio/TV. More than that, they need to provide for life-changing productive activities within the current monthly expenditure of \$5–\$20. From the end user's perspective, a \$5–\$20 monthly expenditure should cover the cost not only of reliable electricity but also of transitioning to (and purchasing) electric appliances. So over the lifetime of the technology, monthly payments of about \$3–\$15 cover the cost of electricity, while monthly payments fall in the range of \$2–\$5 for appliances. These costs pose a challenge for the mini grid industry if it is to fulfil its full market potential.

Countries with a comprehensive approach involving main grid extensions, mini grids, and solar home systems have achieved the fastest results in electricity access (IEA, World Bank, and others 2022). Strong leadership, supporting policies, and more private financing will be required if electricity access is to reach the remaining unserved people—including those that depend on frail, overburdened urban grids and displaced people and those living in hard-to-reach locations. In Sub-Saharan Africa, electricity services are delivered to end users by 60 utilities, more than 80 solar mini grid companies, and almost 90 main solar stand-alone-system companies (Balabanyan and others 2021; GOGLA 2022).

Mini grids are not a new phenomenon: nearly all centralized electricity grid systems began as isolated mini grids that were connected to each other over time. This first generation of mini grids was pivotal to the early development and industrialization of most modern economies, including Brazil, China, Denmark, Italy, the Netherlands, Spain, Sweden, the United Kingdom, and the United States. Mini grid systems introduced in the late nineteenth and early twentieth centuries can be described as the first generation of mini grids. Today a second generation of mini grids is widespread in many low-income countries. These systems are typically small and isolated, powered by diesel or hydro, and built by local communities or entrepreneurs primarily to provide rural households with access to electricity, especially in areas not yet served by the main grid. Tens of thousands of these systems were built, starting in the 1980s and ramping up through the 1990s and early 2000s. Many of these systems were overtaken by the national grids; the ones that still exist are now prime candidates for hybridization with solar photovoltaic (PV) systems to reduce the fuel cost.

Over the past few years, a third generation of solar mini grids has emerged. These mini grids, mostly solar PV hybrids, are owned and operated by private companies that leverage transformative technologies and innovative strategies to build portfolios of mini grids instead of one-off projects. The typical third-generation mini grid is grid-interconnection ready. It also uses energy management systems, prepay smart meters, and the latest solar hybrid technologies. This third-generation mini grid also incorporates energy-efficient appliances for productive uses of electricity into its business model. These mini grids operate in more favorable business environments, taking advantage of cost reductions in the latest mini grid component technologies and regulations developed specifically for private-sector investment. Developers of third-generation mini grids are joining industry associations to speak with one voice and drive policies and regulations that favor private-sector investment.

The Energy Sector Management Assistance Program (ESMAP) analysis indicates that a combination of falling costs for key components, the introduction of new digital solutions, and early signs of favorable economies of scale, has made solar mini grids an option to connect 490 million people by 2030. Achieving universal access to electricity will require the construction of more than 217,000 mini grids by 2030 at a cumulative investment cost of almost $127 billion. Of these totals, mini grids are the least-cost option for 430 million people who would gain access to electricity for the first time at a cost of about $105 billion. For about $22 billion, an additional 60 million people, mostly in middle- and high-income countries, could be serviced through an interconnected network of mini grids either because the main grid is unreliable or to boost resilience in the face of climate shocks or severe weather. With more than 160,000 mini grids needed, Sub-Saharan Africa accounts for the largest share of mini grids and investment required to achieve universal access, at a cost of $91 billion to connect 380 million people. These projections are based on country-specific scenarios for the 58 countries with data in the Global Electrification Platform (GEP) and ESMAP estimates for countries not included in the GEP. Meanwhile, ESMAP estimates that resilience- and renewable-motivated mini grids could serve an additional 2–3 million new connections globally (serving 6–7 million people) per year, or the equivalent of 10–15 cities or small regional utilities per year deciding to strengthen their power systems by developing interconnected micro/mini/metro grids.

In 2021, the global mini grid market consisted of more than 50,000 installed and planned mini grids in more than 130 countries. Although there is a clear trend toward solar as the dominant technology, the overall pace of mini grid development is not on track to achieve the 2030 mini grid market potential. ESMAP identified 21,557 mini grids in 131 countries and territories, serving more than 48 million people. Most of these systems are first- and second-generation mini grids, and approximately half of installed mini grids are powered by solar, with hydro and fossil fuels accounting for an additional 35 percent and 10 percent, respectively. Another 29,353 mini grids are planned for development in 77 countries and territories, of which 99 percent will be powered by solar. The trend toward solar has been accelerating: more than 10 times as many solar mini grids were built per year from 2016 to 2020 than fossil fuel mini grids. Meanwhile, from 2010 to 2014, by comparison, about three times as many solar mini grids were built per year than fossil fuel mini grids. This is a major acceleration in solar and deceleration in fossil fuels. But the annual pace of mini grid development worldwide—averaging between 1,300 and 1,900 between 2010 and 2021—would see only 44,800 mini grids serving 80 million people at a total investment cost of $37 billion by 2030. This is well short of the 430 million people that could be served at least cost by mini grids in order to achieve universal access.

Year-on-year gains needed to achieve universal access will require scaling up private-sector-led mini grid deployments from tens to hundreds to thousands of mini grids per country per year in each of the top 20 countries with the highest electricity access deficit rates today. Examples showing this exponential growth are with the introduction of mobile phones, solar home systems, and electric vehicles, where the private sector, supported by public policies, provides superior products. Does this mean that more public-sector-led programs cannot be beneficial? Not at all: these programs provide great benefits to the country and the end users. Yet when one must attain universal access by 2030, private-sector-led programs should be the dominant initiative, across the board, in a country or region.

Overarching sector performance indicators and targets can help benchmark the sector. It is within this context of market dynamics as well as through a collaborative, iterative process, that ESMAP and mini grid industry leaders—including the Africa Minigrid Developers Association (AMDA) and development partners—jointly identified five market drivers and associated targets that will set the sector on a trajectory to achieve universal electrification and its full market potential (table MF.1).

These targets are ambitious but achievable if 10 building blocks are in place at the national level. Looking through the lens of innovation and the impact that, for example, digitization and technological advancement can bring to the solar mini grid sector, our analysis identified 10 areas that stood out where notable magnitude-level improvements can be expected to reach the abovementioned targets of cost (C), pace (P), quality (Q), finance (F), and enabling environment (EE). These are identified in table MF.2.

The industry is ahead or on track to achieve most of the key performance indicators (KPIs), but it lags in terms of number of mini grids installed per key energy access deficit country per year, and total cumulative investment. The overall cost of the delivery of electricity services by mini grids has plunged since 2018, from a levelized cost of energy (LCOE) of a best-in-class solar hybrid mini grid equal to $0.55/kilowatt-hour (kWh) to $0.38/kWh in 2021, compared with the $0.45/kWh target for 2021. The quality of mini grid electricity services is also ahead of pace, with AMDA members achieving uptimes of around 99 percent in 2021 compared with 90–97 percent in 2018 and the 2021 objective of 97 percent uptime. A continuation of delivery of high-quality services has improved the average load factor, from around 22 percent in 2018 to 30 percent in 2021, ahead of the 2021 objective of 25 percent. Enabling environments have also improved and are ahead of pace, with the Regulatory Indicators for Sustainable Energy (RISE) score for mini grids in the top 20 access-deficit countries rising from 59/100 in 2018 to 64/100 in 2021, on pace to achieve 90/100 by 2030, compared with 80/100 as the

TABLE MF.1 • Market drivers and 2030 targets

Market Driver	2030 Target
1. Reduce the cost of solar hybrid mini grids.	$0.20/kilowatt-hour (kWh).
2. Increase the pace of deployment through a portfolio approach to mini grid development.	Building around 2,000 projects per key access-deficit country per year by 2030.
3. Provide superior-quality service.	Achieving industrywide average uptime of more than 97 percent and industrywide average load factor of 45 percent.
4. Leverage development partner funding and government investment to "crowd in" private-sector finance.	Attracting approximately $127 billion of investment from development partners, governments, and the private sector, of which $105 billion for energy access mini grids.
5. Establish enabling mini grid business environments in key access-deficit countries.	Raising the average Regulatory Indicators for Sustainable Energy (RISE) score in the top 20 electricity-access-deficit countries to 80 out of 100.

TABLE MF.2 • Building blocks and identified areas for potential magnitude change

Building Blocks / Identified Areas for Potential Magnitude Change	Progress 2018–21
2. Planning national strategies and developer portfolios with geospatial analysis and digital platforms (C, P, F, EE)	
1. Reducing costs and optimizing design and innovation for solar mini grids (C, P, Q)	
9. Enacting regulations and policies that empower mini grid companies and customers (C, P, EE)	
5. Delivering services through local and international companies and utilities (C, P, Q, F)	
6. Financing solar mini grid portfolios and end-user appliances (P, F, EE)	
8. Supporting institutions, delivery models, and champions to create opportunities (C, P, EE)	
3. Transforming productive livelihoods and improving business viability (C, Q)	
4. Engaging communities as valued customers (C, P, Q)	
7. Attracting exceptional talent and scaling skills development (C, P, Q, F, EE)	
10. Cutting red tape for a dynamic business environment (C, P, EE)	

Dark green = magnitude change has been achieved; light green = irreversible progress toward magnitude change; yellow = needs attention. C= cost; EE = enabling environment; F = finance; P = pace; Q = quality.

2030 target. But while the industry has seen a shift from the deployment of mini grids on an individual pilot basis to their deployment by service providers in portfolios of 5 to 10 mini grids per month in 2021, the pace across the industry is still behind the 200 mini grids per country per year in 2021 needed to be on track for achieving 2,000 mini grids per country per year in 2030. In addition, while cumulative investment in mini grids for energy access rose from about $13 billion in 2018 to $16 billion in 2021, this is well behind the $20 billion needed to be on pace to achieve $105 billion cumulative investment in energy access mini grids by 2030.

Over the past three years, notable progress has been evident across all building blocks. Most of the advances were seen in the geospatial portfolio planning and workable regulations. Solid progress has also been evident in technology and costing in the private sector and utilities, along with greater access to finance and supporting institutions. Even though we see advances with productive uses and community involvement (and on attracting exceptional talent and reducing red tape), these are the very areas where transitions must emphasize scale on the ground. For more details on progress by building block, see each of the chapters covering these topics.

A cohort of partners has begun to track building blocks by country for in-country coordination and readiness to scale. For key access-deficit countries and regions in Sub-Saharan Africa, we see that Ethiopia, Kenya, and Nigeria have taken more steps toward achieving magnitude changes across the 10 building blocks than the other countries and regions (table MF.3). The Democratic Republic of Congo and the Sahel, despite being large potential markets for mini grids, need major support on almost all 10 building blocks to prepare the market for scaling up mini grid deployments. The most progress has been made in geospatial planning and the costing, design, and innovation of solar hybrid mini grids. The most work, however, is needed to support these key countries and regions, and others, in community engagement, scaling up private sector participation and utilities to deploy mini grids, and skills development.

BUILDING BLOCKS 1 THROUGH 10 AND FRONTIERS FOR SECTOR GROWTH: Creating the Environment for Takeoff of Mini Grid Portfolios

Building blocks 1 through 10 and the frontiers for sector growth are described in the sections that follow.

BUILDING BLOCK 1. SOLAR MINI GRID COSTS, DESIGN, AND INNOVATION

Solar mini grids consist of specialized components for the generation, distribution, metering, and consumption of electricity (figure MF.1). A typical third-generation mini grid comprises a solar hybrid generation system made up of solar panels, batteries, charge controllers, inverters, and diesel backup generators. The distribution network consists of poles and low-voltage wires; larger mini grids sometimes also have medium-voltage systems. Third-generation mini grids often use smart meters offering both prepaid payment options for consumers and real-time, granular information about energy consumption patterns and system performance. They also use remote-monitoring systems that allow operators to identify technical

TABLE MF.3 • Sub-Saharan African mini grid markets and their progress across the 10 building blocks

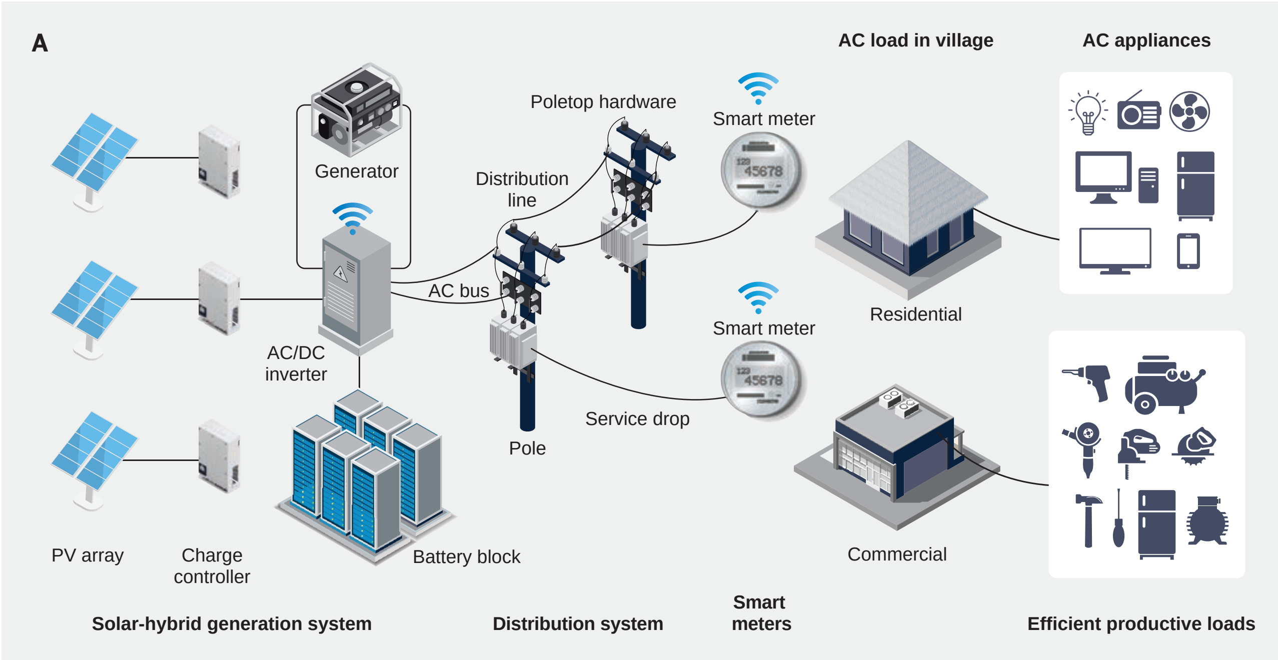
Building block	DRC	Ethiopia	Kenya	Nigeria	Sahel
1. Costing, design, and innovation	light green	light green	dark green	dark green	dark green
2. Geospatial planning	dark green	dark green	light green	dark green	light green
3. Income-generating appliances and machines	yellow	light green	light green	light green	yellow
4. Community engagement	yellow	orange	light green	yellow	light green
5. Companies and utilities	yellow	yellow	light green	dark green	yellow
6. Access to finance	light green	light green	light green	light green	yellow
7. Skills development	orange	orange	yellow	yellow	orange
8. Institutional setup and business models	yellow	light green	light green	dark green	dark green
9. Regulations and policies	yellow	light green	dark green	dark green	light green
10. Cutting red tape	yellow	yellow	yellow	light green	yellow

Source: ESMAP analysis.

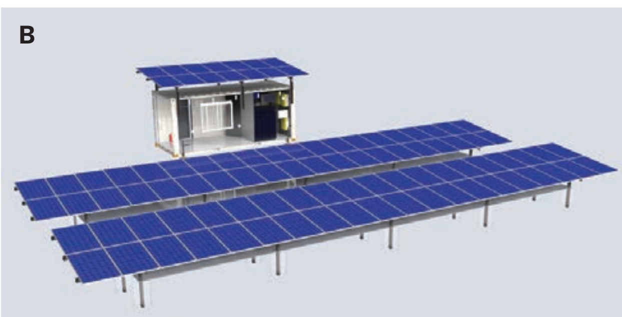
Dark green = magnitude change has been achieved; light green = irreversible progress toward magnitude change; yellow = needs attention; orange = no significant activities to date.

DRC = Democratic Republic of Congo.

FIGURE MF.1 • A mini grid system (part A) and a containerized solar mini grid (part B)



AC = alternating current; DC = direct current; PV = photovoltaic.



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issues before they affect energy services and rectify problems quickly and inexpensively, thus improving the quality of customer service. Many developers of third-generation mini grids encourage and incentivize customers to use efficient household appliances as well as efficient machines and equipment for income-generating activities, and provide or facilitate access to financing options to help customers manage upfront costs.

Smaller solar mini grids with an installed capacity of about 100 kW or less are more and more standardized, ranging from prefabricated components to containerized mini grids. Larger systems with an installed capacity of more than 250 kW remain designed and delivered on an individual system basis. Irrespective of the installed capacity, service providers have chosen their mini grid design around one main technical and business approach, for example, solar battery system only, solar-biomass-based systems, AC (alternating current) or DC (direct current) systems, and high digital solution integration.

The Levelized Cost of Energy of a Solar Mini Grid

In 2021, the LCOE in a best-in-class, third-generation mini grid was $0.38/kWh at a 22 percent load factor, or a 31 percent reduction from 2018. This trajectory is fueled by the falling expenditures for preparation, capital, and operations, combined with more income-generating uses of electricity and more efficient economies of scale. The combination of expected cost reductions and higher load factors (from 22 percent to 40 percent) caused by productive use is expected to bring the LCOE of third-generation mini grids to $0.20/kWh by 2030 (table MF.4).

Preparation costs have been reduced by more than an order of magnitude to $2,300 per mini grid; however, there is limited progress in efficiency. The introduction of geospatial and other digital technologies have decreased the cost of preparation and planning by an order of magnitude. In the past, the unit cost per site was more or less the same, irrespective of the number of sites—about $30,000 per site—because each one required a high level of on-site analysis. Today, portfolios of mini grids can be prepared to the point where they are ready for full feasibility assessment and community engagement at a cost of about $2,300 per site in 2021, based on the World Bank's recent experience in Ethiopia, Nigeria, and South Sudan.

TABLE MF.4 • The levelized cost of energy by load factor, 2018, 2021, and 2030

	Levelized cost of energy (US$/kWh)		
Load factor (percent	2018	2021	2030
22	0.55	0.38	0.29
40	0.42	0.28	0.20

Source: ESMAP analysis.

Note: The 2018 LCOE data are for a best-in-class 294-kW_{firm} solar hybrid mini grid in Bangladesh serving more than 1,000 customers (more than 5,000 people). LCOE data for 2021 are based on a representative mini grid synthesized from average costs and consumption levels in three mini grids in Myanmar, Nigeria, and Ethiopia commissioned in 2020 or 2021. The 2030 LCOE is for a "best-in-class" mini grid based on projected component costs in 2030. A detailed description of the underlying analysis is provided in chapter 1.

kWh = kilowatt-hour.

A best-in-class solar hybrid mini grid costs about $3,700/$kW_{firm}$,[1] and the falling trend is expected to continue through 2030, bringing capital expenditure (CAPEX) to below $2,500/$kW_{firm}$. Components used for generating and distributing electricity account for 66 percent of total capital costs. The components with the largest share of overall CAPEX were batteries (15 percent). PV modules (10 percent), inverters/energy management systems (9 percent), and distribution grids (poles, wires; 27 percent). Meanwhile, component costs vary widely across countries and regions, mostly as a result of a combination of taxes and duties, differences in margins charged by wholesalers and distributors, and other costs incurred in doing business that vary from country to country. Downward trends in component costs mean that the up-front investment cost of solar and solar hybrid mini grids fell from about $8,000–$10,000/kW_{firm} in 2010 to $3,900/$kW_{firm}$ in 2018 and less than 3,700/kW_{firm} in 2021. Looking ahead, the expected decreases in component costs associated with current best practices can reduce up-front investment costs to less than $2,500/$kW_{firm}$ by 2030.

Mini grid operating expenditure (OPEX) averages around $80 per customer per year. Costs are expected to decline because of technological advances over the next decade. Staff costs on average account for 76 percent of operations costs, but economies of scale and new remote-controlled, prepay smart meters and remote-monitoring technologies have slashed labor costs per mini grid. Replacement costs have also fallen as more developers invest in lithium-ion (Li-on) batteries, which have about twice the number of charging cycles before failure compared with conventional lead-acid batteries, and the costs of power electronics, such as PV inverters and battery inverters, are also decreasing.

Further cost reductions per kWh are derived from increasing income-generating uses of electricity, which can decrease the LCOE by 25 percent or more. Most second-generation mini grids today have a load factor of around 22 percent, indicative of low levels of income-generating uses of electricity. However, third-generation mini grids provide high-quality, reliable electricity services that can support income-generating loads, such as agricultural milling. If mini grids can achieve a 40 percent load factor through strong daytime consumption by local businesses and commercial clients, the costs of producing electricity drop 25 percent compared with a load factor of 22 percent. For an 80 percent load factor—achieved by inclusion of a water pump with storage tank and an anchor load, such as a telecommunications tower—LCOE reduction is 37 percent.

Implications for national power sectors

As a result of declining LCOE, increasing income-generating uses of electricity, and the mainstreaming of geospatial planning, solar mini grids can have transformational effects on power sectors. They are on track to provide power at lower cost than many utilities by 2030. At $0.40/kWh, mini grid LCOE would be less than the LCOE of national utilities in 7 out of 39 countries in Africa. At $0.20/kWh, mini grid LCOE would be less than the LCOE of national utilities in 24 African countries (Trimble and others 2016). This would make mini grids the least-cost solution for grid-quality electricity for more than 60 percent of the population in Africa in a scenario assuming that national utilities do not dramatically change their operations—with major implications for the allocation of both public and private investment funds.

However, scaling up mini grids does not mean scaling back the main grid. On the contrary, solar mini grids enhance the economic viability of expanding the main grid. By designing the system from the beginning to interconnect with the main grid and by promoting income-generating uses of electricity through effective community engagement and training, third-generation mini grids can provide early economic growth, so that significant load already exists by the time the main grid arrives, and customers have a greater ability to pay. New regulatory frameworks give developers viable options for what happens when the main grid arrives, and reductions in the cost of components enable developers to build grid-interconnection-ready systems, while still keeping tariffs affordable.

Supporting solar mini grids therefore goes hand in hand with strengthening the power sector. Interconnecting third-generation mini grids with the main grid can increase the resource diversity and overall resilience and efficiency of the power system. However, this presents a couple of operational challenges that are better addressed in a comprehensive strategy for developing the sector, for example, for governments through their electrification strategies to allow for utilities, mini grids, and off-grid companies to deliver services in the country, as well as for utilities to be able to introduce the practical technical functions to support power system operations and planning with multiple mini grids connected to the distribution grid, such as short- and long-term forecasting and other procedures.

Experiences with interconnected mini grid collaborations are emerging, for example, in Nigeria and India, and are providing valuable lessons. These interconnected mini grids are built to serve different market segments: rural and peri-urban towns and villages, large urban marketplaces, commercial and industrial (C and I) installations, and separate urban residential communities. Early evidence seems to indicate that these interconnected mini grids can create "win-win-win" economic outcomes for the three key parties. The arrangement can eliminate or reduce financial losses for distribution companies (DISCOs) that are forced to sell electricity at non-cost-recovering retail tariffs. Interconnections also allow DISCOs to earn new revenues through bulk power sales to the mini grid as well as rental revenues from the leasing of some or all of the DISCO's existing distribution system to the mini grid. For the mini grid operator, a physical connection to the contiguous DISCO offers the possibility of purchasing bulk power, whether on a firm or an "as available" basis from the interconnected DISCO or an upstream supply source. This can lead to lower operating and capital costs (for example, a lower LCOE) for the interconnected mini grid than if operates in a pure stand-alone mode. And for the mini grid's customers, this should lead to lower tariffs than would be possible than if the mini grid operated in a totally isolated mode. Finally, it is well documented that mini grids, whether interconnected or isolated, routinely achieve high levels of reliability for their customers than DISCOs do for theirs (Tenenbaum, Greacen, and Shrestha 2022 forthcoming).

BUILDING BLOCK 2.
Planning national strategies and developer portfolios with geospatial analysis and digital platforms

Countries are using geospatial analysis to develop national electrification plans that delineate areas for mini grids. Through a geospatial approach to national electrification planning, the existing grid network is mapped and its attributes are digitalized. The supply of and demand for electricity are geolocated and overlaid with supporting data, including demographic, social infrastructure, and economic data. Spatial modeling then delivers a least-cost plan that identifies the optimal ranges for grid, mini grid, or off-grid technologies. Even though these national plans now typically include all options for electrification—grid extension, mini grids, and off-grid—they still rely on chosen input assumptions that can result in a more advantaged position of one solution over the other. Furthermore, the chosen parameters can also exclude large groups of customers when turning to implementation of these plans. For example, several national electrification plans have incorporated buffer zones for grid extension (for example, 15 kilometers from the existing grid), which during implementation has created situations where the utility is delayed in certain geographical areas and the mini grid and solar companies are not allowed to sell products and services because they are prohibited to do so under the plan. It is important that during the preparation of these plans, the different stakeholders are carefully consulted so that the underlying assumptions are based in reality. Countries that are using advanced geospatial analysis to develop national electrification plans include Angola, Cambodia, the Democratic Republic of Congo, Ethiopia, The Gambia, Haiti, India, Kenya, Liberia, Mozambique, Myanmar, Nigeria, Pakistan, Rwanda, Sierra Leone, Somalia, Tanzania, Togo, Uganda, and Zambia, among others.

Geospatial analysis is also being used as part of a portfolio planning approach for mini grid development. This would complement a comprehensive national least-cost electrification planning framework or, in the absence of such a framework, identify portfolios of mini grid sites where grid extension is expected to be limited or unlikely because of political considerations, insolvency of the DISCOs, and so forth. Geospatial portfolio planning, which is already being used by a number of established mini grid companies, utilities, and governments in Sub-Saharan Africa, slashes the preinvestment cost associated with preparing sites for mini grid development compared with traditional approaches, which rely on the deployment of multidisciplinary teams to villages to explore the scope for mini grid electrification.

BUILDING BLOCK 3.
Transforming productive livelihoods and improving business viability

Because of their reliability, third-generation mini grids can support income-generating uses of mini grid electricity, which creates an everyone-wins scenario for mini grid developers, rural entrepreneurs, communities, and national utilities over time. Increasing income-generating uses of electricity reduces the LCOE (see table MF.4), which increases the developer's margins and therefore financial viability. Entrepreneurs and small businesses benefit from switching from expensive diesel generators to affordable mini grid electricity. In one of the most comprehensive assessments of productive-use appliances and equipment to date, ESMAP identified more than 130 machines and appliances available today that had payback periods of less than 12 months. Communities benefit from the jobs created and increased economic activity. The growth of rural economies also benefits national utilities once interconnection to the main grid is considered, because it increases customers' ability to pay higher tariffs and creates a strong base of demand for electricity.

But demand uncertainty remains a key area of risk for both developers and financiers. In ESMAP surveys of mini grids presented in this book—the detailed survey of more than 400 mini grids in Africa and Asia (see chapter 1), the high-level survey of installed and planned mini grids globally (see the overview), and the detailed nationally representative surveys of mini grid operators (see chapter 5)—demand per customer varied widely from one mini grid to another, and from one country to another. Most mini grids had demand per customer of between 5 and 35 kWh per month, but all else held equal there is a sevenfold difference in revenue expectations from customers consuming 5 kWh per month and those consuming 35 kWh per month. Developers use demand estimates as key inputs not only to inform the designs of their mini grids, but also to secure external financing. The uncertainties around future demand growth therefore represent a key risk area for both developers and financiers. Mitigating this risk requires concerted efforts to increase the daytime use of income-generating appliances and machines, and financing mechanisms that help de-risk some of the demand uncertainty.

Increasing the uptake of productive-use equipment requires access to approximately $3.6 billion in affordable consumer finance and a proactive involvement of these financiers and appliance providers. Assuming an average up-front cost of $1,200 and 15 appliances per mini grid for 200,000 new mini grids by 2030, approximately $3.6 billion in microfinance will be needed for the purchase of 3 million productive-use appliances by 2030. Although they have relatively high up-front costs, most productive-use appliances and equipment provide opportunities to generate or increase revenue. Financing the up-front purchase cost of the appliances—by the mini grid operator via on-bill financing or by a third party, such as a microfinance organization—is a good way to increase productive uses of mini grid electricity. Both financing pathways have benefits and drawbacks for the mini grid operator, and both require the operator to develop new business model capabilities.

Drawing from existing research and the World Bank's recent experience with productive uses programs across Africa, Asia, and Latin America and the Caribbean, ESMAP has identified six steps to roll out initiatives that support the uptake of income-generating appliances in towns served by mini grids. Step one is a market/demand assessment with geospatial analysis overlying mini grids, appliances, and end use finance. Step 2 is community engagement to confirm and improve data collected during Step 1 through survey(s) and workshops. Step 3 is a demand analysis for mini grid design and market potential for appliances and associated end user finance. Step 4 is preparation of roadshows involving local government, community leaders, interested appliance providers and end user financiers, and mini grid companies. Road shows are the next step, where mini grid developers, appliance suppliers, end user financiers visit load centers to explain the value propositions to potential end users. The final step is the roll-out of mini grid connections, sales of appliances and end user finance.

A number of digital tools are emerging that also allow for a more efficient and lower-cost planning and rollout of productive uses activities in conjunction with the arrival of electricity from mini grids. The above-mentioned geospatial tools that help to identify and prioritize mini grid portfolios are now also used to share the associated market intelligence with the appliance providers and end user financiers. The information supports these companies to make an informed decision if their products have a sufficient addressable market. The tools also support the mini grid developers, appliance providers, and end user financiers to coordinate visits to these communities, so that their collective, potential clients can learn how electricity with the appropriate, affordable appliances can alter their lifestyle and business prospects for the better. Often nongovernmental organizations and social change organizations operate in these peri-urban, rural areas and can play an important role in coordinating these efforts on the ground.

BUILDING BLOCK 4.
Engaging communities as valued customers

Community engagement strategies can help increase productive uses of electricity and stimulate demand for mini grid services. Experience from successful mini grid developers indicates that community engagement begins by raising awareness before moving to adoption, productive operation, and word-of-mouth marketing. Community engagement requires a flexible approach; a clear understanding of the local socioeconomic and cultural characteristics; and tailoring of promotional tools, materials, and channels.[2]

The benefits of prioritizing access to female-led households and small businesses and increasing the participation of women in management positions in mini grid businesses are clear. Mini grids can greatly boost women's productivity, particularly in labor-intensive agricultural and food processing activities that women dominate. Women are 9–23 percent more likely to gain employment outside the home following electrification (Smith 2000). Electrification lowers fertility levels, through greater exposure to television (Buckley 2012). Electrifying health clinics for lighting and the refrigeration of medication is especially beneficial for maternal health. Mini grid projects can create jobs for women while shaping new community decision-making and leadership models by placing women in leadership roles.

Innovations in community engagement are emerging that can reduce costs and improve effectiveness. One example from a few years ago was the smartphone app and accompanying online YouTube-like platform called Mini Grid Stories, developed by Quicksand Design Studio with support from ESMAP. Following simple on-screen instructions, mini grid customers and staff of mini grid companies used the free smartphone app to create short videos—on how a customer uses electricity in her small business, for example—and uploaded them to a Mini Grid Stories website, where the videos could be viewed, shared, and downloaded. The approach was inspired by the success of the agricultural web-based platform Digital Green, which uses videos for agricultural extension work, which was 10 times more cost efficient than traditional community engagement services on a cost-per-adoption basis (Abate and others 2018). Another example is Smart Power India (SPI), supported by the Rockefeller Foundation. This India-based, Indian-led organization intermediates between key stakeholders, including developers, national and local government entities, and community organizations (Rockefeller Foundation 2017). SPI's approach is called "Community Engagement, Load Acquisition and Micro-enterprise Development" (CELAMeD). With SPI support, developers have crafted communication and marketing strategies to inform consumers about the benefits of renewable energy and catalyze the growth of rural businesses (SPI 2017).

BUILDING BLOCK 5.
Delivering services through local and international companies and utilities

Connecting 490 million people by 2030 will require utilities and private companies to develop and operate more than 210,000 mini grids. National utility companies in Kenya, Madagascar, the Philippines, Russia, and many other countries are already important developers of mini grids. Private-sector developers—including Tata Power Renewable Microgrids, Engie Energy Access, Havenhill, PowerGen, OMC Power, Green Village Electric (GVE), and Husk Power, among many others—are developing large portfolios of mini grids. In a well-established market, private-sector-led initiatives have a better chance of reaching exponential growth—something that is needed to reach universal access by 2030. National utilities—including the Ethiopian Electric Utility (EEU), the Kenya Power and Lighting Company (KPLC), and Engie—also see an expanding role for mini grids based on their organizational cost-benefit analysis.[3]

The mini grid industry offers major profit potential to private-sector equipment and service suppliers and developers alike, but financial support packages are needed to unlock this potential. ESMAP analysis projects that the annual profit *potential* across the mini grid value chain will be almost $5.8 billion by 2030.[4] The largest profit centers for mini grid components will be solar PV, battery storage, and distribution infrastructure and technologies like smart meters. As the costs of solar PV and battery storage continue to fall, the fraction of energy produced by solar PV and batteries will approach 100 percent, resulting in the profit *potential* for diesel dropping to nearly zero over the next decade. ESMAP analysis also indicates a profit potential for mini grid developers that could exceed $3.3 billion on an annual basis for all third-generation mini grids deployed between 2022 and 2030. It is important to note that financial support packages, including subsidies from governments and development partners, will be needed to unlock this profit potential, particularly over the next few years to set the market on the trajectory of rapid scale-up. Public funds enabled high-income countries to achieve universal electricity access; the same will be true for electricity access-deficit countries today.

Even in countries in which the government leads mini grid development, the private sector is a key partner in mini grid initiatives. Public-private partnerships are often an effective way of distributing responsibilities to optimize government and private-sector capacities. They enable mini grid operators that do not have substantial financial resources to enter the market. In addition, major opportunities for partnership between local and international firms exist across the mini grid industry value chain. Local entities are best positioned to focus on the aspects of the value chain that require knowledge of local rules and regulations or require coordination with the customer being served by the mini grid; international companies are best suited to perform tasks that can be replicated across geographic boundaries. Recent local-international partnership agreements include Caterpillar and Powerhive in Africa, ABB and Husk Power in India, Mitsui and OMC in India, ENGIE and Mandalay Yoma Energy in Myanmar, and Schneider Electric with both EM-ONE and GVE in Nigeria.

Industry associations can facilitate collaboration and deal making between local and international entities. AMDA comprises more than 40 developers, each operating a portfolio of commercially viable mini grids in Sub-Saharan Africa. AMDA helps its members present a unified voice and facilitates deals between developers and suppliers. By collecting data from their members, associations can present data-driven opportunities to investors as well as suppliers of specialized products and services.

BUILDING BLOCK 6.
Financing solar mini grid portfolios and end user appliances

Private investors—both domestic and international—are financing third-generation mini grids and driving innovation in financing mechanisms. Private financiers invested more than $500 million in developers building mini grids in low-income countries between 2012 and 2022, according to ESMAP's analysis of publicly available data on more than 100 unique deals between developers and investors. Impact investors and commercial investors, as well as local and national banks, have developed equity, debt, and blended finance options to help developers scale up their mini grid business. Acumen, Bamboo Capital Partners, CrossBoundary Energy Access, ElectriFi, InfraCo Africa, and Shell Foundation are just a few examples of recent investors in mini grids.

Development partners, including the World Bank, have increased funding for mini grids, from millions of dollars in the 2000s to billions of dollars in 2018. A group of 15 major international donors and development partners, including the World Bank, has collectively committed approximately $2.6 billion just to mini grid investment (that is, excluding funding for technical assistance and research). The World Bank has committed more than $1.4 billion to mini grids over the next five to seven years, through 50 projects in 42 countries (41 projects approved by the World Bank Board and at least 9 under preparation). The investment plans of this portfolio include the deployment of 3,000 mini grids by 2027, with the expectation of bringing electricity to more than 11 million people. This investment commitment is expected to crowd in close to $1 billion of cofinancing from private-sector, government, and development partners.

In countries where the World Bank has an investment commitment in mini grids, the Bank's investment represents on average about 25 percent of the total investment in mini grids in each country from governments, the private sector, and development partners. On a demand basis, the World Bank will continue to provide support for well-designed, new energy access projects that include mini grid investments. In the broader context, the upscaling of financing in the sector will need the involvement of the World Bank, development partners, and governments, at least at the same level of engagement over the next five years, to create the leverage for exponential private-sector involvement. In the longer run, the percentages of public funds compared with overall investment should taper off with the growth of private-sector investment.

Different financing packages—consisting of different combinations of equity, debt, subsidy, and risk-sharing mechanisms—are required for different types of mini grid developers. In response, governments and their development partners are preparing packages of financial support for mini grid developers that help them overcome barriers and finance the scale-up of mini grid deployments. Larger international and local firms tend to have greater access to equity and debt; smaller, mostly local firms usually do not. Female-led enterprises and project developers may require an expanded support package, as women often face additional barriers to accessing finance.

Performance-based grants have become a mainstream subsidy mechanism, and can greatly lower the cost of mini grid electricity to allow mini grid services to be affordable to a larger group of end users. According to an ESMAP analysis, a 40 percent capital cost grant reduces the LCOE of a best-in-class third-generation mini grid from $0.38/kWh to $0.28/kWh in a scenario with very low productive uses of electricity. In scenarios where productive uses increase the mini grid's load factor to 40 percent, the same 40 percent capital cost grant reduces the LCOE from $0.28/kWh to $0.22/kWh.

Performance-based grants for mini grids based on a percentage of the developer's cost to connect new customers are often less than the implicit or explicit subsidy that the main grid receives for each new connection. A survey of 39 national utility companies in Africa showed that utilities received explicit or implicit subsidies that enabled them to sell electricity at prices that were on average 41 percent—and up to 80 percent—less than the utilities' unsubsidized LCOE (Trimble and others 2016; Kojima and Trimble 2016). This would indicate that many national utilities in Africa receive implicit subsidies that are more than 40 percent of the connection cost. With national utility connection costs often exceeding $2,000 in rural areas (Trimble and others 2016; Blimpo and Cosgrove-Davies 2019), it is therefore likely that many national utilities in Africa receive implicit cost subsidies in excess of $800 per connection. To put this in perspective, a performance-based grant equivalent to 40 percent of a typical third-generation mini grid developer's connection costs would be about $400–$900 per connection.

Performance-based grants should be applied with caution, however, as relying exclusively on final output makes it difficult for developers to finance their up-front capital costs. Therefore, it is reasonable to designate some intermediate results—such as purchase orders or the arrival of goods on site—as a basis for early subsidy payments. Capital cost subsidies can also dilute the benefits of increasing productive uses of electricity. Although the combined impact of grants and productive uses on the LCOE is typically greater than either on its own, their cumulative impact can increase the LCOE when OPEX costs are large relative to CAPEX.[5]

BUILDING BLOCK 7.
Attracting exceptional talent and scaling skills development

Scaling up mini grid deployments will be possible only if human capital keeps pace with financial capital. Innovative technologies and initiatives have emerged to train the stakeholders needed to support a thriving mini grid industry. ESMAP has identified more than 50 training programs for key stakeholder groups in the mini grid ecosystem, including developers, financiers, policy makers, and regulators. Many of these courses leverage new technologies. For example, LED Safari's flexible curriculum design and remote web-based training enables developers and governments to create high-quality, reputable certification programs. Comprehensive training programs that follow a train-the-trainer approach, such as the Institute of Electrical and Electronics Engineers' Smart Village's Comprehensive Training Program, can provide training to thousands of people. These programs seek to create a skilled, knowledgeable ecosystem of stakeholders that can support the rapid scale-up of mini grids.

Capacity needs assessments are a critical early step in designing training and skills-building initiatives. They reveal gaps in key areas, including technical expertise, management skills, institutional capacity, policy frameworks, partnerships, knowledge, and implementation know-how. Needs assessments generally follow a four-step process—(1) identifying key actors, (2) determining the capacity needs of a project or portfolio, (3) assessing existing capacity, and (4) identifying capacity gaps—that uses a mixed-methods approach using existing data or data collected from key interviews with respondents and community members, focus group discussions, and surveys.

BUILDING BLOCK 8.
Supporting institutions, delivery models, and champions to create opportunities

National-level institutions are supporting the scale-up of mini grids as a key element of electrification strategies. Haiti's Ministry of Public Works has developed a special unit, the Energy Cell, to implement a World Bank-supported national mini grids program. Nigeria's Rural Electrification Agency is implementing the largest mini grid program in Africa, targeting 850 mini grids by 2025, out of an estimated potential market of 10,000 sites. Regulatory agencies in Nigeria, Rwanda, Zambia, and several other countries have teams dedicated to mini grids. Ministries, national utilities, and rural electrification agencies are collaborating on national electrification plans, as with Kenya, Myanmar, Nigeria, and Rwanda mentioned earlier.

ESMAP's research identified four characteristics of an institutional framework that can support mini grids, given the diversity in potential mini grid delivery models. The most common delivery models for mini grids are build-own-operate, public-private partnerships, concessions, utility models with and without private-sector involvement, and cooperative models. Strong institutional frameworks that can accommodate diverse delivery models are characterized by:

- Governments that recognize mini grids as a desirable and viable electrification option.
- Government institutions that support mini grid development through their actions and decisions.
- Flexible institutional frameworks able in principle to support various mini grid delivery models.
- Frameworks that minimize duplication of oversight and conflicting roles.

BUILDING BLOCKS 9 AND 10.
Regulating the sector and making it easier to do business

No single approach to regulating mini grids works best in all settings, and regulation has costs as well as benefits. ESMAP has developed a series of decision trees that present options for how to regulate mini grids and the conditions under which each option is suitable. The decision trees are not prescriptive. They can provide guidance to help regulators and policy makers make informed decisions in five regulatory areas: market entry, tariffs, technical specifications, service standards, and what happens when the main grid arrives in the service area of a mini grid.

Several countries are developing mini-grid-specific regulatory frameworks that support private-sector investment. Across Asia and Africa, countries such as Bangladesh, Cambodia, India, Kenya, Nigeria, Rwanda, Tanzania,[6] and Zambia have developed regulatory frameworks for mini grids that address key issues.

The goal of a regulatory framework for mini grids should be to promote good service at the lowest cost-recovery tariffs. Pursuit of this goal throughout the stages of development of a country's mini grid sector—taking into account subsidies and the broader national electrification strategy—requires a regulatory framework that is predictable but flexible enough to evolve as the market does.

Meanwhile, innovative solutions that cut down on red tape and make it easier for mini grid developers to do business are emerging, and include the following:

- Standardized templates for key bureaucratic processes that affect mini grids, including standardized power purchase agreements, which define the terms under which mini grid developers sell electricity to the main grid, and standardized environmental and social management systems, which identify when mini grid developers obtain environmental approvals.
- Technology platforms to connect developers with investors and suppliers and to run large-scale mini grid tenders, greatly boosting market efficiencies.
- Formal delegation of mini grid industry oversight authority to a single entity—usually the local government or a

government agency that provides grants or subsidies to mini grid developers (such as a rural electrification agency)—in countries where the absence of a formal regulator increases the risk that mini grid developers face multiple layers of government oversight.

- Introduction of e-government to reduce overhead cost for business registration, land and building permits, and environmental approvals.

A CALL TO ACTION

Connecting half a billion people to mini grids by 2030 is a monumental task that requires unprecedented levels of investment, innovation, and commitment from development partners, governments, and the mini grid industry. This book calls for action by stakeholders across the mini grid value chain. Key recommendations are for the following actors:

- Policy makers to leverage the latest geospatial analysis technology to develop national electrification plans that can guide investment in mini grids, main grid extension, and solar home systems, as well as develop initiatives that promote productive uses of electricity and build human capital.
- Development partners to work with government counterparts and the private sector to create enabling environments for mini grids through investments in portfolios of projects and technical assistance for developing workable regulations and strengthening institutions.
- Regulators to adopt an evolving, light-handed approach for a maturing mini grid sector, providing at each stage of development clear guidance on market entry, retail tariffs, service standards, technical standards, and arrival of the main grid.
- The mini grid industry and its associations to work toward increasing the pace of deployment, retaining superior-quality service delivery of third-generation mini grids, and reducing the cost of these systems through innovation to reach a value proposition that is affordable to the end users.
- National utilities to adopt an openness to partnerships with the third-generation mini grid industry on the basis that the systems are grid-integration ready, which can provide for more financially viable grid expansion programs for the utility in the long run.

Finally, there is a clear need for accurate, up-to-date, and widely available data to inform any type of initiative that supports mini grids. To this end, we strongly recommend the development of a global tracking tool to monitor and measure the global mini grid industry's progress against the 10 building blocks and 5 market drivers outlined above.

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NOTES

1. Firm power output means that the peak load for which the system was designed can be supplied by the mini grid any second of the day throughout the year. In solar hybrid mini grids, we approximate firm power output as the sum of the generator capacity and 25 percent of the PV array capacity. For a more detailed description of this metric and the rationale for using it, please see chapter 1.
2. The importance of tailoring the community engagement approach to the local context was emphasized in an interview with Havenhill Synergy Ltd., a Nigerian mini grid developer operating several solar hybrid mini grids in the Kwali and Kuje local government areas of Nigeria.
3. RAO Energy in Russia, TANESCO in Tanzania, JIRAMA in Madagascar, and KPLC in Kenya are utility companies that operate dozens of mini grids nationwide. These mini grids are typically diesel powered (or, in the case of JIRAMA, hydro powered). They tend to be large, typically on the order of several hundred kilowatts to a few megawatts. Some utilities (in Niger, for example) have started to hybridize their diesel systems with solar PV panels.
4. Rather than provide a definitive number, this analysis is designed to understand the relative profit *potential* among different mini grid value chain stakeholders. Such an analysis can be used to determine the viability of establishing business lines focused on the mini grid market. The data reflect the profit potential after all variable production and manufacturing costs are taken into consideration. Detailed assumptions and methodology are documented on the companion website to this handbook: www.esmap.org/mini_grids_for_half_a_billion_people.
5. On average, CAPEX accounted for about 65 percent and OPEX for about 35 percent of the fully cost-recovering tariff.
6. While the mini grid regulations in Tanzania are some of the most advanced in Africa, issues concerning implementation and enforcement, as well as elements within the regulations themselves, have recently restricted private-sector investment in mini grids.

OVERVIEW: The New Electricity Access Landscape and the Growing Space for Solar Mini Grids

SDG 7: A GLOBAL AGENDA RUNNING BEHIND

In September 2015, the United Nations (UN) General Assembly adopted Resolution 70/1, which introduced a new global path for sustainable development. The 2030 Agenda laid out 17 ambitious Sustainable Development Goals (SDGs), to be achieved by 2030 (UN 2015).

The SDGs focus on key economic and social development issues, such as education, health, and climate change. Recognizing that access to basic energy services is a prerequisite for poverty alleviation, sustainable livelihoods, and economic growth, one of the goals (SDG 7) aims to ensure access to affordable, reliable, sustainable, and modern energy for all. Its targets include universal access to electricity, clean fuels and clean cooking technologies, a doubling of the rate of improvement in energy efficiency, and a substantial increase in the share of renewables in the global energy mix.

ACCESS TO ELECTRICITY HAS INCREASED . . .

Impressive advances have been made in closing the electricity access gap in recent decades. Between 2010 and 2020, the share of the global population with access to electricity grew from 83 percent to 91 percent, as 1.3 billion people gained access during this time period (IEA, World Bank, and others 2022).[1]

The pace of electrification accelerated from 2000 to 2018 but has since tapered off: between the years 2000 and 2010, 100 million people gained access every year, ramping up to 130 million people per year between 2010 and 2018. But in the final two years of the decade, 2018–20, the number of new people gaining access dropped to 109 million per year (IEA, World Bank, and others 2022).

. . . BUT PROGRESS HAS BEEN INSUFFICIENT TO MEET THE GOAL OF UNIVERSAL ACCESS

These achievements notwithstanding, progress has fallen far short of what is needed. According to the latest *Tracking SDG 7: The Energy Progress Report,* taking into account population growth and recent slowdowns in access as a result of the COVID-19 pandemic, a total of 930 million people will need to gain access to electricity over the next eight years if universal access is to be achieved. However, under current and planned policies and taking into account the effects of the pandemic, 670 million people are still projected to remain without access in 2030 (IEA, World Bank, and others 2022).

Meanwhile, adjusted for global population growth rates, the annual pace of access has been steadily decreasing since 2018. While the annual rate of grown in energy access was 0.8 percent between 2010 and 2018, it fell to 0.5 percent in 2018–20. Furthermore, these increases have been concentrated in a handful of countries and very unevenly distributed across regions, between rural and urban areas and across socioeconomic groups.

Between 2010 and 2020, about 1.3 billion people gained access to electricity, but 733 million people are still currently without access. After taking into account population growth, about 930 million people will need to gain access to electricity by 2030 to achieve SDG 7. However, if the current pace of electrification, current policies, and current population trends continue, as many as 670 million people are predicted to remain without access to any source of electricity by 2030.

Countries that pursue a comprehensive approach to electrification through main grid extension, mini grids, and solar home systems achieved the fastest gains. In most of the countries with the fastest gains in electrification between 2010 and 2020—including Bangladesh, Cambodia, Kenya, Myanmar, Nepal, Rwanda, and Tanzania—national electrification strategies leveraged a combination of main grid, mini grid, and solar home system investments. Nigeria is another recent example of a country that has developed a comprehensive national electrification strategy and implementation plan. This comprehensive approach is the only way to connect the 930 million people that will need access to electricity by 2030.

Meanwhile, slightly fewer than 76 percent, or 560 million people living without electricity are concentrated in 20 countries with the highest absolute deficit in energy access (IEA, World Bank, and others 2022).[2] Closing the gaps in these countries is therefore essential to achieving the goal of universal access by 2030. Within these countries, Kenya and Uganda made the greatest gains since 2010, expanding access by more than 3 percentage points a year between 2010 and 2020 (IEA, World Bank, and others 2022).

Fragile and conflict-affected countries also require substantial support if SDG 7 is to be achieved by 2030. The 39 countries on the World Bank's list of fragile and conflict-affected countries account for well over half of the global access deficit—nearly 57 percent. The access rate in these countries from 2010 to 2020 rose only by 11 percent—from 44 to 55 percent (IEA, World Bank, and others 2022).

The rural-urban divide in energy access is also stark. In 2020, global access rates were almost 97 percent in urban areas but just 83 percent in rural areas. Given that 80 percent of the world's unelectrified population reportedly lives in rural areas, identifying electrification solutions that meet rural needs is essential to reaching universal access (IEA, World Bank, and others 2022).

Populations without access to electricity tend to be concentrated geographically. Just 20 countries account for almost 76 percent of the global population without access to electricity; fragile and conflict-affected countries collectively account for well over half of the global access deficit; and more than 80 percent of the world's unelectrified population lives in rural areas. As a result, identifying electrification solutions that meet rural needs, particularly in these key electricity access-deficit countries, is essential to reaching universal access to electricity by 2030.

MORE FINANCING IS NEEDED, AND IT MUST BE BETTER TARGETED

A major cause of the present gap in electricity access is lack of financing. Current commitments to all electrification projects in the 20 highest-access-deficit countries—which account for 560 million people—are estimated at $32 billion a year. This is 78 percent of the $41 billion a year needed to achieve universal access by 2030, and a 27 percent decline from 2018, when the figure reached $43.6 billion (SEforALL and CPI 2021).

This financing has been distributed highly unevenly, both across the group and within different customer categories. As such, most financing targets provision of electricity services to nonresidential customers. As of 2021, only $12.9 billion—less than a third—of the funds committed in the 20 high-deficit countries—were aimed at households; the rest targeted commercial, industrial, and public consumers (SEforALL and CPI 2021).

Forecasts by the International Energy Agency (IEA) indicate that 95 percent of the additional investment in electrification must target Sub-Saharan Africa if the world is to reach universal access by 2030 (IEA 2021). At present, however, investments in these countries are estimated at only approximately 15 percent of what would be required for them to reach full electricity access (IEA 2021). One notable example of this gap is the Democratic Republic of Congo, the country with the second-highest number of people without access to electricity on the continent (72 million), which by 2021 saw only approximately $18 million per year committed to electricity access, compared to the nearly $3 billion estimated to be needed annually to reach universal electrification (SEforALL and CPI 2021). This is in contrast to the progress made by India, where by 2019 the government declared the country to have reached a 99 percent electrification rate, moving it from third to seventeenth place in the list of highest-access-deficit countries (IEA, World Bank, and others 2022).

Encouragingly for the global sustainable development agenda, electrification investments in the highest-access-deficit countries appear to be firmly shifting from fossil fuels to renewables. While grid-connected fossil fuels received over $21 billion in investments in 2018—compared to the $17 billion invested in grid-connected renewables—by 2019, the numbers nearly flipped, with grid-connected renewables receiving over $14 billion in investments, compared to the under $8 billion in grid-connected fossil fuels. Much of this shift can be attributed to the firmer commitments to renewables made by the governments in some of the key high-access-deficit countries—such as Pakistan and Bangladesh—which saw them end approvals for new coal-powered projects. At

Current financing commitments to energy access in the 20 highest-access-deficit countries are estimated at $32 billion a year—just 78 percent of what is needed to achieve universal access by 2030. Forecasts indicate that 95 percent of the additional investment has to be directed to Sub-Saharan Africa, with only 15 percent channeled to the continent so far, and largely to nonresidential customers.

the same time, at 0.9 percent ($294 million) of the total electricity investments in the group of countries in 2019, financing flows toward mini grid and off-grid renewable solutions remain far behind what is needed to reach universal access (SEforALL and CPI 2021).

When viewed through the lens of private and public sources of funds, the financing trend appears quite uneven. By 2018, the flow of international private financing into energy access in the 20 highest-access-deficit countries reached nearly $11.5 billion—a major ramp-up from less than $3 billion in 2013. However, in 2019 the number shrank to under $7.5 billion. A parallel trend can be noted in domestic private financing for energy access—while it followed a steady growth pattern since 2013 and peaked at over $14 billion in 2018; in 2019 it came down to a little over $8.5 billion (SEforALL and CPI 2021). Similarly, public investments—both international and domestic—appear to have come down slightly from a peak of over $18 billion in 2018 to under $15.9 billion in 2019.

Some countries are bucking the global trend by developing, in collaboration with development partners, comprehensive support packages for all three electrification pathways—main grid extensions, solar home systems, and mini grids. Support packages for mini grids consist of subsidies—increasingly in the form of performance-based grants —as well as debt facilitation and risk-sharing mechanisms, alongside private-sector debt and equity. The objective of these support packages is to increase the affordability of mini grid electricity and incentivize private-sector investment, while ensuring that public funds are deployed appropriately and efficiently. For example, performance-based grants are increasingly favored by private-sector developers and investors. The Energy Sector Management Assistance Program (ESMAP) analysis presented in chapter 6 shows that these subsidies can reduce the cost of electricity by almost 50 percent, but at the same time can dampen the effect of productive-use programs and put additional pressure on developers to secure major up-front funding.

Recognizing the need for increasing the impact of each dollar of international public financing and the private sector's growing relevance in development finance, in 2018 the World Bank Group adopted a new approach of Maximizing Finance for Development (MFD). Otherwise known as the "cascade" approach, MFD is aimed at pursuing private-sector solutions for reaching development goals and reserving the limited public funds for key areas where the engagement of the private sector is not optimal or possible (World Bank and IMF 2017).

The guidelines for implementing the "cascade" follow a decision tree approach, designed to determine whether a new project has a sustainable private-sector solution that limits public debt and contingent liabilities. It encourages the use of nonlending World Bank Group instruments—such as support for policy and regulatory reforms or de-risking mechanisms—to promote such private solutions whenever feasible.

DOUBLE DOWN ON SOLUTIONS THAT HAVE THE POTENTIAL FOR EXPONENTIAL GROWTH CURVES

Another reason for the financing gap is that electrification programs have traditionally focused on extending the national grid. Doing so is often both expensive and slow in remote settlements and areas with low population densities and low demand for electricity. Developing electrification models that complement grid extension is therefore critical to achieving SDG 7.

Mini grids and off-grid systems are two practical and complementary approaches to grid extension. Recent technological breakthroughs, the emergence of innovative business models, and enabling regulations and policies have made mini grids and off-grid systems affordable, scalable options for expanding electricity services along exponential growth curves.

THE PLACE FOR SOLAR MINI GRIDS

WHAT ARE SOLAR MINI GRIDS?

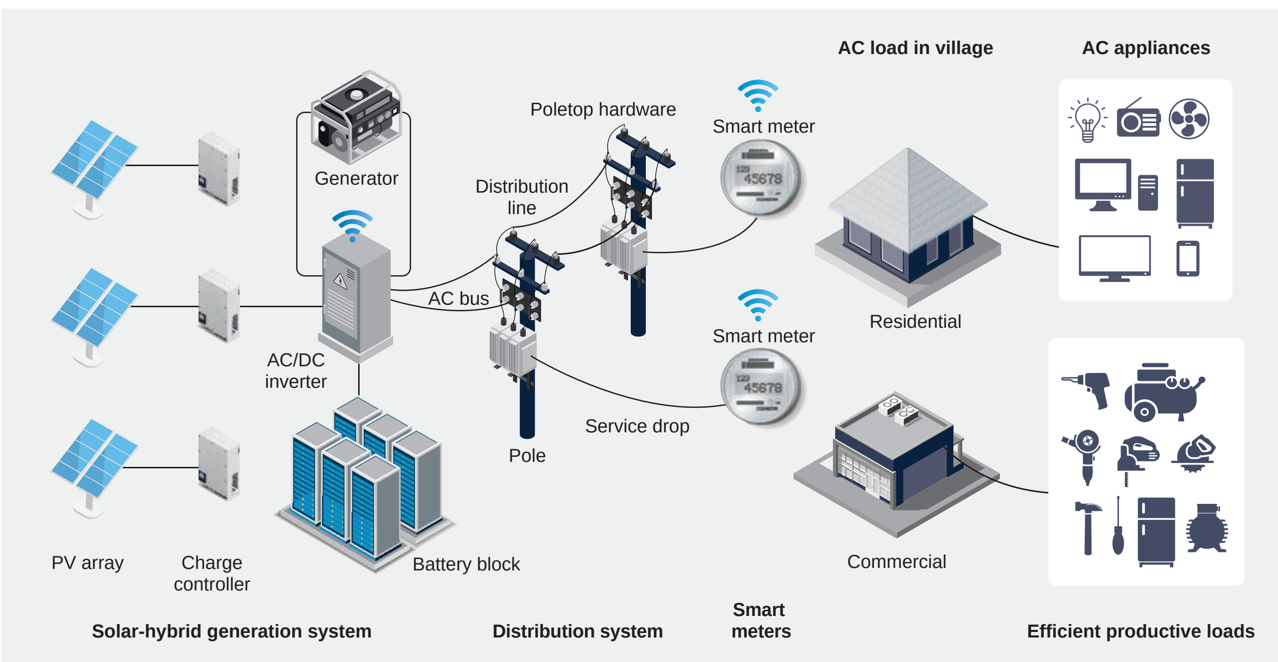
While there is no unanimously accepted definition of mini grids, they are commonly described as power generation and distribution systems built to provide electricity in areas that have not been reached by the main grid or whose costs of a grid-based connection are prohibitive. Mini grids typically supply electricity to local communities, covering domestic, commercial, and industrial demand. They range in size, from systems that provide electricity to just a few customers in a remote settlement to systems that bring power to tens of thousands of customers (usually groups of households, businesses, and public institutions) in a town or city (Tenenbaum, Greacen, and Vaghela 2018). Most mini grids are powered by alternating current (AC).[3]

Mini grids can be either fully isolated from the main grid or connected to it in some capacity—to feed excess energy into it, take energy from it whenever needed, or both. Mini grids that are connected to the main grid generally have the capacity to intentionally isolate—or "island"—themselves from it. This means that they are able to disconnect and reconnect to it, ideally without disturbing power quality, with the intention of improving power reliability, for safety reasons in the event of faults or surges on the main grid, and for the purpose of maximizing opportunities for additional revenue generation for the mini grid operator. The majority of mini grids in low-income countries are considered, at present, to be totally isolated (for example, electronically disconnected) from the main grid. Figure O.1 illustrates a common setup for a solar hybrid mini grid.

In various contexts, the term mini grid is often replaced with or juxtaposed with the term microgrid. For instance, microgrids are often defined as mini grids with generation capacity below 10 kilowatts (kW) (alternatively often referred to as pico-grids), with mini grids described as having generation capacities from 1 kW up to 10 megawatts (MW) (IRENA 2016). The two terms are also often used differently in high-income (primarily the Organisation for Economic Co-operation and Development [OECD]) and low-income countries for installations of similar capacity size but serving somewhat different purposes and customers. In OECD countries, the term microgrid is used to refer to systems that are almost always connected to the main grid, but that can operate in an "island" mode to achieve exceptionally high levels of reliability, to supply power for applications for which a power outage would prove extremely costly or hazardous, such as industrial processes, military or medical facilities, and data farms. Such microgrid systems are also frequently individually designed as one-off bespoke projects with no intention for scale. By contrast, in low-income

Mini grids are electric power generation and distribution systems that supply electricity to local communities, covering domestic, commercial, and industrial demand. Mini grids come in all sizes, from systems that provide electricity to just a few customers in a remote settlement to systems that bring power to hundreds of thousands of customers (usually groups of households, businesses, and public institutions) in a town or city. Mini grids can be fully isolated from the main grid or connected to it. Those that are connected to the main grid generally have the ability to intentionally isolate, or "island," themselves from it.

Figure O.1 • Example of a common solar hybrid mini grid setup



AC = alternating current; DC = direct current; PV = photovoltaic.

countries, what is referred to as mini grids of similar generation capacities are generally built in areas not connected to the main grid and at some distance from it, and by developers who often strive to achieve modularity, replicability, and economies of scale over time.

For the purposes of this report, the term *mini grid* will be used to refer to all forms of mini grids, regardless of their generation capacity or location, and regardless of whether they are interconnected with the main grid, as long as they have the capacity to operate in an "island" mode.

Mini grids may be owned and managed by communities, local governments, utilities, private companies, or some combination of the above. The delivery mechanism necessary to finance, develop, operate, and maintain a mini grid depends on characteristics like ownership structure, size, and technology (or a combination of technologies). For example, diesel-only mini grids require lower up-front costs as compared with solar, solar hybrid, or hydropower mini grids, but are expected to have much higher and less predictable operations and maintenance (O&M) costs (Greacen, Nsom, and Rysankova 2015), often resulting in limitations or restrictions to the electricity supply service. While government or utility-run mini grids often charge subsidized tariffs, mini grids that are owned and operated by private companies require rates of return sufficient not only to cover O&M costs but also to turn a profit. This means that, in the absence of a government subsidy, they must charge cost-reflective tariffs, which are often higher than the average national electricity tariff.

THE HISTORIC ROLE OF MINI GRIDS IN NATIONAL ELECTRIFICATION EFFORTS

Mini grids are not a new phenomenon: all current centralized power grid systems started with small, isolated power systems and mini grids. These systems were the initiating "spark" of electricity uptake some 130 years ago, and were pivotal to the early development and industrialization of most modern economies, such as Spain, Sweden, the United Kingdom, and the United States. Although these systems were initially few and scattered, their development was coupled with, and amplified by, the coevolution of supply, demand, disruptive technology, and policy. Gradually, and as electricity systems became more complex, physical expansion and interconnection came as a natural consequence, leading to today's power systems.

Many dynamics affected these systems' development, some of which (technical advancements, innovation, entrepreneurial drive, and decisions) were endogenous, while others (economic principles, legislative constraints and support, institutional structures, historical contingencies, and geography) were exogenous (Hughes 1983). Historically, areas with robust socioeconomic activity were the earliest adopters. The first modern electric utility was the Pearl Street Station in Manhattan, New York. Fired by coal, this thermal power plant initially served electricity for lamp lighting in 1882 to about 80 customers via a direct current (DC) distribution system (Hughes 1983). It was thus, by definition, an isolated mini grid.

From New York City and Chicago in the United States to London and Berlin in Europe and Kimberly in South Africa, mini grids started to emerge and operate autonomously in cities throughout that period. Other similar systems developed to provide electricity to industrial loads or to serve particular populations, such as rural US agricultural producers.

Various factors supported the early deployment of decentralized electricity systems in areas of high demand density (urban areas and industrial facilities) or low-cost supply (such as hydro sites). First, DC systems and early low-voltage AC systems had physical limits that kept distribution local; technology in the late nineteenth and early twentieth centuries did not allow for larger systems covering long distances. Second, electricity demand was initially limited to a few services, such as public lighting. Third, the capital intensity of electric power systems meant that cost recovery required the maximization of electricity output and sales. These early power systems therefore sought to improve the load factor and economic performance.

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As technologies improved, demand increased, and the policy and regulatory regimes stabilized, larger generators could be built and electricity could be transmitted over longer distances. These factors resulted in the emergence of centralized utilities (either privately or publicly owned). Mini grids either became integrated with one another, forming the nucleus of a larger centralized system, or were absorbed by a larger grid system as it expanded.

The process was not always smooth. In Bolivia, for example, lack of technical coordination meant that different mini grids used different frequencies, making their integration in a central grid challenging. In the United Kingdom, competing business and institutional interests resulted in aggressive competition and stranded assets. Over time, however, the increasing variety of sources, loads, and control nodes created the extensive and complex grid network many countries have today.

These historical systems can be described as the first generation of mini grids, which faced many of the same policy, regulatory, and operational challenges experienced by mini grids in developing countries in Sub-Saharan Africa and Asia today. A retrospective overview of a number of these systems is available online (www.esmap.org/mini_grids_for_half_a_billion_people), highlighting the origin stories of modern grids from isolated mini grids in Bolivia, Cambodia, China, India, Ireland, Spain, Sweden, the United Kingdom, and the United States. That brief historical review provides a number of insights:

- Rapid industrialization and the socioeconomic shifts it spurred created demand for new, low-cost forms of energy.
- The electric power sector soon became a strong new business opportunity, attracting substantial entrepreneurial and investment activity. The competitive environment in the electric power industry promoted technological innovation, leading to new technical systems that were quickly adopted by utilities.
- Regardless of their type or size, the earliest power systems were designed to be successful in terms of economics as well as engineering, contributing to their profitability and competitiveness.
- Early deployment of isolated stations and urban mini grids (and later peri-urban systems) was driven primarily by the growing demand for electricity. In rural areas, system expansion was largely a function of an explicit social welfare policy aimed at bridging the gap between urban and rural areas.
- Private power companies would not or could not serve all of the population and provide power at large scales. The unelectrified areas were filled with small municipal public systems, rural cooperatives, and large federally owned power generation corporations—and supported through public and nonprofit entities, such as rural electrification agencies and, in the United States, the National Rural Electric Cooperative Association.
- Local participation and ownership appear to be attributes of many public and cooperative efforts, particularly in small communities and rural areas. Rural communities were eager to access electricity. In most cases, the local population was actively involved in the process. Community engagement and political commitment through financial and regulatory support were crucial.
- Interconnecting neighboring mini grids was a way to cope with load variation and to increase system flexibility. Increasing generating capacities (per unit) was a way to lower costs through economies of scale.
- Choosing between centralized grid versus mini grid electrification was a lengthy process that depended upon technological advances, geographic factors, resource availability (for example, hydropower), sociodemographic factors (for example, demand density), and policy. With the exception of resources and geography, the other factors shifted and changed over time, with accompanying changes in how electricity demand was met, both technically and institutionally. These factors pushed the industry to ever-increasing interconnection, standardization, and centralization.

Second-generation mini grids

Unlike the first generation, what has often been referred to as the second generation of mini grids can be found in modern low-income countries (Tenenbaum, Greacen, and Vaghela 2018). These systems are typically small and isolated, and generally built by local communities or local entrepreneurs to provide access to electricity in zones with low population densities and low demand, primarily in rural areas that have not yet been reached by the main grid or where it would be too prohibitively expensive to extend it. Typically, such second-generation systems are built to supply electricity to single villages. Tens of thou-

> Mini grid systems that came about in the late nineteenth and early twentieth centuries can be described as the "first generation" of mini grids, which faced many of the same policy, regulatory, and operational challenges as those experienced by mini grids in developing countries in Asia and Sub-Saharan Africa today.

sands of these systems were built, starting in the 1980s and ramping up through the 1990s and early 2000s.

The second generation of mini grids provided important lessons about technical design, the importance of productive uses for financial viability, and economies of scale to drive down costs. The developers of second-generation mini grids, whether public or private, were motivated by the overriding need to supply rural communities with a higher level of electricity service as soon as possible. Developers of such second-generation mini grids almost always relied on standard existing technologies—such as diesel or mini hydro generation—and mini grids were built as one-off projects instead of as part of a larger portfolio. Second-generation mini grids typically used basic meters, on-site meter reading, and in-person bill collection, which was expensive and did not permit innovative pricing schemes that could promote productive uses of electricity during the day. They also often charged flat monthly tariffs or postpaid fees calculated and collected at the end of each month based on the customers' power consumption for that month (Tenenbaum, Greacen, and Vaghela 2018).

Second-generation mini grids also provided important lessons about regulatory frameworks, particularly to reduce the risk of stranded assets once the main grid arrives (for a detailed discussion of what happened when the main grid arrived in Cambodia, Indonesia, and Sri Lanka, see Tenenbaum, Greacen, and Vaghela [2018]). When these mini grids were developed, little thought was given to the possibility of later interconnecting with the main grid, and many of them were simply abandoned when the main grid arrived (Tenenbaum, Greacen, and Vaghela 2018). If they did not go out of existence, these mini grids often chose to become small power producers (particularly if using a more affordable renewable energy generation source rather than diesel); or small power distributors, converting to buying all of their electricity supply wholesale from the main grid and selling it to the local customers at retail prices. These options for what happened when the main grid arrived in the service area of second-generation mini grids are now being codified in new mini grid regulations—from Tanzania to Nigeria, to Haiti, Zambia, Rwanda, and elsewhere—to explicitly and preemptively provide economic options for mini grid developers when the main grid arrives.

"Second-generation" mini grids are common in low-income countries today. These systems are typically small and isolated, and built by local communities or entrepreneurs to provide access to electricity in zones with low population densities and low demand, primarily in rural areas that have not yet been reached by the main grid.

Third-generation mini grids

In the past decade, a new, third generation of mini grid technologies and business models has emerged. These third-generation mini grids differ from the earlier generations in several important ways.

New technologies. Technological developments have allowed third-generation projects to use more modular technologies—especially solar photovoltaic (PV) generation backed up with diesel, batteries, or both—and state-of-the-art hydropower. In most of Africa and parts of Asia (for example, Bangladesh, Myanmar, and India), the dominant emerging technology is solar hybrid mini grids. These new systems are usually combined with sophisticated pay-as-you-go (PAYG) billing, smart metering, mobile payment options, and real-time internet-based monitoring systems, enabled by cellular data, allowing company engineers to spot problems as they start to emerge and make adjustments or repairs before small problems snowball into larger ones. Some third-generation mini grid developers use sophisticated load dispatch technologies to ensure that priority loads always get electricity by automatically shifting low-priority loads to times of energy surplus.

New players. In addition to local entrepreneurs and community organizations, new national and international private companies are building or proposing to build these third-generation projects. They seem to be motivated by the possibility of using the modular (often proprietary) technologies that can be scaled up quickly to serve different-sized villages and towns, providing opportunities for cost-reducing economies of scale that were not available to second-generation developers. The very early evidence suggests that this will be accomplished through joint ventures with local firms. Large multinational corporations that have previously not operated in the mini grid market—such as Caterpillar, Tesla, Siemens, General Electric, and ABB—have publicly announced their intentions to enter it. Unlike second-generation local private entrepreneurs, these new third-generation companies have better access to national and international financial markets.

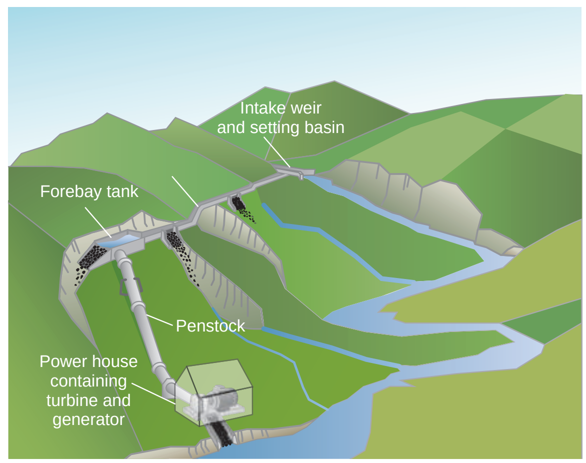
Public-private partnerships. In Kenya, Sierra Leone, and elsewhere, governments have proposed public-private partnerships to build and operate mini grids. This is an alternative to pure publicly owned or pure privately owned mini grid systems that have been used in second-generation mini grids. These new partnerships appear to be motivated, in part, by the reality that it is politically easier to channel a subsidy through a government entity in a joint venture than to openly give the same or even a smaller subsidy to a private company.

Not necessarily isolated. Mini grids are no longer being built only in isolated rural villages at a distance from the main grid. For example, in the Indian state of Uttar Pradesh, one private mini grid operator (OMC Power) has built many mini grids in villages that are already served by a government-owned distribution utility, because the distribution utility has not been able to provide reliable service, especially during peak evening hours (Rockefeller Foundation 2018). These mini grids are not currently interconnected with the main grid but have been built to be grid compatible in the future. A similar arrangement has been proposed in the mini grid regulations recently issued by the Nigerian electricity regulator.

Access to new geospatial tools. In the last few years, low-cost geospatial planning tools have become more widely available to those planning to develop mini grids. These new tools use satellite imagery data that allow potential developers to obtain important market intelligence on the physical characteristics, likely initial customer base, and probable daily electricity demand profiles of individual villages. The cost of acquiring the data is rapidly coming down. Several years ago, one donor organization paid $1 million to gather this information on 25 villages in Nigeria without the use of geospatial tools. More recently, similar information was obtained for 300 villages in Nigeria at roughly the same total cost with the application of latest geospatial analysis and planning applications.

FIGURE O.2 • The first, second, and third generations of mini grids

1st generation



2nd generation

3rd generation

Source: Upper left: International Magazine Co. 1925; upper right: World Bank design; bottom left: World Bank photo.

In the past decade, a new "third generation" of mini grids has emerged, characterized by new technologies, new business models, new players, new types of partnerships, new tools, and tailored policy and regulatory systems.

Targeted regulatory systems. Until recently, developers were "flying blind" on government policies and regulations that would apply to mini grid projects. This, too, is changing. Mini grid regulatory systems have been developed by governments in India, Kenya, Myanmar, Nigeria, Rwanda, Sierra Leone, and Tanzania, among several others. These systems reduce regulatory uncertainty for mini grid developers, though there is always the remaining uncertainty as to whether the regulatory rules will be implemented as written.

THE ROLE OF SOLAR MINI GRIDS IN UNIVERSAL ELECTRIFICATION

Electrification programs have traditionally focused on extending the national grid, primarily through power generated from fossil fuels. Experience in electricity-access-deficit countries over the past five decades, however, has shown that the main grid is typically unreliable. Across Sub-Saharan Africa, more than half of households connected to the main grid reported receiving electricity less than half of the time (Blimpo and Cosgrove-Davies 2019). In most electricity-access-deficit countries, the main grid usually provides only Tier 3 or Tier 4 electricity.[4] The main reasons for this unreliability are the challenges with the national transmission and distribution networks, rather than with the generation systems. Given the region's size and frequently very low population densities, the vast distances between rural economic hubs in many countries prove to be prohibitively expensive to connect to centralized systems.

In addition, research has shown that most utilities in Africa are not financially solvent. Most national utilities in Sub-Saharan Africa sell electricity at a loss, as the full cost of connecting residential customers (typically $800–$2,000 but often much higher for rural areas) is too expensive for most households (Trimble and others 2016), and this cost is frequently subsidized by the national government. In addition, the amounts that the rural, remote, and poorest groups of the population are able to pay for electricity generally do not reach the cost-recovery threshold for national utility companies, and the tariffs charged to these customer segments are often cross-subsidized across the utilities' large customer bases. The average fully cost-reflective tariff for 39 utilities across Sub-Saharan Africa is $0.27/kilowatt-hour (kWh); 25 percent of utilities require a cost-reflective tariff of more than $0.40/kWh, about half require a tariff of $0.20–$0.40/kWh, and 25 percent require less than $0.20/kWh. Only 2 of the 39 utilities (Seychelles and Uganda) charged tariffs that enabled them to recover their costs (Trimble and others 2016; Kojima and Trimble 2016). Mini grids are therefore often the least-cost, best solution to connect communities where the cost of extending the main grid is simply too expensive.

Meanwhile, the penetration of off-grid solar—including solar lanterns, pico PV systems, and solar home systems—grew rapidly over the last two decades, with more than 100 million systems sold in Africa alone. This market growth has been the result of increasing consumer demand for electricity services in homes, as well as the pace of innovations in telecommunications, which enabled the rise of the PAYG model for electricity access. Significant consumer data that emerged from the mobile money and PAYG revolution provided lenders and investors with more confidence with regard to the credit risk of the end users, enabling them to raise more capital and consequently expand their services. Today, such solar home systems, depending on their size, can typically cost $30–$200 and provide electricity service at Tiers 1 and 2. Some larger, component-based systems are also in use (GOGLA 2019).

WHERE DO SOLAR MINI GRIDS FIT IN?

Mini grids have characteristics of both utilities and solar home system companies, creating both challenges and opportunities for their large-scale deployment. Like the main grid, mini grids have sunk cost assets, are subject to regulatory oversight, and have the possibility of providing 24/7 electricity and supporting productive loads. Mini grids also have features of the solar home system industry, with the possibility for very rapid expansion when the value proposition is right for the market.

Both utilities and solar home system companies are entering the mini grid space for economic reasons, in ways that mirror their respective business models, with utility mini grids operating as rural distribution networks and solar home system companies interconnecting individual standalone systems. This trend would lead to modest growth in the deployments of mini grids, as the two sectors develop mini grids at the margins of their current target markets. If, however, the unique position of mini grids can build on the strengths of both sectors—24/7 electricity from the utility sector and agility and customer service from solar home system companies—mini grids will be able to bring affordable access to high-quality electricity to millions of people at an accelerated pace.

Indeed, as a result of the declining levelized cost of energy (LCOE), increasing income-generating uses of electricity, and mainstreaming of geospatial planning, solar mini grids are on track to provide power at lower cost than many utilities by 2030. At $0.40/kWh, mini grid LCOE would be less than the LCOE of national utilities in 7 out of 39 countries in Africa. At $0.20/kWh, mini grid LCOE would be less than the LCOE of national utilities in 24 African countries (Trimble and others 2016). This would make mini grids the least-cost solution for grid-quality electricity for more than 60 percent of the population in Africa in a scenario assuming that national utilities do not dramatically change their operations—with major implications for the allocation of both public and private investment funds.

However, scaling up mini grids does not mean scaling back the main grid. On the contrary, solar mini grids enhance the economic viability of expanding the main grid. By designing the system from the beginning to interconnect with the main grid and by promoting income-generating uses of electricity through effective community engagement and training, third-generation mini grids can provide early economic growth, so that significant load already exists by the time the main grid arrives, and customers have a greater ability to pay. New regulatory frameworks give developers viable options for what happens when the main grid arrives, and reductions in the cost of components enable developers to build grid-interconnection-ready systems while still keeping tariffs affordable.

Supporting solar mini grids therefore goes hand in hand with strengthening the power sector. Interconnecting third-generation mini grids with the main grid can increase the resource diversity and overall resilience and efficiency of the power system. However, this presents a couple of operational challenges that are better addressed in a comprehensive strategy for developing the sector, for example, for governments through their electrification strategies to allow for utilities, mini grid, and off-grid companies to deliver services in the country, as well as for utilities to be able to introduce the practical technical functions to support power system operations and planning with multiple mini grids connected to the distribution grid, such as short- and long-term forecasting and other procedures.

First experiences with interconnected mini grid collaborations are emerging, for example, in Nigeria and India, and are providing valuable lessons. These interconnected mini grids are built to serve different market segments: rural and peri-urban towns and villages, large urban marketplaces, commercial and industrial (C and I) installations, and separate urban residential communities. Early evidence seems to indicate that these interconnected mini grids can create "win-win-win" economic outcomes for the three key parties. The arrangement can eliminate or reduce financial losses for distribution companies (DISCOs) that are forced to sell electricity at non-cost-recovering retail tariffs. Interconnections also allow DISCOs to earn new revenues through bulk power sales to the mini grid as well as rental revenues from the leasing of some or all of the DISCOs' existing distribution systems to the mini grid. For the mini grid operator, a physical connection to the contiguous DISCO offers the possibility of purchasing bulk power, whether on a firm or an "as available" basis from the interconnected DISCO or an upstream supply source. This can lead to lower operating and capital costs (that is, lower LCOE) for the interconnected mini grid than if it operates in a pure stand-alone mode. And for the mini grid's customers, this should lead to lower tariffs than would be possible if the mini grid operated in a totally isolated mode. Finally, it is well documented that mini grids, whether interconnected or isolated, routinely achieve high levels of reliability for their customers than DISCOs do for theirs (Tenenbaum, Greacen, and Shrestha 2022 forthcoming).

Product cost: LCOE, portfolio development, CAPEX, OPEX including major replacements

The plummeting cost of mini grid electricity is on pace to achieve $0.20/kWh by 2030. Indeed, the LCOE of "best-in-class" mini grids already dropped from $0.55/kWh in 2018 to $0.38/kWh in 2021. Up-front investment costs per customer have also fell dramatically, from around $2,000 per connection just a few years ago to $700–$800 per customer in 2021 (AMDA 2021).

These cost declines are the result of decreases in the cost of major components, and increasing economies of scale as mini grids are built as part of ever-larger portfolios of projects by private-sector developers and national utilities. As table O.1 shows, prices for major components declined 60–90 percent between 2010 and 2020, and are projected to decrease even further through 2030.

In addition, economies of scale can further drive down costs for mini grids. Companies like Tata Power Renewable Microgrids, Husk Power, Engie PowerCorner, OMC, and others, are planning hundreds and thousands of mini grids over the next several years. At this scale, the unit costs of distribution infrastructure, batteries, solar PV modules, and power electronics drop dramatically, as we discuss in more detail in chapter 1.

With these cost declines, mini grid electricity is on pace to achieve an unsubsidized cost whereby $10 buys 50 kWh of energy each month— transformative consumption levels for hundreds of millions of people and millions of communities worldwide.

TABLE O.1 • Benchmarks and price projections, mini grid component costs, 2010–30

Component	Unit	Percent of total capital cost	Median cost in ESMAP survey	Best in Class 2020 LCOE modeling assumption	Mainstream industry benchmark in 2010	Mainstream industry benchmark in 2020 (% change from 2010)	Mainstream industry estimate by 2030 (% change from 2020)	Best in Class 2030 LCOE modeling assumption (% change from 2020)
PV module	US$/kWp	9.7	441	596	1,589	198 (−88)	114 (−42)	343 (−42)
PV inverter	US$/kWp	*	*	*	320	80 (−75)	70 (−12.5)	*
Battery (Li-ion)	US$/kWh	14.9	314	297	1,160	126 (−89)	58 (−54)	137 (−54)
Battery inverter	US$/kVA	8.6 †	415	303	565	113 (−63)	99 (−12.5)	265 (−12.5)
Smart meters	US$/ customer	‡	‡	‡	106	40 (−62)	35 (12.5)	‡

Source: Bloomberg New Energy Finance Solar Spot Price Index; ESMAP analysis; Feldman and others 2021; Kairies 2017; National Renewable Energy Laboratory US Solar Photovoltaic System Cost Benchmark: Q1 2020.

* PV inverter is included with PV module cost.

† Battery inverter is grouped with EMS and monitoring equipment.

‡ Smart meters are included in distribution cost. Average, median, minimum, and maximum costs are all expressed in inflation-adjusted dollars.

ESMAP = Energy Sector Management Assistance Program; kVA = kilowatt-ampere; kWp = kilowatt-peak; LCOE = levelized cost of energy; Li-ion = lithium-ion; PV = photovoltaic.

Addressable market and demand: Number of load centers, current expenditure, income-generating appliances

Meanwhile, as costs for mini grid electricity continue to fall, the addressable market for its services remains immense and continues to grow along with the population. Indeed, taking into account population growth, ESMAP's Global Electrification Platform estimates that mini grids are the least-cost option to provide first-time access to electricity to 430 million people. This represents around 86 million mini grid connections and an estimated up-front investment cost of $100 billion.

For Sub-Saharan Africa, nearly 291,000 load centers have the profile that favors the deployment of solar mini grids. The analysis based on digitalized rooftops for the region shows that over 177,000 clusters consist of 100 to 500 people each, matching smaller solar mini grid of up to 20 kW, almost 96,000 clusters with 500 to 2,500 people matching medium-sized solar mini grids of up to 80 kW, more than 15,000 clusters with 2,500 to 10,000 people that would be best serviced with larger solar mini grids of up to 200 kW, and nearly 3,000 population centers of 10,000 to 100,000 people where customization rather than standard sizing of mini grids would likely be appropriate based on GRID3 data (CIESIN 2020).

The end users in these load centers spend on average an estimated $5–$20 per month on alternative forms of energy such as candles, kerosene, dry-cell batteries, car-batteries, and petrol and diesel fuel for stand-alone gensets. Lessons from the introduction of innovative technologies in the marketplace (like solar home systems or mobile phones) show that these new solutions need to be not a little, but much better than the current alternative: why else would consumers take the risk to change their behavior? For these clusters of clients, the service provided by the solar mini grids should be a reliable source for their consumptive activities (lighting, charging, radio/TV) as well as provide for life-changing productive activities within the current expenditure of $5–$20 per month. From the end user's perspective, a $5–$20 expenditure should not only cover the cost of the reliable electricity provided but also cover the cost of transitioning into electric appliances as well as the purchase of appliances themselves. When calculating this over the lifetime of the technology, this would mean that roughly $3–$15 per month covers the cost of electricity and about $2–$5 per month, the appliances. This equation shows the tall order that needs to be met by the mini grid industry to fulfil its full market potential.

This addressable market represents a major business opportunity not only for mini grid developers but also for suppliers and financiers of income-generating appliances and machines. Households in low- and middle-income countries receiving electricity for the first time have an available budget for energy services of between $5 and $20 per month. If we use the 86 million connections estimate from the Global Electrification Platform, and a $10 per month expenditure in 2030, the resulting global market potential for mini grid electricity services is $10 billion per year by 2030. Furthermore, ESMAP's research has identified more than 130 income-generating machines and appliances with a payback period of less than a year, and a median up-front cost of $1,200. If we apply this cost globally and assume 15 appliances per mini grid and 200,000 new mini grids by 2030, the market potential for income-generating appliances connected to mini grid electricity is at least $3.6 billion.

The private sector has taken note of this market opportunity, and is already going after it, by treating communities as valued customers and partners rather than beneficiaries. Leading developers today across Africa and Asia are expanding their portfolios, raising capital to deploy dozens of new mini grids in the next two years, and hundreds of mini grids in the next five years, on a per-developer, per-portfolio basis.

A transformational end-user value proposition

In addition to declining costs and a large, addressable market, mini grids today are providing high-quality electricity services to their customers. A recent benchmarking report by the Africa Minigrid Developers Association (AMDA) found that modern solar hybrid mini grids in Africa had 99 percent uptimes on average, with only seven mini grids reporting uptimes below 95 percent.

Third-generation mini grids are true engines of economic development, especially when taken as a package. Their declining costs are on pace to deliver 50 kWh of electricity for $10 by 2030, while a large, addressable market is already attracting private sector investment and superior service. They offer a powerful value proposition for end users, communities, and governments.

Strengthening the power sector: Win-win with utilities

Older diesel-powered mini grids were expensive, inefficient, polluting, and dangerous. Nor were they managed as businesses. The fact that they existed at all proved that customers were willing to pay for electricity and suggested that demand would develop once the main grid arrived. Most customers used little electricity. But that meant the main grid would sustain ongoing financial losses when it reached areas served by these older mini grids. Modern mini grids are flipping this narrative. By designing the system from the beginning to interconnect with the main grid and by promoting productive uses of electricity through community engagement and training, mini grids can provide early economic growth. So by the time the main grid arrives, substantial load already exists and customers are able to pay. In parallel, new regulatory frameworks give developers viable options for what happens when the main grid arrives, and lower-cost components enable developers to build interconnection-ready grid systems while keeping tariffs affordable.

To restate the important point above, supporting mini grids therefore goes hand in hand with supporting utilities. When interconnection of modern mini grids with the main grid is properly planned and executed as part of a national electrification strategy, it can increase the resource diversity and overall resilience and efficiency of the power system. But this presents operational challenges such as those described earlier. This means that mini grid development—as a viable strategy for helping deliver universal access to electricity—also entails a greatly strengthened utility sector able to accommodate interconnecting mini grids with the main grid. Many electricity-access-deficit countries lack clear procedures for integrating mini grids into the utility's system planning and operations. So national electrification plans will need to accommodate scenarios in which mini grids are isolated from the main grid or connected only to other mini grids.

At the same time, mini grids developed today are challenging the existing centralized approach to electricity service delivery. The cost of mini grid electricity is expected to plummet over the next decade to levels that make it competitive with main grid electricity in a large number of electricity-access-deficit countries (more discussion on this point is provided in chapter 1). In addition, modern mini grids provide higher-quality service—in terms of reliability, availability, and customer service—than many national utilities in low-income countries. As mini grid developers establish strong reputations in their respective countries of operation, demand for their services in urban and peri-urban areas is likely to increase, incentivizing developers to target these customers as well. This will put pressure on national utility companies to evolve and improve their service offering.

HOW TO SCALE SOLAR MINI GRID DEPLOYMENT TO SERVE HALF A BILLION PEOPLE

FIVE DRIVERS: COST, QUALITY, PACE, FINANCE, AND ENABLING ENVIRONMENT

Through a collaborative, iterative process, ESMAP and mini grid industry leaders—including AMDA[5] and development partners—have jointly identified five market drivers for the sector to achieve its SDG 7 targets:

- A more rapid deployment of mini grids through a portfolio approach;
- Better service;
- Crowding in private-sector and government finance;
- Creating an enabling business environment for mini grids in access-deficit countries; and
- Reducing the cost of solar hybrid mini grids—which the other four market drivers will also support.

With support from ESMAP and the World Bank, the mini grid industry can work toward clear and measurable targets for these market drivers. These drivers will enable the sector to connect 490 million people by 2030. We summarize these targets in table O.2.

In addition to helping the mini grid sector achieve magnitude changes in scale, these five market drivers support the overall value proposition of mini grids as an electrification strategy. Mini grids can be deployed faster than main grid extensions, often at a lower cost per connection; they tend to provide better-quality electricity and customer service than utility companies; they support productive uses, unlike solar home systems; and they can attract both private- and public-sector finance (AMDA 2019).

TABLE O.2 • SDG 7 and mini grid industry targets, 2020–30

			Target		
Objective/indicator	**What is measured**	**2018 Baseline**	**2020**	**2025**	**2030**
1. Increase pace of mini grid development					
Time from purchase order to commissioning (weeks)	Cohort of leading private-sector developers	6–12	7	6	5
Time from goods arriving on site to commissioning (weeks)	Cohort of leading private-sector developers	6–12	5	4	3
Mini grids per key access-deficit country per year	Portfolios from rural electrification agencies, utilities, private developers, or industry associations	20–75	150	500	2,000
2. Provide superior-quality service					
Industrywide standard for minimum technical specifications	Industry associations	Under preparation	Developed for solar hybrid mini grids	Developed for solar hybrid and hydro mini grids	Developed for all renewable energy mini grids
Industrywide standard for reliability of electricity supply	Representative sample of mini grid developers	90–97 percent uptime	97 percent uptime during promised availability times	97 percent uptime for 24/7 electricity	>97 percent uptime for 24/7 electricity
Customer satisfaction (percent)	Representative sample of mini grid customers	82–84	85	88	90
Average load factor across the industry (percent)	Representative sample of mini grid developers	22	25	35	45
3. Establish enabling mini grid business environment in key access-deficit countries					
Average RISE score for mini grids framework in top 20 electricity-access-deficit countries	Top 20 electricity-access-deficit countries	59	60	70	80
4. Crowd in government and private-sector funding					
Cumulative government and development partner funding committed to mini grids in key access-deficit countries (US$, billions)	Estimated from a cohort of leading development partners	8	10	18	32
Cumulative private sector debt and equity invested in mini grids in key access-deficit countries (US$, billions)	Global estimates from market research	5	10	27	73
Total cumulative investment in mini grids for energy access (US$, billions)	Sum of all funding for mini grids in key energy-access-deficit countries	13	20	45	105
5. Reduce cost of solar hybrid energy					
Levelized cost of energy (US$/kWh)	Average across a cohort of leading mini grid developers	0.55	0.40	0.25	0.20

Source: ESMAP analysis.

Note: See the discussion of the underlying analysis for each target is presented in the overview.

kWh = kilowatt-hour; RISE = Regulatory Indicators for Sustainable Energy.

TEN BUILDING BLOCKS

The World Bank's experience over the past decade working with mini grid developers, electricity regulators, investors, policy makers, ministries, rural electrification agencies, experts, and donor partners has helped it identify a set of 10 building blocks that need to be in place to achieve country-level scale-up in mini grid development. These 10 building blocks are as follows.

- **Solar mini grid costs and technology:** Reducing costs and optimizing design and innovation for solar mini grids.
- **Geospatial planning:** Planning national strategies and developer portfolios with geospatial analysis and digital platforms.
- **Productive uses:** Transforming productive livelihoods and improving business viability.
- **Community engagement:** Engaging communities as valued customers.
- **Companies and utilities:** Delivering services through local and international companies and utilities.
- **Access to finance:** Financing solar mini grid portfolios and end-user appliances.
- **Skills and training:** Attracting exceptional talent and scaling skills development.
- **Institutions and delivery models:** Supporting institutions, delivery models, and champions to create opportunities.
- **Regulations and policies:** Enacting regulations and policies that empower mini grid companies and customers.
- **Doing business:** Cutting red tape for a dynamic business environment.

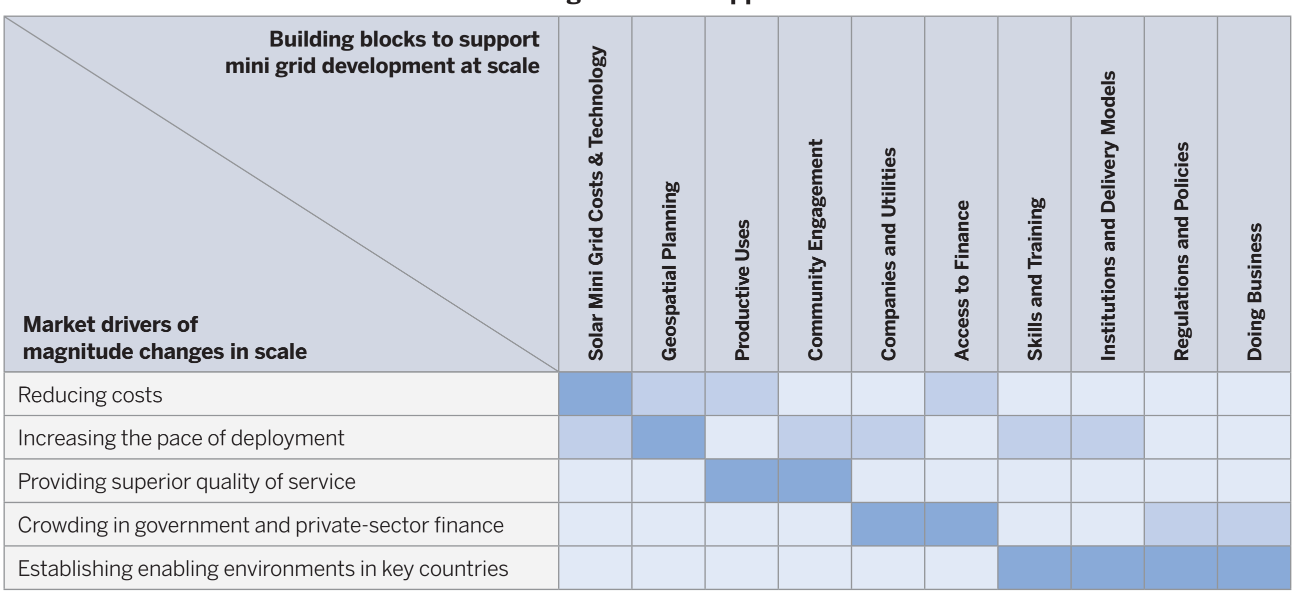
The market drivers focus mainly on PV and solar-diesel hybrid mini grids, as these two types of mini grids are likely to be the most prevalent technologies for scaling up mini grid deployments in key electricity-access-deficit countries. A similar focus on solar PV and solar-diesel hybrid mini grids is evident in the chapters on the 10 building blocks. The building blocks themselves, however, are conceptualized to support vibrant renewable energy mini grid sectors at the national level, regardless of renewable energy technology.

Each building block contributes to different market drivers presented above. Collectively, they represent the foundation of successful national mini grid programs. How each of the building blocks supports various market drivers is shown in figure O.3.

As the matrix illustrates, there is a logic to the order in which we present these building blocks. The first six building blocks, read from left to right in figure O.3, primarily support market drivers at the project and portfolio levels, while the remaining four building blocks primarily support the country-level market driver of establishing enabling environments in key electricity-access-deficit countries.

The next 10 chapters of this handbook present these 10 building blocks. Each chapter presents the frontier of knowledge in its topic area and speaks directly to public-

FIGURE O.3 • Matrix of market drivers and building blocks to support them



Source: ESMAP analysis.

Note: The darker the shading in the figure, the more direct the impact a building block is expected to have on a driver.

and private-sector decision-makers working on mini grids by trying to answer the "how" question.

Building block 1: Solar mini grid technology
The objective of this building block is to benchmark and analyze mini grid component costs and technologies to identify and promote opportunities to reduce costs and improve the quality of mini grid services. Innovations presented in the chapter include benchmarking mini grid component costs based on in-depth analysis of more than 400 operational mini grids in Africa and Asia, identifying trends in costs and technologies, modeling the LCOE of solar and solar-diesel hybrid mini grids, and understanding the impacts of productive uses and subsidies on LCOE. This building block directly supports the reduction of the mini grid costs market driver, and indirectly supports the pace of the mini grid deployment market driver by identifying technologies that decrease the time it takes to build a mini grid.

Building block 2: Geospatial planning
The goal of deploying the latest geospatial analysis tools and techniques is to support national-scale least-cost electrification planning and portfolio-scale mini grid design. Chapter 2 presents frontier knowledge on how geospatial analysis is making national electrification planning more precise and credible, thereby giving it more weight for policy makers and other decision-making stakeholders, and presents an innovative process to use geospatial analysis alongside other portfolio planning and auctioning tools to quickly and efficiently (in terms of cost per site) develop large portfolios of mini grids. Geospatial planning directly supports the pace of mini grid deployment by enabling a portfolio approach to mini grid development, and indirectly supports the reduction of the mini grid cost market driver by helping developers design mini grids that are appropriate for their respective sites.

Building block 3: Productive uses
Given the vital importance of productive loads for the cost efficiency and sustainability of mini grids, ensuring that productive uses are a priority for the design and implementation of mini grid programs and facilitating their availability to mini grid customers are the objectives of this building block. Chapter 3 answers the questions of how to increase a mini grid's load factor through productive uses of electricity, what impacts this can have on a mini grid's profitability and long-term sustainability, and how to increase productive-use appliance uptake by mini grid customers. This building block directly supports the quality of the service market driver, and indirectly supports the reduction in the mini grid costs market driver because of the strong link between increasing load factor and decreasing LCOE, as discussed earlier.

Building block 4: Community engagement
This building block entails engaging with local communities at every stage of the mini grid development process to ensure community buy-in, promote productive uses, and support gender equality, thus increasing the likelihood that the mini grid will operate successfully over the long term. Chapter 4 presents examples and innovations from leading mini grid developers on their community engagement strategies, and identifies community engagement tactics at every stage of a mini grid project's life cycle. This building block directly supports the superior quality of the service market driver, and indirectly supports the pace of the mini grid deployment market driver by tackling an inherent paradox—community engagement is typically time and resource intensive but the sector needs to scale quickly—by presenting innovative processes and strategies to conduct community engagement at scale.

Building block 5: Companies and utilities
This building block aims to accelerate private-sector participation in the deployment of mini grids, while strengthening national-utility-led approaches to mini grid development in countries where this approach has a proven track record. Engaging the private sector also means facilitating deal making and collaboration between local and international industry players in the mini grid market. Chapter 5 describes the industry's value chain and companies taking part in various stages of the value chain, calculates the profit potential along the value chain, provides examples of effective deal making and collaboration between local and international players, and presents the results from nationally representative surveys of mini grid developers in three countries, giving readers a sense of what second-generation mini grids look like. This building block directly supports the crowding in of the private-sector finance market driver by supporting collaborations between local and international companies, and indirectly supports the pace of the mini grid deployment market driver by supporting the upstream and downstream elements of the mini grid industry value chain.

Building block 6: Access to finance
The objective of this building block is to develop financial packages that complement private-sector debt and equity and crowd in large private-sector investors. Chapter 6 presents frontier innovations in grants, equity, and debt that can address the different barriers that mini grid developers face when trying to finance their projects and portfolios, provides financing options for utility-owned mini grids and public-private partnerships, and details the World Bank's mini grid portfolio. In addition to directly supporting the crowding in of the private-sector and government investment market driver, this building block indirectly supports the reduction of the mini grid costs market driver by help-

ing finance large portfolios of mini grids that lead to economies of scale.

Building block 7: Skills and training

The objective of this building block is to support training for key stakeholders in the mini grid sector, including developers, financiers, technicians, regulators, and policy makers. Chapter 7 identifies existing training programs and training program gaps for key mini grid sector stakeholders, and highlights innovative technologies and methods for large-scale training programs—an essential element of scaling up in mini grid deployment in key electricity-access-deficit countries. This building block directly supports the enabling environments market driver by increasing human capacity across the mini grid ecosystem, and indirectly supports the pace of the mini grid deployment market driver by increasing the availability of high-skilled, knowledgeable stakeholders who can support a portfolio approach to mini grid development.

Building block 8: Institutions and delivery models

This building block aims to ensure that the agencies responsible for implementing a mini grid program have the required mandate and capacity and that collaboration among agencies happens in the most effective way possible. Chapter 8 identifies the institutions both within and outside the energy sector with which mini grid developers interact, as well as the relationships among these institutions, and presents country-level models that can support mini grid development at scale and the institutional arrangements therein. This building block directly supports the establishment of enabling environments for the private-sector mini grids market driver and, as a result, indirectly supports the crowding in of the private-sector finance market driver.

Building block 9: Regulations and policies

The goal of this building block is to ensure that mini grid regulations are clear, light-handed, and conducive to private-sector participation in national-level mini grid markets. Chapter 9 presents the five key decisions for regulators: market entry, tariffs, service standards, technical specifications, and main grid arrival. Recognizing that there is no one-size-fits-all solution in these decision areas, the chapter presents a decision tree approach as well as a way for regulations to evolve as the sector evolves. This building block directly supports the establishment of enabling environments for the private-sector mini grids market driver and in doing so indirectly supports the crowding in of the private-sector finance market driver.

Building block 10: Doing business

This building block focuses on reducing red tape and increasing the ease with which mini grid developers can do business in each country where they operate. Chapter 10 presents innovative solutions to reduce red tape in two key areas: the long and complicated processes for environmental and social approvals and for interactions with the main grid, and the high costs of connecting with suppliers and investors and participating in tenders. In addition to directly supporting the enabling environments market driver, this building block indirectly supports the crowding in of the private-sector finance market driver by making national mini grid markets more attractive to private-sector investors.

GLOBAL MARKET SNAPSHOT, OUTLOOK 2030, AND CALL TO ACTION

Where we are, where we are headed, and where we need to go

The mini grid market globally is undergoing seismic transformations, particularly as a source of electricity in populous countries with little current access. Many electricity-access-deficit countries are pursuing holistic approaches to electrification, including main grid extension, mini grids, and solar home systems. Market analysis from Bloomberg New Energy Finance (BNEF 2018) predicts that in the next five to seven years, decentralized renewables—both mini grids and solar home systems—will bring electricity to more people every year than extensions of the main grid.

This section examines some key elements of the global mini grid sector. In particular, it presents data on installed and planned mini grids to understand three important questions for mini grid development that motivate the remainder of this report:

- Where are we today, in terms of number of mini grids, number of connections, investment, and capacity?
- Where are we headed if we keep up the current pace of mini grid development?
- How big is the gap between where we are headed and where we need to go to achieve the mini grid portion of SDG 7 ("universal access to modern energy services") by 2030?[6]

Table O.3 provides a global overview of the installed and planned mini grid projects around the world.[7] For the purposes of our database, mini grids were defined as electricity systems that have both electricity generation and distribution infrastructure, either isolated from the main grid or, if connected to the main grid, capable of operating as an electrically separate, or "islanded," mini grid. Both alternating current and direct current mini grids are included. To be included in our database, a mini grid had to serve multiple customers. *Installed* mini grids are those we know to have been built. Planned mini grids are those that developers, governments, and other organizations have said they plan to build over the next several years.

TABLE O.3 • Installed and planned mini grid projects worldwide: A summary

Totals calculated	Number of mini grids	Number of connections (millions)	Number of people (millions)	Average capital cost (US$/kW)	Total capacity (MW)	Total investment (US$, millions)
Global totals: installed	21,557	10.3	47.9	3,955	7,224	28,571
Global totals: planned	29,353	8.0	35.4	3,501	2,657	9,304
Grand total	**50,910**	**18.3**	**83.2**	**3,833**	**9,881**	**37,874**

Source: ESMAP research and analysis; proprietary and in-house databases of mini grid projects from Bloomberg New Energy Finance, CLUB-ER, Guidehouse, Infinergia, and Sustainable Energy for All; and, unpublished World Bank surveys. This book's website provides a full list of sources.

Note: A cascading process was followed to fill gaps in the data. When a country has many projects with usable data for a given metric (for example, connections per mini grid), that country's median value for that metric was used to fill in gaps for the remaining projects in that country. When only few projects in a country had usable data for a given metric, or no data at all, that region's median value for that metric was used to fill data gaps. Finally, in the rare cases when no data existed at the country or regional level for a particular metric, gaps were filled using the global median value for that metric. Mini grids smaller than 1 kW were excluded from the database, but no strict maximum capacity was used to exclude large mini grids. That said, of the more than 50,000 mini grids in our database, only 73 had an installed capacity of greater than 15 MW, and we used median values in our analyses instead of averages to minimize the risk that outliers skewed results. The data may be skewed toward mini grids that have a renewable energy component, as data are more abundant for renewable and hybrid mini grids. As a result, the data may underestimate the total number of mini grids globally, and may overestimate the capital costs. The data are incomplete for a number of countries where there are likely to be large numbers of mini grids, particularly countries in Eastern Europe, North Africa, and Asia.

kW = kilowatt; MW = megawatt.

Leveraging proprietary data from three leading market research firms—Guidehouse, BNEF, and Infinergia—as well as a large database compiled by SEforALL and BNEF, World Bank surveys of mini grid operators, and extensive desk research, ESMAP identified 21,557 installed and 29,353 planned mini grids in 138 countries and territories.[8]

Mini grids currently provide electricity to about 48 million people worldwide. Mini grids that are currently being planned are expected to bring electricity to an additional 35 million people. To put this number in perspective, the combined total number of people connected to, or expected to be connected to, a mini grid—about 83 million—is approximately equal to the entire population of Germany.

Installed mini grids have a combined power capacity of more than 7 gigawatts (GW); however, the total *operational* capacity is almost certainly lower, since many mini grids—particularly small hydro—do not operate at their full capacity.[9] A further 2.7 GW of installed capacity is expected from mini grids currently being planned.

In terms of generation technology, the trend toward solar is already clear today, and is accelerating. Approximately 51 percent of installed mini grids are solar or solar hybrid, followed by those powered only by hydro (35 percent), fossil fuel (10 percent), and other generation technologies such as wind or fuel cells (5 percent). The trend is also accelerating: more than 10 times as many *solar* mini grids were built every year from 2016 to 2020 than *fossil* fuel mini grids. Meanwhile, from 2010 to 2014, by comparison, about three times as many solar mini grids were built every year than fossil fuel mini grids. This is a major acceleration in solar and deceleration in fossil fuels. And, almost 99 percent of all planned mini grids are solar or solar hybrid.

> ESMAP identified 21,557 mini grids installed in 131 countries and territories around the world, providing electricity to 48 million people, and an additional 29,353 mini grids being planned in 77 countries that are expected to provide electricity to almost 35 million people.

The mini grid market currently represents almost $29 billion of cumulative investment in capital costs, with an additional $9 billion capital cost investment expected for mini grids currently being planned. The total $38 billion represents an average investment cost of around $2,100 per connection, though this is skewed higher by more costly systems serving fewer customers in high-income countries. Planned mini grids are expected to be much less costly, with an average expected investment globally of around $1,200 per connection, though this figure varies by region.

Table O.4 summarizes the installed mini grid projects regionally and table O.5 shows the breakdown of installed and planned mini grids by region.

Asia has the most mini grids installed and planned, with a combined total of 16,819 installed mini grids and 19,824 planned mini grids across South Asia and East Asia and Pacific. With 3,174 mini grids installed and 9,006 mini grids planned, Africa has many more mini grids than the com-

The trend toward solar is clear already and is accelerating. Approximately half of all installed mini grids to date are powered by solar, but nearly 99 percent of all planned mini grids will be solar or solar hybrid.

bined total of all other regions outside of Asia. It is important to note that the number of mini grids we identified as being planned does not equal the total market potential for mini grids. Planned mini grids have already secured or been allocated funding.

Mini grids provide electricity to about 18 million people in Asia, 27 million people in Africa, and 2 million people in Latin America. A further 14 million people in Asia and 20 million people in Africa are expected to receive electricity from mini grids currently being planned. In Asia and Africa, this represents a small but significant percentage of the region's total population, using World Bank population data: the combined total of installed and planned mini grids in Africa would connect less than 3 percent of the region's current population; in Asia, installed and planned mini grids would connect less than 1 percent of the region's population.

With almost 2 GW of installed mini grid capacity, Africa has the most installed capacity of any region, followed by the United States and Canada (1.8 GW) and East Asia and Pacific (1.5 GW). South Asia leads the world in planned mini grid capacity (0.87 GW), followed by Africa (0.66 GW) and the United States and Canada (0.50 GW).

Total cumulative investment in mini grids is spread out evenly among the top four regions: Africa ($7 billion), United States and Canada ($6 billion), East Asia and Pacific

Asia—including South Asia and East Asia and Pacific—has a combined total of 16,819 installed mini grids and 19,824 planned mini grids, which is 78 percent of all installed mini grids and 68 percent of all planned mini grids in the ESMAP database. Meanwhile, Africa has more mini grids installed (3,174) and planned (9,006) than all other regions outside of Asia combined.

($6 billion), and Europe and Central Asia ($6 billion). The high investment figures for these regions are explained by several factors, including relatively high up-front capital costs (for example, Africa and Europe and Central Asia), relatively large mini grids (for example, United States and Canada), and a large number of mini grids (for example, East Asia and Pacific). South Asia leads the market share for planned mini grids, with approximately $2.8 billion, followed by Africa ($2.4 billion) and the United States and Canada ($1.6 billion).

Table O.6 presents top-10 lists of countries and companies across a set of key mini grid metrics, focusing on installed mini grids.

Six countries in the database have more than 1,000 installed mini grids: Afghanistan, Myanmar, India, Nepal, China, and Indonesia. Afghanistan has the most mini grids of any country in the database, with more than 4,700 installed mini grids. The top 10 countries account for 84 percent of all installed mini grids.

Installed mini grids in Afghanistan, the Democratic Republic of Congo, and Madagascar serve electricity to about 19 million people, which represents about 40 percent of all

TABLE O.4 • Summary of installed mini grid projects by region

Region	Number of mini grids	Number of connections (millions)	Number of people (millions)	Total capacity (MW)	Total investment (US$, millions)
South Asia	9,592	2	12	407	1,555
East Asia and Pacific	7,227	2	6	1,530	6,271
Africa	3,174	6	27	1,960	7,238
Europe and Central Asia	624	< 1	1	1,110	6,092
United States and Canada	615	< 1	1	1,783	6,447
Latin America and the Caribbean	286	< 1	2	390	810
Middle East and North Africa	39	< 1	< 1	46	158

Source: ESMAP analysis.

Note: Data remain scarce for the Europe and Central Asia, Latin America and the Caribbean, and Middle East and North Africa regions, where there are likely to be many more mini grids than this table has captured.

kW = kilowatt; MW = megawatt.

TABLE O.5 • Number of installed and planned mini grids by region

	Installed	Planned
South Asia	9,592	19,035
East Asia and Pacific	7,227	789
Africa	3,174	9,006
Europe and Central Asia	624	226
United States and Canada	615	198
Latin America and the Caribbean	286	88
Middle East and North Africa	39	11

Source: ESMAP analysis.

people served by mini grids today. Collectively, the top 10 countries in terms of people served by mini grids account for about 69 percent of all people served by the mini grids in the database.

The United States has the highest total capacity of installed mini grids of any country for which data are available, at 1.4 GW. This is a result of the relatively large number of mini grids identified in this country, and each mini grid tends to have a relatively large capacity compared with mini grids in other countries. With 671 MW of installed capacity for installed mini grids, Russia is second in the top-10 list. Nearly all of this capacity is from 500 diesel-powered mini grids in remote parts of Russia operated by a regional utility company, RAO Energy.

TABLE O.6 • Top-10 lists for key mini grid indicators for installed mini grids

	Number of minigrids	Number of people (millions, % of population)	Total capacity (MW)	Total investment (US$, billions)	Utility portfolios (country, installed mini grids)	Private-sector portfolios (country, installed mini grids)
1	Afghanistan (4,712)	Afghanistan (7, 19%)	United States (1,424)	United States (4.9)	RAO Energy (Russia, 500)	BRAC (Afghanistan, 356)
2	Myanmar (4,016)	Congo, Dem. Rep. (7, 8%)	Russian Federation (671)	Russian Federation (3.7)	NPC-SPUG (Philippines, 278)	Husk Power (India, 300+)
3	India (3,192)	Madagascar (5, 15%)	China (529)	China (1.9)	NIGELEC (Niger, 115)	OMC (India, 280)
4	Nepal (1,541)	Tanzania (3, 5%)	Congo, Dem. Rep. (363)	Philippines (1.8)	JIRAMA (Madagascar, 110)	Tata Power Renewable Microgrids (India, 163)
5	China (1,236)	Kenya (3, 5%)	Canada (359)	Canada (1.6)	Eskom (South Africa, 100)	MeshPower (Rwanda, 85)
6	Indonesia (1,190)	Burkina Faso (2, 10%)	Philippines (338)	Congo, Dem. Rep. (1.3)	CREDA (India, 32)	Optimal Power Solutions (India, 59)
7	Senegal (677)	India (2, <1%)	Angola (333)	Angola (1.2)	EEU (Ethiopia, 32)	NS RESIF (Senegal, 53)
8	Russian Federation (501)	Philippines (1, 1%)	Madagascar (253)	India (0.9)	KPLC (Kenya, 32)	Sud Solar (Senegal, 50)
9	United States (478)	Nepal (1, 5%)	Kenya (239)	Madagascar (0.9)	Energie du Mali (Mali, 30)	Jumeme (Tanzania, 42)
10	Philippines (455)	Myanmar (1, 2%)	Australia (217)	Australia (0.9)	Alaska Village Electric Coop. (United States, 25)	Yoma Micro Power (Myanmar, 42)
Total (% global total)	**17,998 (84%)**	**33 (69%)**	**4,724 (65%)**	**$19 (67%)**	**1,256 (6%)**	**1,132 (5%)**

Source: ESMAP analysis.

kW = kilowatts; MW = megawatts; n.a. = not applicable; NPC-SPUG = National Power Corporation Small Power Utility Group.

Six countries have more than 1,000 installed mini grids each: Afghanistan, Myanmar, India, Nepal, China, and Indonesia. Mini grids serve more than 2 million people in seven countries: Afghanistan, the Democratic Republic of Congo, Madagascar, Tanzania, Kenya, Burkina Faso, and India.

Seven countries have seen more than $1 billion of cumulative investment in mini grids, led by the United States, for a combined investment of $16 billion. These seven countries account for around 57 percent of the market, with the United States alone accounting for 17 percent.

The utility company with the largest portfolio of installed mini grids is RAO Energy, which provides power to remote areas of the country. The second largest, National Power Corporation Small Power Utility Group (NPC-SPUG), is the national utility in the Philippines, a country with more than 7,600 islands. Notably, 6 of the 10 largest utilities by number of installed mini grids are in Africa: NIGELEC, JIRAMA, Eskom, EEU, KPLC, and Energie du Mali. The largest private-sector developer is BRAC in Afghanistan, but four of the top 10 private-sector developers are in India: Tata Power Renewable Microgrids, OMC, Optimal Power Solutions, and Husk Power.

Though not shown in the table, the largest portfolios of planned mini grids are all vertically integrated private-sector developers, led by Tata Power Renewable Microgrids (more than 9,800 planned in India), Husk Power (5,000 mini grids across India and Africa), OMC Power (5,000 mini grids in India), Engie PowerCorner (2,000 mini grids across Africa), and Renewvia (700 across Africa).

Table O.7 provides a snapshot of the characteristics of the installed and planned mini grid projects around the world.

For mini grids built as part of a developer's portfolio, the average size of the portfolio is 33 mini grids. We defined a portfolio as a collection of more than two mini grids built by the same entity. Only 258 portfolios of mini grids were identified. Portfolios of planned mini grids, however, were an order of magnitude larger than portfolios of installed mini grids.

Planned mini grids are expected to be larger than installed mini grids. The median installed mini grid serves 137 connections, while the median planned mini grid serves 386 connections. Similarly, the median capacity of installed mini grids is 123 watts (W) per connection, compared to 245 W per connection for planned mini grids. To be clear, the capacity per connection numbers here do not reflect the capacity that every customer is guaranteed at any given time. Nor are they meant to represent the tier of service provided by the mini grid. Instead, they are calculated as total installed capacity divided by total number of connections. That said, the capacity per connection of installed mini grids varies by two orders of magnitude across regions—the capacity per connection of installed mini grids in the United States and Canada is more than 100 times higher than in South Asia—likely as a result of differences across regions in household income, and therefore ability to pay for electricity.

One area that our data are likely to underestimate is the size of the diesel mini grid market. The primary databases and sources used to compile the data set focus principally (but not exclusively) on mini grids that contain a renewable energy generation source. However, thousands of diesel-fired and other nonrenewable mini grids are likely in operation today, for which no data are available.

One way to estimate the number of diesel-fired mini grids is to use global estimates for diesel generator shipments using trade statistics tracked by the United Nations. In

TABLE O.7 • Characteristics of installed and planned mini grids

Totals calculated	Mini grids per portfolio*	People per mini grid	Connections per mini grid	Capacity per connection (watts)	Capacity per mini grid (kW)
Global totals: installed					
Median	6	1,040	137	123	20
Average	33	1,524	291	371	540
Number of observations (N)	258 portfolios	7,489 mini grids	9,601 mini grids	8,659 mini grids	19,670 mini grids
Global totals: planned					
Median	20	780	386	245	147
Average	544	1,836	853	405	1,304
N	45 portfolios	23,827 mini grids	26,189 mini grids	24,471 mini grids	26,758 mini grids

Source: ESMAP analysis.

*A portfolio is defined as a collection of more than two mini grids built by the same developer.

kW = kilowatt

its analysis of these data, BNEF found that in the 10-year period 2008–17, 92.49 GW of diesel generator capacity—from generators with a capacity of less than 375 kilovolt-amperes, or 300 kW, assuming a power factor of 0.8—was shipped around the world. If we assume that 5 percent of this capacity is used to power diesel-only mini grids (4.6 GW), and that the average diesel capacity per mini grid is 150 kW, then around 30,800 diesel-only mini grids may be currently installed today. Meanwhile, our database identified only about 1,400 diesel-only mini grids.

Hybridizing existing diesel-powered mini grids by adding solar PV and battery capacity represents a market opportunity of $7–$18 billion. In the database, diesel-only mini grids had a total combined capacity of 1.8 GW. As mentioned above, this is likely to underestimate the global total. Therefore, it can be assumed that the total installed capacity for diesel-only mini grids is around 1.8–4.6 GW (using the BNEF analysis of diesel genset trade data). Using an estimate of $4,000/kW for the investment costs of hybridizing diesel-fired mini grids, the total market opportunity for hybridizing diesel mini grids is $7–$18 billion.

A market snapshot like the one presented above should be conducted every three years. This allows for enough preparation time and sufficient new data to become available to make updates meaningful, but is frequent enough to capture trends as they happen. The database developed for this chapter will facilitate this effort: based in Microsoft Excel, aggregate country-level data can be shared to identify areas for improving the accuracy and completeness of the data.

PROJECTIONS

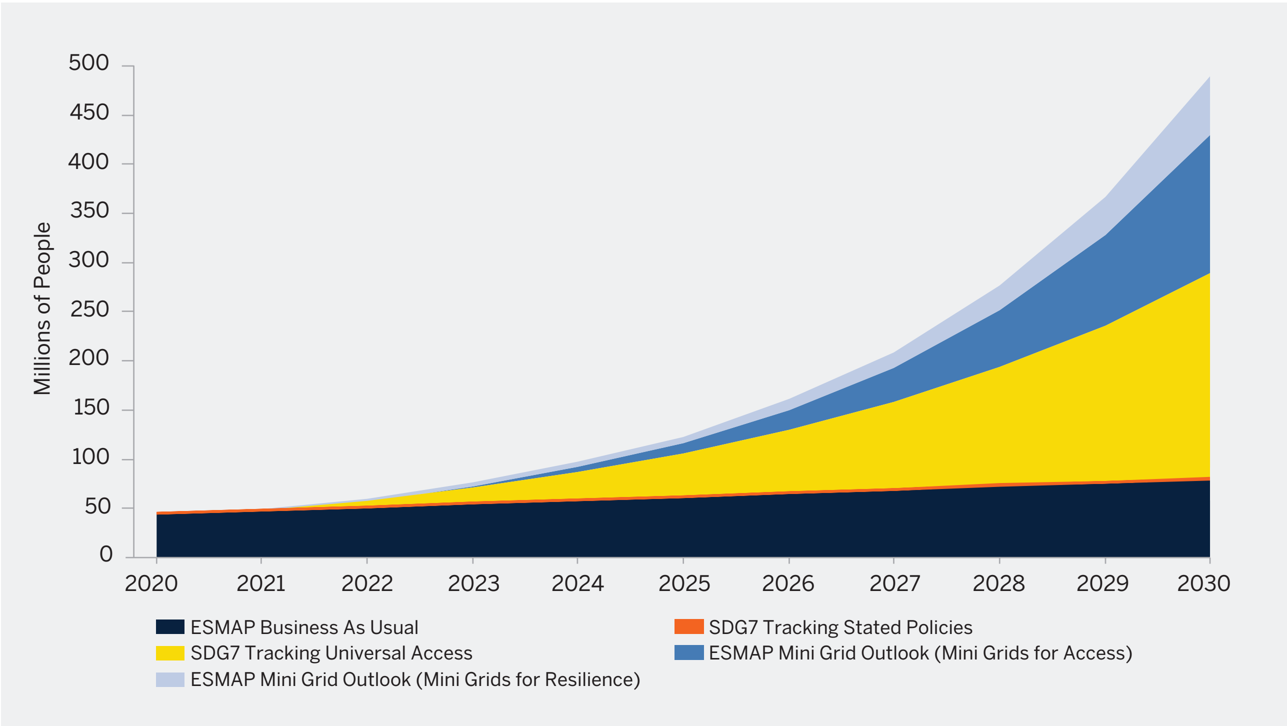
This section explains the gap between where we are headed now, in a business-as-usual (BAU) case, and where we need to go to achieve universal access to electricity by 2030. ESMAP estimates that under the right conditions, mini grids have the potential to be the least-cost way to provide electricity to almost half a billion people by 2030 (figure O.4).

ESMAP developed four scenarios for mini grid deployment between now and 2030. Each is described in turn.

ESMAP Mini Grid Outlook Scenario

Under this scenario, mini grids are the least-cost option for 430 million people to receive electricity for the first time, and an additional 60 million people will be serviced through an interconnected network with mini grids due to reliability issues on the main grid or to increase resilience in the

FIGURE O.4 • Number of people connected to mini grids under business-as-usual and universal access scenarios, 2020–30



Source: ESMAP analysis.

ESMAP = Energy Sector Management Assistance Program; SDG 7 = Sustainable Development Goal 7.

face of climate shocks/severe weather. The resulting total is 490 million people connected to more than 217,000 mini grids at a cumulative investment cost of approximately $127 billion. These projections are based on the following considerations.

- ESMAP ran country-specific scenarios for the 58 countries with data in the Global Electrification Platform and found that, under enabling circumstances, 430 million people can be best served at least cost by mini grids by 2030, at a cumulative investment cost of about $105 billion.[10] This assumes modest cost declines in key components such as batteries and solar PV and the main grid expanding at a rate of 2.5 percent of the population per year.
- In addition, as more cities, islands, and utility companies consider risks of extreme weather and invest in more resilient infrastructure, we expect to see more and more transitions toward interconnected mini grids that can isolate from the network in "island mode" if needed. This is complemented by grid-connected towns and communities investing in grid-connected mini grids in order to increase the fraction of renewable energy supplying their electricity. The team estimates that these resilience- and renewable-motivated mini grids could serve about 2–3 million new connections (about 6–7 million people) per year globally, equivalent to about 10–15 cities or small regional utilities per year deciding to strengthen their power systems by developing interconnected micro/mini/metro grids. Using costs from microgrids in high-income countries, the cumulative expected investment by 2030 for these additional mini grids is about $22 billion.

The ESMAP Business-As-Usual Scenario

The BAU scenario assumes that development in 2021–30 follows the same linear growth trajectory that was observed in the 2010–20 data in the ESMAP database, for number of people served by mini grids, and uses actual data from planned mini grids to estimate the total number of mini grids and total cumulative investment by 2030. The 2021 baseline starting points for the scenario are the totals from the database: 21,557 mini grids, 48 million people served by mini grids, and $29 billion of investment. The results for 2030 are 80 million people served by almost 44,800 mini grids at a cumulative investment cost of approximately $37 billion.

The SDG 7 Tracking Stated Policies Scenario

The basis for this scenario comes from the IEA's World Energy Outlook 2021, which developed a "Stated Policies Scenario" that accounts for policies and initiatives adopted as of mid-2021 that have an impact on energy access, together with relevant policy proposals not yet enacted. This scenario sees 260 million people gaining access to electricity between 2022 and 2030 (IEA 2021). We then conservatively estimate that 31 percent of these people will be served by mini grids—the same proportion used by the 2021 SDG 7 Tracking Report under the Sustainable Development Scenario (IEA and others, 2021, p. 160), resulting in 81 million people served by about 45,300 mini grids at a cumulative investment cost of $36 billion.

The SDG 7 Tracking Sustainable Development Scenario

This scenario is based on the IEA's Sustainable Development Scenario in *World Energy Outlook 2021* (IEA 2021), which takes universal access to electricity as the point of departure and thus sees 930 million people receiving electricity access between 2022 and 2030, after taking into account population growth. This scenario identifies mini grids as the least-cost electrification pathway for 31 percent of new connections (IEA and others 2021, p. 160), which ESMAP's analysis and estimates indicate results in 288 million people connected to approximately162,000 mini grids at a cumulative investment cost of around $93 billion.

Table O.8 presents a regional breakdown of the ESMAP mini grid outlook scenario.

Upon analysis of the regional breakdown of the global ESMAP Mini Grid Outlook Scenario, several important points stand out. First, the largest number of mini grids, and associated investment, will be needed in Africa. Indeed, almost 80 percent of all access-related investment for mini grids between now and 2030 will need to go to Africa to achieve SDG 7 by 2030. This means connecting 380 million people to 160,000 mini grids at a cost of about $91 billion. By contrast, the total number of mini grids and investment required in Latin America and the Caribbean is small relative to other regions because of this region's current high energy access rates, with the exception of Haiti. Finally, mini grids for resilience and increased penetration of renewable energy represent a major market opportunity, accounting for 12 percent of people connected to mini grids and 18 percent of cumulative investment, by 2030.

The gap between even the most optimistic BAU and universal access scenarios is still vast. The gap for energy access alone (that is, counting only mini grids needed for providing first-time access to electricity, and not counting additional mini grids built for resilience), using only ESMAP's scenarios, is 382 million people, $76 billion, and 183,000 mini grids.

The purpose of the remainder of this book is to identify concrete ways to bridge this gap.

TABLE O.8 • ESMAP mini grid outlook scenario: A regional breakdown

	Population connected to mini grids (millions)		Cumulative investment in mini grids (US$, billions)		Total number of mini grids installed	
Region	**2021**	**2030**	**2021**	**2030**	**2021**	**2030**
Africa	27	380	7	91	3,100	160,000
South Asia	12	24	2	3	9,600	27,000
East Asia & Pacific	6	19	6	9	7,200	15,000
Latin America & Caribbean	2	6	< 1	1	300	1,800
Rest of World including new mini grids for resilience and renewable energy penetration	2	60	13	22	1,400	12,300
Total	**48**	**490**	**29**	**127**	**21,500**	**217,000**

Source: ESMAP analysis.

If the current pace of mini grid development continues, about 44,800 mini grids will be installed by 2030, serving around 80 million people. However, achieving universal access to clean and reliable electricity by 2030 will require more than 217,000 mini grids serving 490 million people, at a cost of around $127 billion. For energy access alone, not counting new mini grids for resilience, this represents an expected shortfall by 2030 of 382 million people, $76 billion, and 183,000 mini grids.

STATUS OF THE FIVE DRIVERS AND TEN BUILDING BLOCKS

ESMAP has begun tracking the mini grid industry's progress against the 5 drivers and 10 building blocks, to gauge the pace of development against the 2020 targets and assess whether the sector is on track to meet the 2030 targets. More comprehensive stocktaking will be needed over the next few years in order to gain a more accurate understanding of the whole industry's progress.

Increasing the pace of deployment

The targets for the pace of mini grid development are derived from what would be needed to achieve SDG 7 in each of the top 20 countries lacking access to electricity. The pace of development grows from around 150 mini grids per country per year in 2020 to around 2,000 per country per year by 2030 (figure O.5).

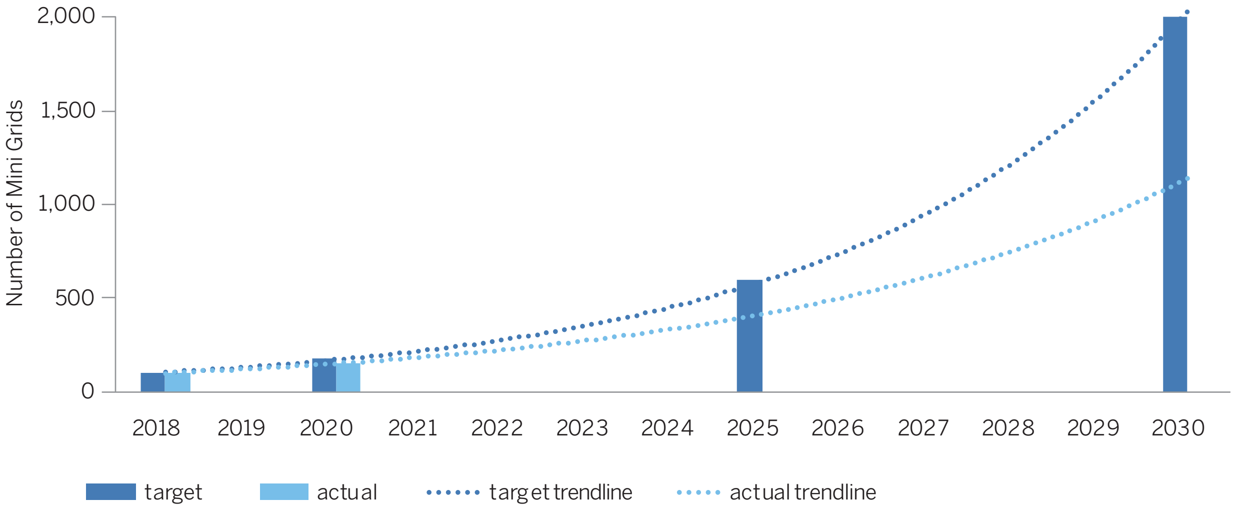
2018 benchmark. A program in Indonesia supported by the German Society for International Cooperation (GIZ) set the benchmark for the pace of development of mini grid portfolios. This Indonesia Solar Mini-Grid Programme installed 236 mini grids in just more than two years, from 2012 to 2014, setting the pace at approximately 100 mini grids per year (Schultz, Suryani, and Puspa 2014). This achievement is made even more impressive given that Indonesia is an archipelago of 6,000 inhabited islands characterized by jungles, mountainous terrain, and limited transport and communication infrastructure.

2020 progress. In 2019–20, Tata Power Renewable Microgrids was able to achieve a similar pace of development in India as the Indonesia program, constructing more than 150 mini grids in a little more than a year. The rapid pace of development for these projects was greatly aided by the choice to use a standardized design for mini grids. Standardization improved the efficiencies of carrying out tenders and enabled developers to bid on multiple sites knowing they would be installing the same type of equipment across all sites. Note that this does not mean that every mini grid should be the same size but, instead, that standardization across components facilitates modular mini grid design.

Indicators embedded in mini grid development show how long a build will take. From our conversations with AMDA, we know that some are able to develop mini grids in around six weeks once initial site identification and assessment work are completed. But the length of time from placing a purchase order to commissioning for the typical solar-diesel hybrid mini grid is usually measured in months.[11] In general, components arrive on site at different times, while delays in customs can set projects back days or weeks. Only a handful of the largest developers have systematized construction and installation in ways that allows quick and efficient deployment. The pace of deployment must speed up if we are to proceed from building tens of mini grids a year to building thousands by 2030.

One key innovation that has already been deployed to reduce the setup time for individual mini grids is containerization and the associated standardization of mini grid components—the upstream integration of standardized major mini grid components into one or two shipping containers,[12] which are then delivered, unpacked, and installed

FIGURE O.5 • Mini grids installed annually in each of the top 20 electricity-access-deficit countries, 2018–30



Source: ESMAP analysis.

at the mini grid site. Indeed, the 2030 target for solar-diesel hybrid mini grids—working toward a five-week timeframe from purchase order to commissioning—is already possible for some containerized mini grids. Both large multinational companies like General Electric and ABB, as well as smaller, more specialized companies like Redavia, BoxPower, and Nayo Tropical Technology, already have off-the-shelf containerized hybrid mini grids at the tens to hundreds of kilowatts scale. While not a silver bullet, this type of containerization—combined with standardization of mini grid components and improved efficiencies in constructing the distribution network—will have to transition from breakthrough technology to industry norm.

Increasing the pace of deployment for portfolios of mini grids will also require systematized construction and project management processes. The same practices and processes in use today by large construction firms that manage portfolios of hundreds of small- and medium-size projects are translatable to both private-sector developers and public utility companies as they seek to scale up from tens to hundreds of mini grids a year by 2030.

Providing superior service

LOAD FACTOR

As shown in chapters 1 and 3, the viability of a mini grid depends on productive-use customers, those who use electricity at off-peak, typically daytime, hours. This makes intuitive sense: if the mini grid is only able to sell electricity during the evening peak hours, it is earning revenue only during this limited time period. One way to determine how well a mini grid is performing in terms of selling electricity during off-peak times is a metric called load factor, which is the average load divided by the peak load in a specified time period. The more productive uses of electricity a mini grid serves during the day, the higher the mini grid's load factor, and the more economically viable the mini grid.

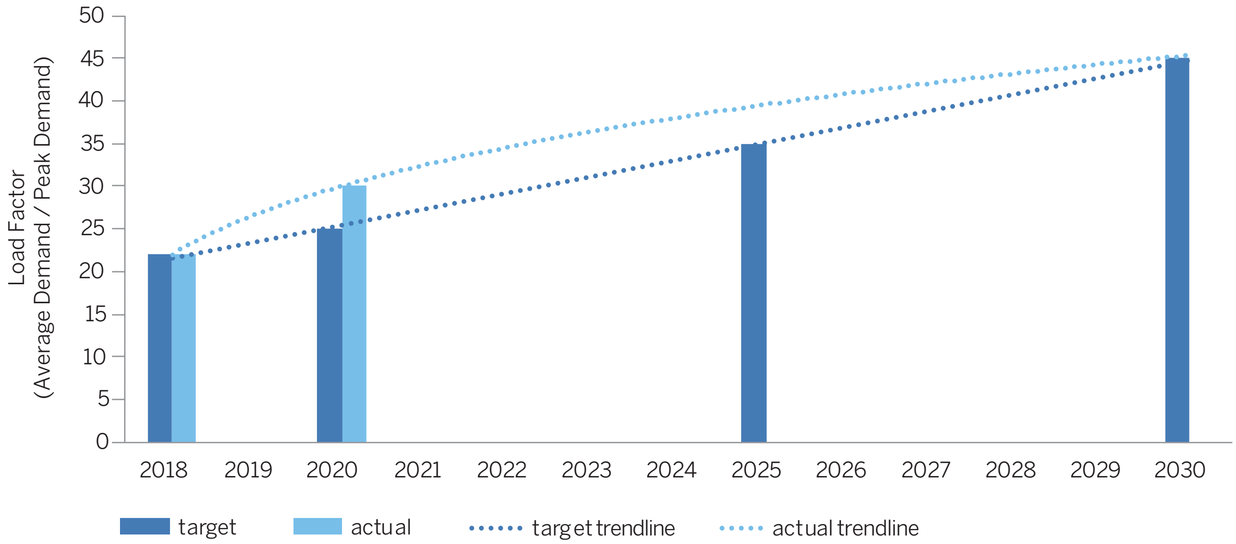
Boosting productive uses of electricity also contributes to the economic development of the communities in which mini grids operate and helps entrepreneurs and small business customers get the most value for their money from their connection to the mini grid. For the mini grid industry, increasing productive uses of electricity means increasing demand for mini grid electricity—a necessary component of growing at scale.

2018 benchmark. For the 2018 benchmark, we use HOMER's default load factor of 22 percent.

2020 progress. While data remain scarce on load factor for a sizeable cohort of mini grids, recent analysis of new solar hybrid mini grids in Haiti offers a reference point for 2020 progress. These mini grids were able to achieve a load factor of 30 percent, due in part to the fact that they served large towns with significant daytime economic activity. This is ahead of pace toward the 2030 target of 45 percent, as figure O.6 shows, although the 2030 target is the industry average.

Achieving the load factor targets will require integrating the imperative to promote productive uses from the outset of every mini grid project's development process. In addition, it will require developers to address the appliances' up-front costs by partnering with local financial institutions such as microfinance institutions or selling customers the appliances on credit paid back through on-bill financing. To achieve the productive-use targets, developers will

FIGURE O.6 • Average mini grid load factor, 2018–30



Source: ESMAP analysis.

also need to work directly with appliance suppliers to seek attractive commercial arrangements in terms of both price and after-sales service. Finally, developers must earn the trust of productive-use customers. Only if customers trust that electricity will be supplied to them reliably and in the long run will they invest in a productive-use appliance or machine powered by the mini grid's electricity. Meanwhile, governments can also incentivize mini grid developers to encourage productive uses of electricity in their mini grids. In Tanzania, for example, Rule 43 of the 2018 mini grid regulations in Tanzania allow developers to factor in the "associated administrative costs" of promoting productive uses of electricity in their retail tariffs.[13]

TECHNICAL SPECIFICATIONS

2018 benchmark. Mini grid technical specifications typically define the minimum power, safety, engineering, and other technical specifications for mini grid components and installations to which developers must adhere. Recent examples of mini-grid-specific technical specifications can be found in Annex 7 of the Nigeria mini grid regulations,[14] as part of a mini grid tender in Kenya,[15] and as part of the new draft regulatory framework for mini grids in Zambia,[16] among many other countries. Technical specifications tend to differ in each country, if they exist at all as part of a national mini grid program, which creates at least three barriers to growth. First, developers who want to build portfolios of mini grids in different countries cannot aggregate their component orders if their portfolio spans jurisdictions with different technical specifications. Second, different technical specifications restrict the size of the potential mini grid market for component manufacturers. Consider batteries as an example. If the global mini grid industry could agree with national governments and regulators on minimum performance requirements for mini grid batteries, the mini grid market would become more attractive to manufacturers of batteries that meet those specifications. Third, regulatory and rural electrification agencies tasked with overseeing a national mini grid program must develop their own mini grid technical specifications, which takes time and resources away from other important activities.

2020 progress. Efforts are underway to develop an industrywide standard for mini grid technical specifications. ESMAP has developed a set of minimum standards for technical specifications that take a light-handed approach and prioritize safety, with the goal of providing an off-the-shelf product that countries can adopt for their mini grid programs. The ESMAP specifications are in use in Haiti and Rwanda.

MINIMUM QUALITY OF SERVICE STANDARDS: UPTIME

2018 benchmark. Several years ago, a handful of leading mini grid developers in AMDA's membership were able to achieve around 97 percent uptime on average. This set the benchmark, leading to the targets of achieving 97 percent uptime as the industry standard by 2025, and increasing this level of reliability through 2030.[17]

2020 progress. In 2020, the average uptime for mini grids in AMDA's membership was already 99 percent for 24/7 electricity, surpassing the 2020 target of 97 percent uptime during promised service hours (AMDA 2021). This sets a high, but attainable, standard for new entrants to the market, and helps ensure that mini grids retain their good reputation as providers of reliable electricity.

CUSTOMER SATISFACTION

Successful mini grid developers provide high-quality electricity service, delivering reliable and predictable power while maintaining close relationships with their customers.

2018 benchmark. In a study from Smart Power India (SPI 2019), mini grids scored 84 out of 100 for small business customer satisfaction and 82 out of 100 for household customers. For comparison, the main grid scored 41 out of 100 and 34 out of 100 for these two customer groups, respectively (SPI 2019).

2020 progress. We do not have more recent survey data to provide a quantitative update on 2020 progress for this indicator. To grow at scale, the mini grid industry will need to develop and sustain a reputation for high-quality customer service, to ensure that customers feel that they are receiving value for their money. This will require surveying mini grid customers on a regular basis to ascertain their satisfaction with the services they receive. We know that many developers already invest in a variety of activities to increase customer satisfaction, including call centers for customer support and rapid response to customer complaints, as well as continued close engagement with the communities they serve.

Cumulative investment in mini grids

Achieving growth of two orders of magnitude in the global mini grid industry by 2030 will require an unprecedented level of investment from governments and their development partners. Achieving the SDG 7 targets will require total cumulative investment of around $105 billion in mini grids for energy access by 2030, shared between the public and private sectors—but not in equal proportions. As the mini grid industry grows and matures, the proportion of development partner and government funding will decrease, from 60 percent or higher today to 30 percent or lower in 2030. As figure O.7 shows, total cumulative investment in mini grids is not on track to reach the 2030 target that is necessary if SDG 7 is to be achieved.

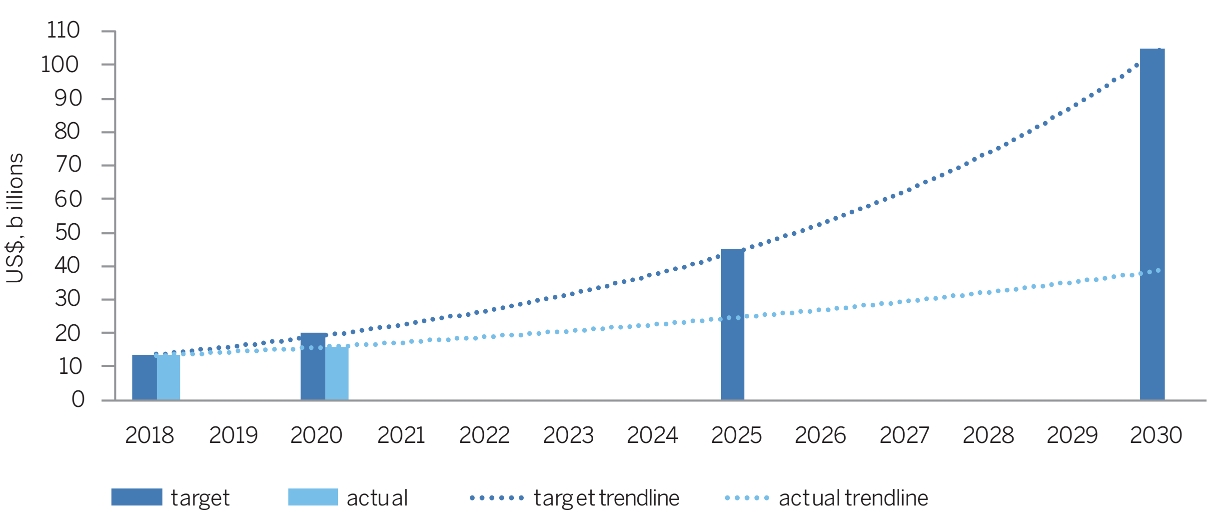
2018 benchmark. By 2018, ESMAP data indicate that the total cumulative investment in mini grids in Africa, South Asia, East Asia and Pacific, and Latin American and the Caribbean stood at around $13 billion. We estimate that at least 60 percent of this funding came from governments and development partners, equal to roughly $8 billion.

2020 progress. By 2020, the total cumulative investment in mini grids in these same regions was about $16 billion, according to data from ESMAP's database of mini grid projects around the world. While we do not have good data on the global breakdown of public vs. private sector financing, we estimate that still about 60 percent of this funding came from governments and development partners, based on results-based grant programs across the World Bank's mini grid portfolio. This is behind pace toward 2020 targets, both in terms of total cumulative investment (about $4 billion short of the $20 billion target for 2020), and in terms of the fraction of funding coming from the private sector (50 percent of funding from private sector sources by 2020).

Establish enabling mini grid business environments in key access-deficit countries

Developing mini grids at scale will require major improvements in the regulatory environment, making it easier for mini grids to operate as companies. A light-handed and predictable business climate would address the needs of mini grids be conducive to private-sector participation in mini grid development.

FIGURE O.7 • Total cumulative investment in mini grids for energy access, 2018–30



Source: ESMAP analysis.

The World Bank tracks these elements of an enabling environment for mini grids in its Regulatory Indicators for Sustainable Energy (RISE) index (World Bank 2019b), which covers the regulatory environment for mini grids in more than 50 countries. To achieve the SDG 7 objective, countries with energy access deficits must improve their enabling environments, as measured by their RISE scores. Efforts to raise these scores should focus on the 20 countries that account for almost 80 percent of the global population that does not currently have access to electricity (figure O.8).

2018 benchmark. In 2018, the average RISE score for these countries was just 59 out of 100.

2020 progress. By 2020, the average RISE score for the top 20 electricity-access-deficit countries rose to 64 out of 100, ahead of the 2020 target of 60/100. Table O.9 provides the RISE scores for each of these 20 countries.

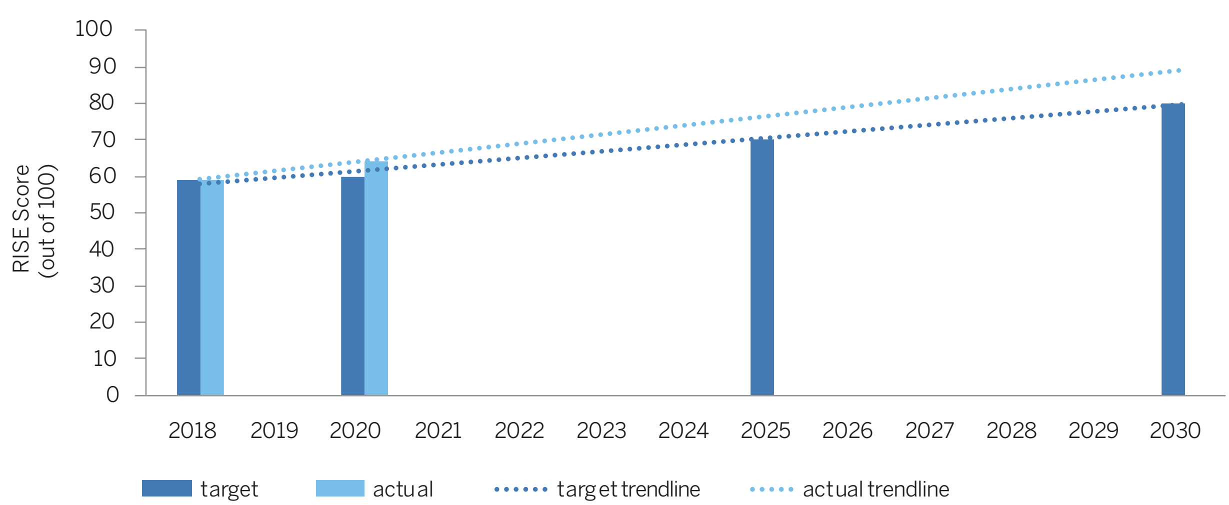
Reducing the cost of solar hybrid mini grids

One chief driver of growth for the mini grid market is the cost to build and operate a mini grid. The typical metric used to combine and quantify these costs is the LCOE, which also serves as a proxy for the average tariff at which the mini grid must sell its electricity to break even over its lifetime. For mini grid deployment to scale up rapidly, the LCOE of mini-grid-based electricity will need to plummet by 2030. Much lower LCOE would raise market demand and speed deployment in low-income areas, where ability to pay often limits the potential for mini grids as a solution for electrification, since mini grid developers often set their tariffs at or below what customers pay per month for alternatives, such as kerosene, car battery- and phone-charging services, and diesel gensets. These traditional energy services can be expensive: households and small businesses

TABLE O.9 • Top 20 countries with energy access deficits: Doing Business and RISE scores, 2020

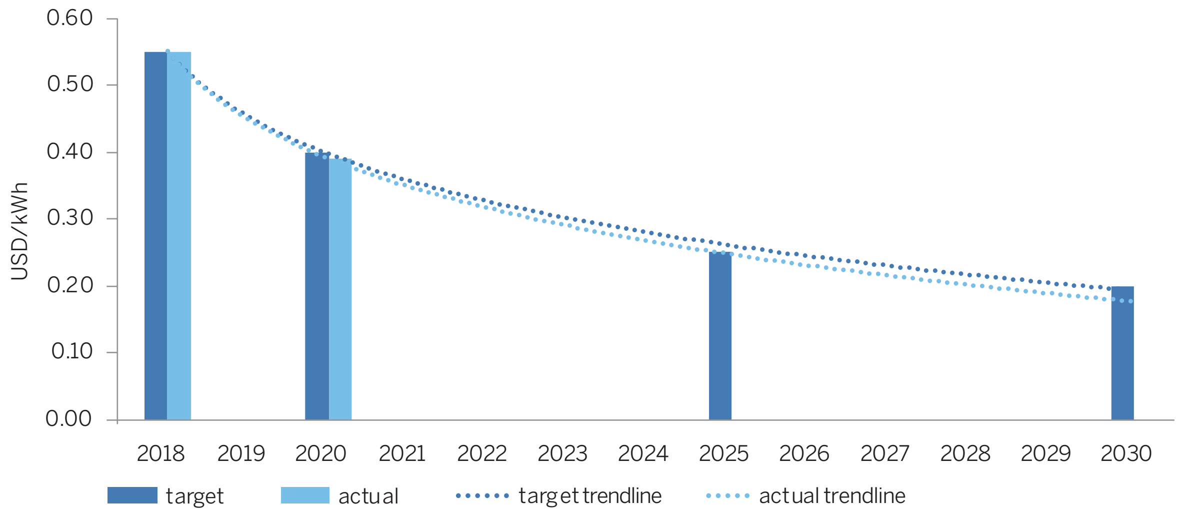
Country	Population without electricity access in 2020 (millions)	Share of global population without electricity access (%)	RISE score for mini grids in 2020 (out of 100)
Nigeria	85	11	100
Congo, Dem. Rep.	68	9	62
India	64	8	78
Pakistan	61	8	60
Ethiopia	60	8	70
Tanzania	36	5	100
Uganda	25	3	73
Bangladesh	24	3	80
Mozambique	20	3	45
Madagascar	19	2	52
Niger	18	2	73
Myanmar	18	2	73
Angola	17	2	60
Burkina Faso	17	2	42
Sudan	17	2	37
Malawi	15	2	77
Chad	14	2	35
Korea, Dem. People's Rep.	13	2	No Data
Kenya	13	2	82
Yemen	11	1	20
Total	**617**	**78**	**Average 64**

FIGURE O.8 • Average RISE score in top 20 electricity-access-deficit countries



Source: ESMAP analysis.

FIGURE O.9 • LCOE of best-in-class solar hybrid mini grids



Source: ESMAP analysis.

routinely pay the equivalent of $1/kWh or more for lighting and charging services (Tenenbaum and others 2014).

The LCOE targets that the mini grid industry can work toward—$0.40/kWh by 2020, $0.25/kWh by 2025, and $0.20/kWh by 2030 (figure O.9)—are therefore ambitious but not impossible. They are indicative targets that a cohort of leading mini grid developers can realistically achieve, thus setting the pace for other developers in the sector. Achieving these targets would bring mini grid electricity close to universal affordability levels by 2030. In addition, they make the value proposition of mini grids that provide reliable power 24 hours a day every day competitive with—if not more attractive than—other options such as backup diesel generation. Achieving these LCOE levels would greatly limit, if not eliminate, the need for subsidies in areas where customer ability to pay aligns with these targets.

2018 benchmark. According to detailed costing analysis that ESMAP conducted in 2019, the LCOE of a best-in-class solar hybrid mini grid was $0.55/kWh in 2018 (ESMAP 2019).

2020 progress. As we discuss in greater detail in chapter 1, the LCOE for a best-in-class solar hybrid mini grid was $0.38/kWh in 2020. This was ahead of the 2020 target and puts the industry on pace to achieve $0.20/kWh by 2030.

On the one hand, hitting all the targets across the five market drivers does not guarantee the 2030 scale of deployment required to realize the mini grid portion of the SDG 7 objective. On the other hand, it would make reaching the goals much easier.

Mini grid industry progress across all 10 building blocks

Table O.10 presents an overview of the global mini grid industry's progress across all 10 building blocks, based on ESMAP's internal assessment of energy access deficit countries. Note that each country has made its own unique progress; the table below, meanwhile, gives an overall sense of which building blocks have seen more progress and which generally require more work.

Key energy-access-deficit countries have made notable progress across all 10 building blocks over the past decade. Arguably the most progress, particularly in just the past three to four years, has been made in geospatial planning and in the development of regulatory frameworks and policies specific to mini grids. Advances in technology, combined with widespread adoption as part of technical assistance support to client governments, have mainstreamed geospatial analysis at the national level to identify least-cost options for electrification over the short, medium, and long terms. Furthermore, whereas site-specific geospatial analysis was typically used just for feasibility studies, today's technologies and service providers are able to identify and analyze thousands of high-potential mini grid sites, complete with distribution and generation system sizing and costing, and demand estimation that includes productive uses and public institutions. Countries have also made strong progress on developing mini-grid-specific regulatory frameworks, whether embedded into licenses (for example, Rwanda) or concession contracts (many francophone countries), developed as stand-alone regulations (for example, Nigeria), or government directives (for example, Ethiopia). We note, of course, that there is still a long way to go toward mainstreaming regulatory

TABLE O.10 • The global mini grid sector and its progress across the 10 building blocks

Building block	Progress	Notable achievements
Solar mini grid costs and technologies	Significant progress made	Large portfolios of solar hybrid mini grids in India
Geospatial planning	Significant progress made	National and portfolio-level planning in Pakistan, Nigeria, Ethiopia
Productive uses	Significant work needed	Productive uses embedded in mini grid planning in Ethiopia
Community engagement	Significant work needed	Signed community agreements in Nigeria, Haiti, Myanmar
Companies and utilities	Some progress made	AMDA's growing membership; utility hybridization in Niger, Ethiopia
Access to finance	Some progress made	Comprehensive financial package in the Democratic Republic of Congo
Skills and training	Significant work needed	Training programs in Mali and Nigeria
Institutions and delivery models	Some progress made	Strong institutions and private-sector approach in Bangladesh
Regulations and policies	Significant progress made	High RISE scores for mini grids in Nigeria, Kenya, Bangladesh
Doing business	Significant work needed	e-Government initiatives in Ghana and India

KEY:

(yellow)	Significant work needed
(light green)	Some progress made
(dark green)	Significant progress made

Source: ESMAP analysis.

AMDA = Africa Minigrid Developers Association; RISE = Regulatory Indicators for Sustainable Energy.

best practices, particularly in how regulations are implemented and the processes underpinning them.

When considering the mini grid market globally, more support is needed for productive uses of electricity, community engagement, skills and training, and the overall business environment than for the other building blocks. Of these, we see the most positive momentum in productive uses, with dedicated organizations like CLASP and EnerGrow, as well as the importance of (and funding for) income-generating uses of electricity embedded in a growing number of national mini grid programs. However, progress toward large-scale initiatives to engage with communities and build skills, as well as innovative approaches to reducing red tape, lags behind the progress in other building blocks globally. We present some ideas for how to accelerate progress in each of these areas in chapters 4, 7, and 10, respectively.

CALL TO ACTION

Connecting half a billion people to mini grids by 2030 is a monumental task that requires unprecedented levels of investment, innovation, and commitment from development partners, governments, and the mini grid industry. This book calls for action by stakeholders across the mini grid value chain. Key recommendations are for:

- Policy makers to leverage the latest geospatial analysis technology to develop national electrification plans that can guide investment in mini grids, main grid extension, and solar home systems, as well as develop initiatives that promote productive uses of electricity and build human capital.
- Development partners to work with government counterparts and the private sector to create enabling environments for mini grids through investments in actual portfolios of projects and technical assistance for developing workable regulations and strengthening institutions.
- Regulators to adopt an evolving, light-handed approach for a maturing mini grid sector, providing at each stage of development clear guidance on market entry, retail tariffs, service standards, technical standards, and arrival of the main grid.
- The mini grid industry and its associations to work toward increasing the pace of deployment, retaining superior-quality service delivery of third-generation mini grids, and reducing the cost of these systems through innovation to reach a value proposition that is affordable to the end users.
- National utilities to adopt an openness to partnerships with the third-generation mini grid industry on the basis that the systems are grid-integration ready, which can provide for more financially viable grid expansion programs for the utility in the long run.

Lastly, there is a clear need for accurate, up-to-date, and widely available data to inform any type of initiative that supports mini grids. To this end, we strongly recommend the development of a global tracking tool to monitor and measure the global mini grid industry's progress against the 10 building blocks and 5 market drivers outlined above.

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NOTES

1. This report defines access to electricity in accordance with the Multi-Tier Framework (MTF), which is elaborated further in this section.
2. The 20 countries are Angola, Bangladesh, Burkina Faso, Chad, the Democratic People's Republic of Korea, the Democratic Republic of Congo, Ethiopia, India, Kenya, Madagascar, Malawi, Mali, Mozambique, Myanmar, Niger, Nigeria, Pakistan, Sudan, Uganda, and Tanzania (data available: https://data.worldbank.org/).

3. Notable exceptions include the solar DC mini grids built, owned, and operated by Mera Gao India in the Indian state of Uttar Pradesh, and by Devergy in Tanzania.
4. The World Bank's MTF defines electricity access by five tiers of service provision. The tiers rank seven attributes of electricity service: capacity, service hours, reliability, quality or voltage fluctuations, affordability, legality, and safety. The MTF then assigns any given household to one of the five tiers, from no meaningful access at Tier 0; basic lighting and charging at Tier 1; Tier 2 households can power a few small appliances; Tier 3 households have formal grid connections with limited service; Tier 4 access supports refrigeration; and Tier 5 is unrestricted continuous service.
5. More information about AMDA is available on its website: https://africamda.org/.
6. Sustainable Energy for All website: https://www.seforall.org/
7. We have less confidence in the reliability of data for planned mini grids than we do for installed mini grids, and fewer data points were available for planned mini grids than for installed mini grids. For this reason, the main text and tables related to the mini grid market today focus on installed mini grids. However, we will provide tables and analysis of planned mini grids on the website associated with this book. For installed mini grids, we made every effort to determine their current operating status; when we found a mini grid was no longer operational, we did not include it in the database. That said, we cannot claim that every mini grid in our database is operational as of January 2022 owing to the sheer number of individual projects in the database.
8. It is important to note that despite the scope and depth of the database, it is almost certainly incomplete. For example, data are scarce for North African, Latin American, Eastern European, and Central Asian countries. It is therefore entirely possible that the global mini grid market is much larger than what this chapter describes, and what the underlying data set supports. Nevertheless, the quality of the available data is quite high, and the result of the data collection is the most comprehensive database of mini grids around the world to date.
9. We learned from conversations with AMDA and energy sector experts that many of the main grids in Sub-Saharan Africa have a similar issue: many generation plants are not operating at full capacity, and some countries are planning to export electricity because of poor-quality in-country distribution infrastructure.
10. This is inclusive of ESMAP estimates for countries not covered by the GEP.
11. Before placing a purchase order and having the goods arrive on site, mini grid developers and their partners will have already completed a number of time-consuming activities, from site identification and assessment to feasibility studies to community agreements. For the purposes of tracking the sector's progress, however, clear and measurable start and end dates are required as proxies. This requirement motivated our decision to use the purchase order and goods arriving on site as start dates as initial benchmarks for the pace of mini grid development.
12. It is important to note that shipping containers, even if modified by cutting doors and windows into them, do not always meet the minimum standards for powerhouse facilities, particularly where these standards specify rules for preventing overheating and insulation.
13. The 2018 mini grid regulations in Tanzania are available at http://www.ewura.go.tz/wp-content/uploads/2018/06/The-Electricity-Development-of-Small-Power-Projects-Rules-2018.pdf.
14. See the NERC Regulation for Mini Grids, annex 7, available at https://nerc.gov.ng/index.php/library/documents/Regulations/NERC-Mini-Grid-Regulation.
15. The mini grid technical specifications for the tender in Kenya are available at https://tenders.go.ke/website/tender/TenderDocument/9034.
16. Technical specifications for Zambia are available on the Energy Regulation Board's website as a downloadable "zip" folder from http://www.erb.org.zm/content.php?viewpage=mini.
17. The Service Standards target for 2020 focuses on increasing reliability during the times of day when the developer has promised to provide electricity—for example, during evening hours. The target for 2025 focuses on maintaining high reliability and increasing availability to 24/7 electricity—which brings the standards on par with (or above) those of the main grid.

CHAPTER 1

REDUCING COSTS AND OPTIMIZING DESIGN AND INNOVATION FOR SOLAR MINI GRIDS

CHAPTER OVERVIEW

This chapter presents the results of the deepest and most extensive survey of the costs and technology innovations of solar mini grids and solar-diesel hybrid mini grids in developing countries conducted by any organization to date. Detailed data were collected from 411 solar and solar-diesel hybrid mini grids in Africa and Asia. According to our analysis, a 40 percent load factor plus expected decreases in component costs would lower the levelized cost of mini grid electricity to $0.20/kilowatt-hour (kWh) by 2030. After outlining the present status of mini grids' capital and operating costs, the chapter concludes with an outlook for these costs through 2030.

The solar mini grid industry is in the early stages of scale-up. Whether solar mini grids' potential will be fulfilled depends crucially on their cost. What are the key drivers of mini grid costs? What do the data suggest are key opportunities for lowering mini grid costs without sacrificing quality and reliability? What is the variation in costs among projects, and what does it suggest about best practices that should be emphasized as the rollout of mini grids scales up?

To help answer these questions with real-world data, the Energy Sector Management Assistance Program (ESMAP) undertook the deepest and most extensive survey of the costs and technology innovations of solar[1] mini grids and solar-diesel hybrid mini grids in developing countries conducted by any organization to date. This survey of 411 mini grids implemented by national electrification programs supported by the World Bank probes the technology design and costs of mini grids commissioned or contracted between 2012 and 2021.[2] The portfolio of projects encompasses 22 countries. The survey responses include detailed data down to the component level (solar panels, batteries, inverters and energy management systems, distribution networks, land, logistics and transport, and so forth), including technical specifications.

The mini grids analyzed in this chapter are isolated from the main grid. Most are powered by a combination of solar panels and a diesel generator. Some run on just solar panels. They include battery storage and deliver alternating current (AC) electricity to customers.[3] (Please see https://www.esmap.org/mini_grids_for_half_a_billion_people for more information about the mini grids analyzed in this chapter.)

THE LEVELIZED COST OF MINI GRID ELECTRICITY

This chapter focuses on the capital expenditure (CAPEX) required to build a mini grid, including for its preparation, and the operational expenditure (OPEX) required to keep it going. We can combine these costs into a single cost per unit of energy, called the levelized cost of energy (LCOE).[4] For mini grids, LCOE pertains to the cost of electricity on a per kilowatt-hour (kWh) basis delivered to mini grid customers over the lifetime of a mini grid. LCOE considers project development costs (engineering, obtaining permits, management), initial costs (for example, equipment and installation), the costs of operations (for example, staff and fuel), and equipment replacement over the lifetime of the project. As such, it is equivalent to the minimum average tariff that electricity must be sold for in order to cover project costs, including project financing.

We calculate LCOE in two different ways: financial and economic. The financial perspective on a project is from the point of view of the developer, and incorporates all costs reported by developers in constructing and operating a mini grid, including import duties and taxes. The simplified economic perspective endeavors to remove the influence of taxes, duties and subsidies, and thus represents the cost to society at large, or equivalently, the cost of mini grid electrification if a country were to impose no duties or taxes or subsidies on mini grids. A private sector operator competing in the marketplace and paying import duties and taxes must consider the *financial* cost. Policy makers deciding among approaches to electrification, meanwhile, are most concerned by the *economic* cost. A separate analysis of how subsidies affect the affordability of mini grids for end users, and the viability of their development, is provided in chapter 6.

THE LEVELIZED COST OF ENERGY FROM MINI GRIDS: SEVEN ANALYTICAL CASES

We developed financial and economic LCOE estimates for seven mini grid cases, described below (and in detail in the website accompanying this handbook). For each of these cases, we collected data from multiple mini grids, in some cases hundreds of them, to determine the average unit cost for mini grid component categories. These component categories included the following:

- Solar panels
- Batteries
- Inverters
- Energy management systems
- Backup generators
- Distribution networks
- Installation
- Land
- Management

Using case-specific costs, we used HOMER® Pro (Hybrid Optimization of Multiple Energy Resources) software to optimize a solar hybrid mini grid for each case and to calculate the LCOE for each optimized mini grid over a 20-year lifespan.

The seven cases of LCOE analysis covered three different levels: country, global, and best-in-class.

For the country level (cases 1–3), we picked three countries deploying mini grids at scale: Ethiopia (10 mini grids), Myanmar (61 mini grids), and Nigeria (with unit costs based on averages of 150 mini grids).[5]

For the global average (cases 4 and 5), we pursued the same approach, but aggregated data that met internal data consistency check thresholds from countries around the world. Case 4—"Global Li-ion"—is based on data from 221 mini grids in six countries[6] and is restricted to mini grids that use lithium-ion (Li-ion) batteries, whereas case 5—"Global" (355 mini grids from 19 countries[7])—calculates an average LCOE for all mini grids, including those with lead-acid batteries. The distinction between battery types is important because our data show a major shift from the use of lead-acid batteries (comprising about 97 percent of mini grids in our database up to year 2017) to Li-ion (69 percent of mini grids in our database installed between 2018 and 2021). Because Li-ion batteries have superior lifetimes and performance characteristics, they lower mini grids' LCOE. For more on this, including the viable role of lead-acid batteries in mini grids, see the discussion on batteries later in this chapter.

Case 6 represents the best-in-class mini grid; its LCOE is based on component costs and load magnitude averaged from three high-performing mini grids in our database, one each from Ethiopia, Myanmar, and Nigeria.

Finally, case 7 is a best-in-class 2030 mini grid, based on case 6 but with equipment cost reductions expected in 2030, as the mini grid industry ramps up and other associated industries achieve scale that drive cost reductions for important components such as solar panels (driven by global solar panel deployment in solar farms) and Li-ion batteries (driven by global expansion of electric vehicles and utility-scale electricity storage). Drivers of cost changes are discussed at the end of this chapter.

The number of mini grids in each sample used to determine representative mini grid unit costs, the average peak load (in kilowatts, kW), and average number of customers per mini grid are shown in table 1.1. Mini grids varied considerably across and within countries. For example, in Nigeria the average mini grid served an average of 916 customers, but only had a peak load of 69 kW—about 75 watts per customer; whereas Ethiopian mini grids on average served 228

TABLE 1.1 • Representative mini grids from seven cases: An analysis of key characteristics

	Mini grids in sample	Peak load (kW) of average mini grid	Number of Customers for average mini grid
1. Nigeria	150	69	916
2. Myanmar	61	96	409
3. Ethiopia	10	178	228
4. Global Li-ion	221	79	716
5. Global	355	68	587
6. Global best in class	3	141	793
7. Global best in class 2030	3	141	793

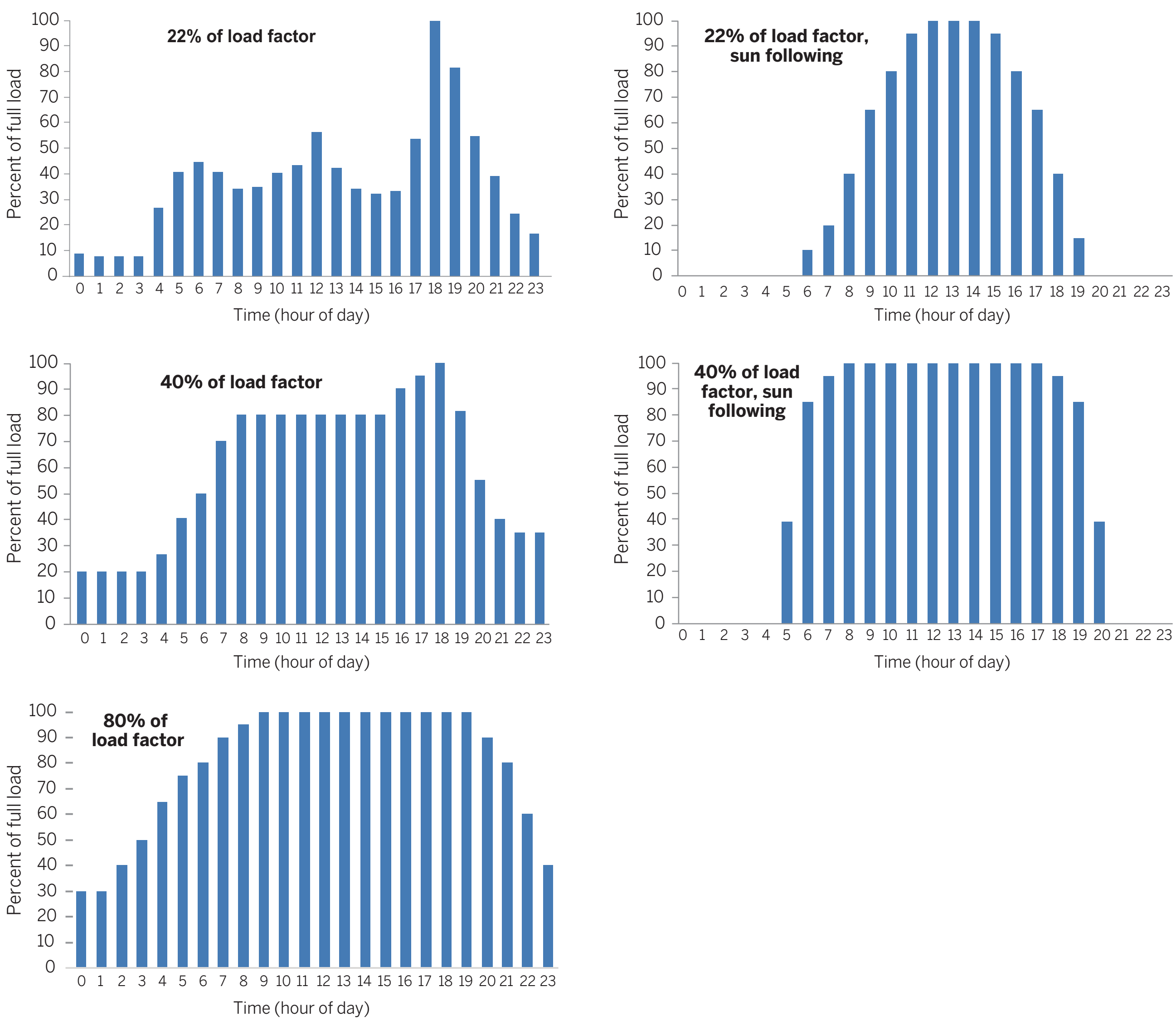
customers but with a peak load nearly three times higher (178 kW), averaging 780 watts per customer.

MODELING ASSUMPTIONS AND SCENARIOS

When calculating LCOE with HOMER Pro, we included a number of assumptions based on prior research and experience, including a 20-year lifetime for the mini grid,[8] a discount rate of 9.6 percent,[9] inflation of 3 percent,[10] and diesel prices of $1/liter.[11] For all cases except Myanmar, inadequate data were available on non-fuel OPEX and we assumed an OPEX of $1,700 per staff person with three staff ($5,100 per year) required for a mini grid with up to 500 customers, and four staff ($6,800 per year) for a mini grid with more than 500 customers. Individual mini grid components such as generators, batteries, and photovoltaic (PV) panels had additional variable OPEX expenses.[12] More information about the modeling and assumptions is available at https://www.esmap.org/mini_grids_for_half_a_billion_people.

Peak hours generally occur in the evening, when households use the most electricity. So for each case, we looked at five scenarios to analyze the impact of daylight and non-peak operation of local manufacturing on productive-use loads. The variable adjusted in each scenario is the load factor—a measure of the mini grid's utilization rate, defined as average load divided by peak load over a year. The first of these scenarios is a base case (22 percent load factor) representing a typical rural residential load. The third and fifth scenarios bring the load factor up to 40 percent (the medium case) or 80 percent (the high case) (figure 1.1). Higher load factor scenarios (40 percent and 80 percent) represent the addition of off-peak (primarily daytime) pro-

FIGURE 1.1 • Load profiles for 22 percent load factor, 22 percent load factor (sun following), 40 percent load factor, 40 percent load factor (sun following), and 80 percent load factor



ductive-use loads such as water pumping, agricultural processing, cold storage with thermal inertia, and charging of electric vehicles.

The second and fourth scenarios illustrate the benefits of lower LCOE that arise from using electricity during sunny hours, coincident with its production by solar panels, thus minimizing the costly battery storage and retrieval or the burning of diesel fuel in backup generators. These two "sun-following" scenarios use the same amount of daily load in the 22 percent (base case) and 40 percent (medium case) load factor scenarios but modify the timing of the consumption to be concentrated during sunlight hours. These sun-following load profiles should be seen as aspirational, and are included to provide a sense of the benefits of incentivizing daytime consumption.

In calculating the financial LCOE presented in this chapter, we have assumed zero grants. However, a second set of scenarios considers the impact of performance-based capital subsidies (grants), at levels of 40 and 60 percent of initial CAPEX, on seven representative mini grid cases. Because these address financing, this set of subsidy scenarios is discussed in detail in chapter 6.

MODELING RESULTS

Our economic and financial LCOE results are for Ethiopia, Myanmar, and Nigeria as well as representatives of global and best-in-class cases. The LCOE and renewable energy fraction of each varies depending on the load curve, including the degree to which loads occur during sunlight hours (figure 1.1).

The next section discusses the portion of costs that each category of expense (for example, solar panels, batteries, management, taxes, duties, and so on) involves, how these costs have been trending since 2012, and the projections that justify our 2030 best-in-class LCOE projections.

LCOE analysis: Base case load profile with 22 percent load factor

Our economic analysis indicates that the economic cost of electricity delivered to households from representative mini grids in Nigeria and Myanmar is $0.43 to $0.46 per kWh for our base-case typical village residential load profile with a 22 percent load factor (figure 1.2). In our modeling based on winning engineering, procurement, and construction contract bids, Ethiopian mini grids on average cost somewhat less, at $0.41 per kWh. This reflects that their commissioning was relatively recent (in 2021) in our sample, and thus they benefited most from the declining global prices of solar panels and batteries, as well as economies of scale due to being relatively large in terms of peak load and average customer load (figure 1.2).

At the global level, mini grids with Li-ion batteries had similarly low LCOE. A representative mini grid based on component costs from 221 mini grids from 6 countries (but dominated by the large number of Li-ion mini grids in Nigeria and Myanmar) was calculated to have an LCOE of $0.46 per kWh. Adding in mini grids with lead-acid batteries from 16 countries brought the average LCOE up to $0.53 per kWh for the 22 percent load factor case. It is noteworthy that the mini grids with lead-acid batteries were often more expensive, not necessarily because of the battery type, but because they tended to be older—built as far back as 2012—and therefore had a variety of higher-cost components.

The economic LCOE from a representative best-in-class mini grid is $0.38 per kWh, reflecting a nearly 29 percent decrease from the LCOE of current global mini grids in our data set and a 17 percent decrease from current global Li-ion mini grids. At component prices expected in 2030, this drops further to $0.29/kWh, a 22.5 percent drop from current best-in-class LCOE.

The financial LCOE follows the general trends of the economic LCOE but is higher by up to 13 percent. The amount of increase depends on the country, since duties and taxes vary from country to country. The increase also depends on the load factor and load curve since mini grids in the highest load factor cases rely heavily on batteries (both larger battery banks and also deeper cycling and thus more frequent need for replacement) to provide large amounts electricity in the hours of little or no sunlight, and batteries are generally assessed higher duties and taxes than solar panels.

LCOE analysis: Adding productive use loads and impact load shifting

The mini grids in our analysis had much lower LCOE when loads shifted from evening to daytime sunlight hours (see the "sun-following" cases in figure 1.1), or when productive uses that increase the profile's load factor were added (resulting in a 40 percent or 80 percent load factor). Both shifting to daylight hours and increasing the load factor are likely to be accomplished through encouraging loads such as agricultural milling, light manufacturing, water pumping, or cold storage, for which demand is greatest during daytime hours.

A simple way to understand the benefits of daytime use is to consider that the marginal cost of adding new generation capacity (solar panels, PV inverters) to meet solar-coincident consumption costs around $0.10 per kWh at mini grid scales. Meanwhile, the levelized cost of new capacity to cycle electricity into and out of a battery for later use adds at least twice that per kWh (taking into account losses of

BOX 1.1

THE LEVELIZED COST OF ENERGY FOR BEST-IN-CLASS MINI GRIDS DROPPED NEARLY 31 PERCENT FROM 2018

Best-in-class mini grid costs have plummeted in the past few years. In 2018 ESMAP conducted a cost analysis of 53 mini grids (ESMAP 2019). At that time, the best-in-class mini grid produced electricity with a levelized cost of energy of $0.55 per kilowatt-hour (kWh). By 2021, best-in-class costs had dropped nearly 31 percent to only $0.38 per kWh in the unsubsidized 22 percent load factor case, and more in cases with a higher load factor.

This drop in the levelized cost of energy in the past two years reflects dramatic decreases in the costs of mini grid components, including solar panels (dropping 18 percent) and a shift in battery type from lead-acid to lithium-ion, which has similar upfront costs but superior performance characteristics and thus lower life-cycle costs. While batteries appear to be decreasing in capacity, the switch to lithium-ion batteries enables deeper discharge, leading to higher effective capacity. Cheaper storage and PV generation, in turn, enables reductions in fuel usage: our 2021 best-in-class case used less than one-quarter of the diesel fuel consumption of the 2018 best-in-class mini grid. These trends also reflect decreased project development and installation costs due to economies of scale in deployment.

TABLE B1.1.1 • Estimated and potential levelized cost of mini grid energy, 2018 and 2021

	LCOE ($/kWh) from best-in-class mini grid		
Load factor (%)	**2018**	**2021**	**Percentage decrease (%)**
22	$0.55	$0.38	31
22 sun following	—	$0.30	
40	$0.42	$0.28	35
40 sun following	—	$0.26	
80	$0.35	$0.23	35
Initial CAPEX	$1,160,000	$847,000	
Number of customers	1099	793	
Solar capacity (kWp)	228	286	
Battery type	lead-acid OPzS	Li-ion $LiFePO_4$	
Battery capacity (kWh)	887	690	
Average daily load (kWh)	890	758	
Firm power (kW_{firm})	207	230	
$/$kW_{firm}$	$5,604	$3,659	35

Note: Levelized cost of energy data in 2018 is for the best mini grid in the ESMAP database at the time, representing a well-designed mini grid serving 1,100 customers in Bangladesh; 2021 best-in-class data are from a representative mini grid synthesized from average costs and consumption levels in three mini grids in Myanmar, Nigeria, and Ethiopia commissioned in 2020 or 2021. Calculations assume that annual peak load is 75% of installed battery inverter capacity and average daily load is calculated as the area under the daily load profile curve scaled to the peak load, accounting for 10 percent day-to-day and 20 percent hourly load volatility.

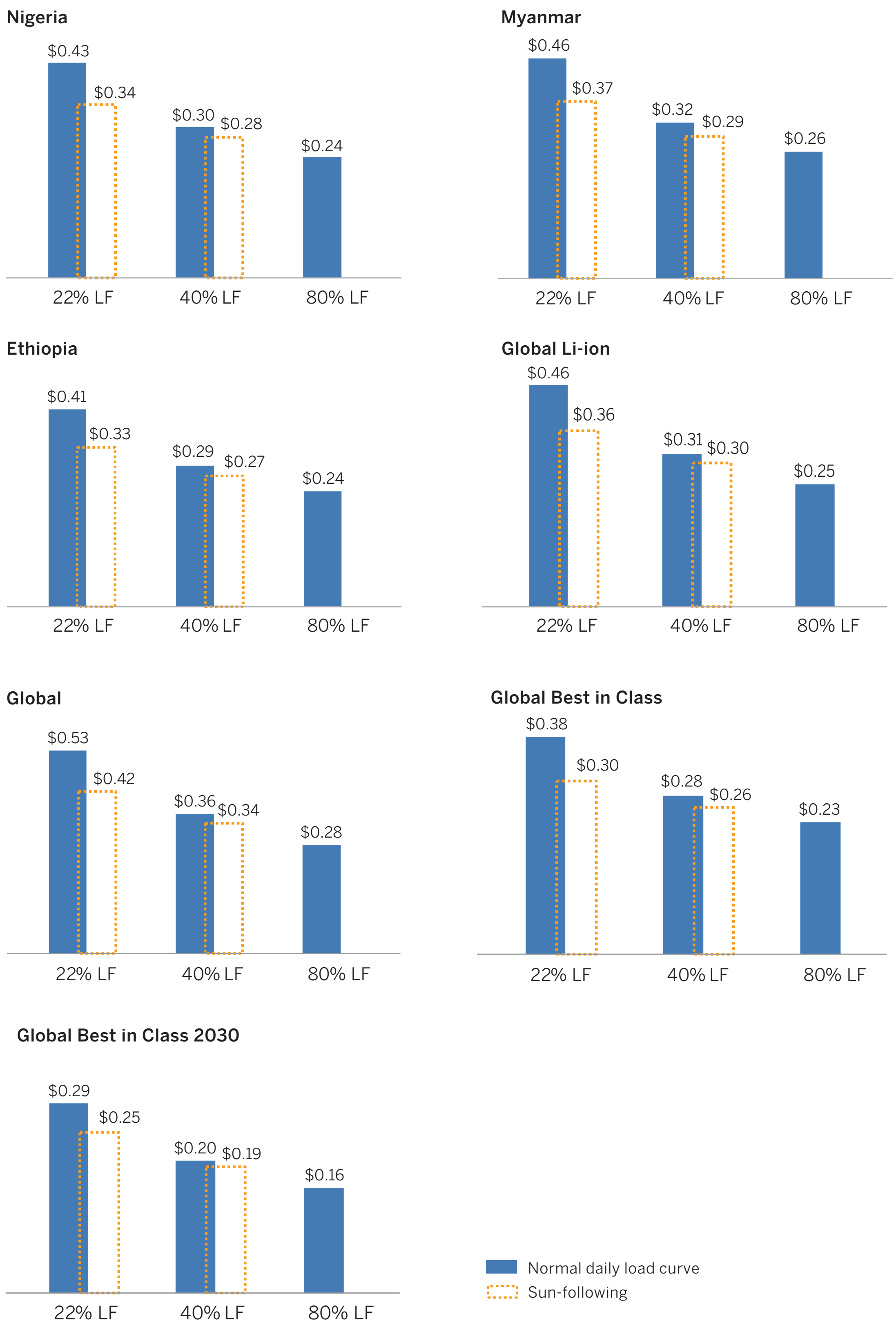
LCOE = levelized cost of energy; CAPEX = capital expenditure; kWh = kilowatt-hour; kWp = kilowatt peak.

electricity in the charge/discharge process). Benefits of solar-coincident consumption can be further maximized by the use of dispatchable loads such as water pumping to a storage tank or non-time-sensitive agricultural processing in which the activity needs to take place sometime, but can wait until there is an energy surplus.

If the load curve remains at a 22 percent load factor but demand is shifted to largely follow solar production (a 22 percent load factor in the sun-following case), the LCOE drops by 4.5–10.6 cents per kWh (15–21 percent of the total) in contemporary mini grids (figure 1.2).

As the load factor is increased to 40 percent, reductions in LCOE are even more substantial, shaving 8.8–16.5 US cents per kW (32–36 percent) from the base case 22 percent load factor scenario. If an 80 percent load factor can be achieved, reductions are 13.0–24.7 cents per kWh (39–47 percent).

FIGURE 1.2 • Economic LCOE calculations for mini grids in 7 cases based on 0 percent subsidy and load profiles described in figure 1.1



Shifting loads to daylight hours for a 22 percent load factor mini grid can decrease LCOE by up to 21 percent, while increasing the load factor of a solar-hybrid mini grid from 22 percent to 40 percent decreases LCOE by up to 36 percent.

Conservative ESMAP analysis indicates that the combination of increased productive uses and decreased component costs resulting from economies of scale and sector-wide technology cost trends can bring best-in-class mini grid LCOE down to $0.20/kWh by 2030.

EFFECT OF EXPECTED DECLINES IN CAPITAL AND OPERATING COSTS BY 2030

The cost reductions seen over the past decade are expected to continue until the end of the current decade for mini grid components, particularly solar panels and battery storage. In addition, ESMAP projects increased savings in management, installation, and OPEX due to scaled-up deployment of clusters of mini grids. Together, these savings are expected to drive down the cost of electricity from mini grids. Our 2030 best-in-class case predicts mini grid economic LCOE to reach $0.29 per kWh for a typical residential load curve with a 22 percent load factor. This is a 23 percent decrease from today's best-in-class LCOE of $0.38 for the same load curve. When combined with a 40 percent load factor, best-in-class mini grids are expected to reach an economic LCOE of $0.20/kWh by 2030.

For the best-in-class 2030 scenario, the following economic cost assumptions were made:

- The costs of key mini grid components available to developers decrease as follows:[13] PV modules and PV inverters (combined) cost $343 per kilowatt-peak (kWp), down from $596/kWp in the 2020 best-in-class representative mini grid;[14] battery inverters cost $265 per kilovolt-ampere (kVA), down from $303/kVA; and Li-ion batteries cost $137/kWh, down from $297/kWh.[15]
- Operation and maintenance (O&M) costs fall 50 percent, thanks to better bill collection through online pay-as-you-go metering, and enhanced remote-monitoring technologies that streamline repairs and reduce staff costs through geographic clustering (Carlin and others 2018).
- We conservatively assume that other CAPEX elements and economies of scale remain constant, even though lower installation costs will be achieved by increasing portfolio sizes, among these, cost reductions from scalable plug-and-play building block components (the "LEGO-fication" of mini grids), decreased management and engineering costs through economies of scale, and better pricing of components through larger volumes of purchases (Carlin and others 2018). Declines in this full range of costs are explored later in this chapter.

THE SHARE OF RENEWABLE ENERGY

HOMER modeling calculated the optimum renewable energy fraction for each case (table 1.2). Hybrid mini grids are largely powered by renewable energy but employ diesel generators as backup during extended cloudy periods or for times of particularly high nighttime loads. HOMER modeling includes consideration of seasonal variations in sunlight as well as random day-to-day and hour-to-hour variation in solar resources and electrical loads. Nearly all of the cases modeled have renewable energy fractions exceeding 90 percent, meaning that over the course of the year less than 10 percent of the electrical energy is derived from operating the diesel generator.[16]

The exception is for the global case at a very high load factor (80 percent), which indicates a renewable energy fraction of 76 percent. The representative mini grid in the global case is derived from a large data set covering 355 mini grids, some installed as early as 2012. As such, it includes many mini grids built when solar panels were much more expensive. Higher equipment costs in this global case combined with the high nighttime loads in the 80 percent load factor case mean that there are more hours in the year in which the diesel generator is dispatched. This effect disappears if the price of fuel is modeled at $1.50 per liter. For recent mini grids and those in the future, high renewable energy fractions (above 90 percent) will continue to be expected.

TABLE 1.2 • Optimum renewable energy share for mini grid cases considered

	Renewable energy share (%)				
Country	**22% load factor**	**22% sun**	**40% load factor**	**40% sun**	**80% load factor**
Nigeria	92	92	94	95	93
Myanmar	93	95	94	95	93
Ethiopia	93	90	94	93	91
Global Li-ion	93	91	94	93	92
Global	87	92	91	91	76
Best-in-class	92	90	93	93	90
Best-in-class 2030	94	94	95	95	94

MODELING RESULTS: LCOE OF OPTIMUM HYBRID VS. 0 PERCENT AND 100 PERCENT RENEWABLE ENERGY

Powering these same loads using only a diesel generator is much more expensive. For example, using the best-in-class case above, HOMER-calculated economic LCOEs are 55 percent to 126 percent higher for diesel only (table 1.3) compared to an optimized hybrid solar mini grid with battery storage and diesel backup.

But using a diesel generator to occasionally cover cloudy periods or periods of particularly high load lowers costs compared to the cost of a mini grid that is sized to meet 100 percent of the load with renewable energy. The economic LCOE of an optimally sized 100 percent solar mini grid with battery storage is 24 to 39 percent higher than an optimally sized hybrid system.

With a renewable energy fraction of 90 percent, the deployment of solar mini grids for half a billion people has vast benefits for the environment. These systems are replacing diesel-fueled systems and/or kerosene-based appliances that on average emit 0.89 kilograms (kg) of carbon dioxide (CO_2) per kWh. Assuming a rollout at scale covering the addressable market of 217,000 systems by 2030, 1.2 billion tonnes of CO_2 emissions would be avoided.

IMPLICATIONS FOR NATIONAL UTILITIES OF LOWER MINI GRID LCOE

As a result of declining LCOE and increasing income-generating uses of electricity, third-generation mini grids can have transformational effects on power sectors. They are on track to provide power at costs lower than many utilities by 2030 (figure 1.3). At an LCOE of less than $0.30 per kWh, mini grids will become the least-cost solution for grid-quality electricity for more than 38 percent of African countries in a scenario in which national utilities do not dramatically change their operations—with vast implications for the allocation of both public and private investment funds. At $0.20/kWh, electricity from mini grids is less expensive to produce than electricity from the main grid in 24 out of 39 countries in Africa.

IMPLICATIONS FOR NATIONAL UTILITIES OF IMPROVING THE QUALITY OF MINI GRID SERVICES

Many of the mini grids that we analyzed in our study provide 24/7 electricity and a level of service that consistently exceeds the level of service provided by the main grid. Remote monitoring technologies and smart meters are increasing the quality of customer service and the reliability of mini grids. According to a 2022 benchmarking study by the Africa Minigrid Developers Association (AMDA), among mini grid sites installed by their members in 2020, only 2 of 35 sites reported service uptime of less than 99 percent (AMDA and ECA 2022).

Across Sub-Saharan Africa, the main grid is much less reliable: households and small businesses typically experience several hours a day of outage. In some countries—including Burundi, Ghana, Guinea, Liberia, Nigeria, and Zimbabwe—more than half of households connected to the main grid reported receiving electricity less than half the time (Blimpo and Cosgrove-Davies 2019). Disaggregated data from the diagnostic survey reports carried out by ESMAP in a range of countries based on the Multi-Tier Framework provide additional evidence of this lack of reliability, both in the Sub-Saharan region and beyond. The report from Rwanda indicates 97 percent of grid-connected households experience more than four electricity disruptions a week (Koo and others 2018). The Ethiopia report shows that 57.6 percent of grid-connected households face 4 to 14 outages a week, and 2.8 percent face more than 14 outages a week (Padam and others 2018). The report from Cambodia indicates that 69.3 percent of grid-connected households face frequent, unpredictable power outages, and 9.9 percent of all grid-connected customers receive less than 4 hours of service per day (Dave and others 2018).

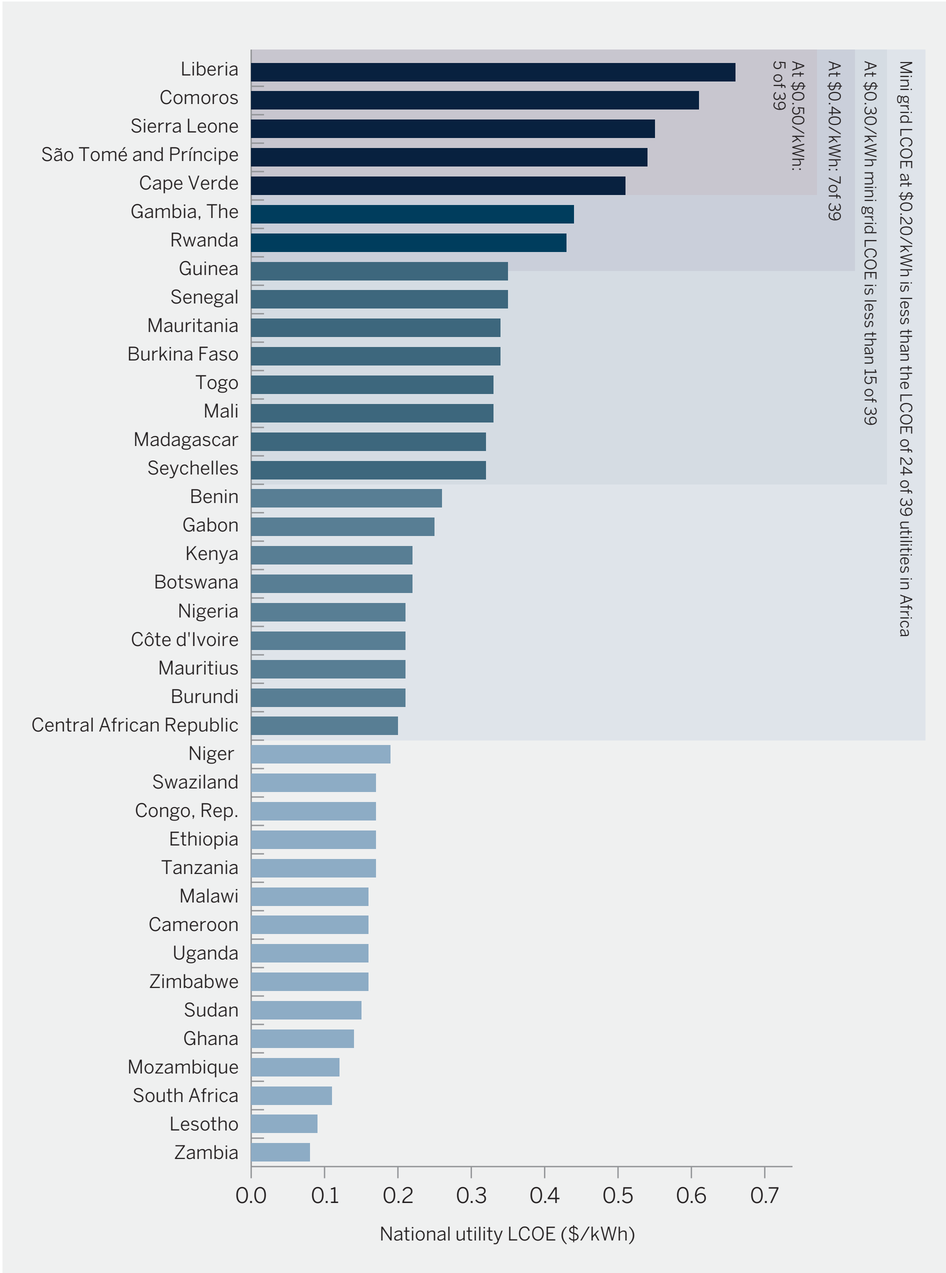
Utility information, while limited, corroborates this survey information. Only about a third of vertically integrated Sub-Saharan utilities reported figures for the average duration and frequency of system interruptions in 2018, and only 5 of 21 distribution companies did so. Of those that did, median reported duration and frequency of interruptions in 2018 were 51.6 hours and 24.7, respectively.

TABLE 1.3 • Economic LCOE of hybrid mini grid versus diesel only and renewables only

	Economic levelized cost of energy (% above hybrid)				
	22% load factor	**22% sun**	**40% load factor**	**40% sun**	**80% load factor**
Optimized hybrid (91 to 94% renewable energy)	0.38	0.30	0.28	0.26	0.23
Diesel only (0% renewable energy)	0.85 (126%)	0.65 (115%)	0.55 (98%)	0.47 (85%)	0.35 (55%)
No diesel (100% renewable energy)	0.47 (24%)	0.40 (30%)	0.37 (34%)	0.35 (38%)	0.32 (39%)

Note: All equipment sizes optimized to meet load profiles based on best-in-class 2021 component pricing.

FIGURE 1.3 • Comparison of levelized cost of energy of mini grids and utilities in Africa



Source: Based on Trimble and others 2016.

Note: Many customers in rural areas are charged tariffs that are much lower than the levelized costs shown above due to subsidies.

kWh = kilowatt-hour; LCOE = levelized cost of energy.

These are high by international standards. In order to receive any points under the scoring methodology used by the World Bank's Doing Business indicators, the maximum SAIDI (System Average Interruption Duration Index) and SAIFI (System Average Interruption Frequency Index) is 12—equivalent to one hour-long outage each month (Balabanyan and others 2021). Information on load factor for these utilities was not available.

WIN-WIN FOR MINI GRIDS AND NATIONAL UTILITIES

However, scaling up mini grids does not mean scaling back the main grid. On the contrary, third-generation mini grids enhance the economic viability of expanding the main grid. By designing a system from the beginning to interconnect with the main grid and by promoting income-generating uses of electricity through effective community engagement and training, third-generation mini grids can provide early economic growth, so that significant load already exists by the time the main grid arrives and customers have a greater ability to pay. New regulatory frameworks give developers viable options for what happens when the main grid arrives, and reductions in the cost of components enable developers to build grid-interconnection-ready systems while still keeping tariffs affordable. New grid-connected mini grid business models are also providing win-win arrangements in which utilities lease distribution assets and sell backup power to mini grid operators that take on customers that utilities have found unprofitable to serve directly, or that require higher levels of service than the utility is able to provide (Tenenbaum, Greacen, and Shrestha 2022).

As a result, supporting third-generation mini grids goes hand in hand with strengthening the utility sector. Interconnecting third-generation mini grids with the main grid as part of a national electrification strategy can increase the resource diversity and overall resilience and efficiency of the power system when interconnection is properly planned and executed. But this presents an operational challenge, requiring utilities to be able to introduce the practical technical functions to support power system operations and planning with multiple mini grids connected to the distribution grid, such as short-term and long-term forecasting and other complex procedures. This means that mini grid development—as a viable strategy for delivering universal access to electricity—entails a much stronger utility sector able to accommodate interconnecting mini grids with the main grid.

How this can be achieved is laid out in several chapters that follow, including chapter 5, 8, and 9.

> As the cost of mini grid electricity continues to fall while its quality continues to rise, mini grids will become competitive with the main grid in more and more countries. When the levelized cost of mini grid electricity hits $0.20/kWh, it will be less expensive to produce than main grid electricity in 24 of 39 African countries. However, scaling up mini grids does not mean scaling back the main grid. On the contrary, third-generation mini grids enhance the economic viability of expanding the main grid, and scaling up mini grids requires much stronger utilities, able to accommodate interconnection over time as the main grid expands.

CURRENT STATUS OF SELECTED MINI GRID CAPITAL AND OPERATING COSTS

COST PER UNIT OF FIRM POWER OUTPUT

Of primary concern to developers and program administrators alike is the total investment cost of the mini grid, by capacity. As a precursor to this discussion, it is important to define what we mean by mini grid capacity. How much electric power (kW) can a mini grid reliably provide on an ongoing basis? For conventional dispatchable power plants, this is called firm capacity, commonly understood as the intended, sustained output of the facility at times of full load.

There is no consensus in the mini grid industry on how to define a metric comparable to firm capacity, based on component specifications. The amount of power available at any given moment from a mini grid is shaped by diverse factors: the capacity of the solar array, the amount of sunlight, the capacity of the inverter, the storage capacity of the battery bank, the capacity of the diesel generator, and, as a practical matter, the availability of diesel fuel. Some of these factors are at times limiting, and others offer alternative pathways to provide electricity. Some have specific time durations or depend on factors such as the weather.

In the absence of an industry metric, we offer an imperfect, but we believe useful back-of-the-envelope definition of mini grid firm power. We define the firm power output of a mini grid as the generator capacity (kW)[17] plus 25 percent of the solar array output rated peak (direct current, DC) power output (kWp). In much of the world, about six hours of midday sunlight is the daily allotment—roughly the sunlight intensity at which solar panels produce their rated output.[18] Six hours is 25 percent of a full day.

$$kW_{firm} = kW_{gen} + 0.25\ kWpPV$$

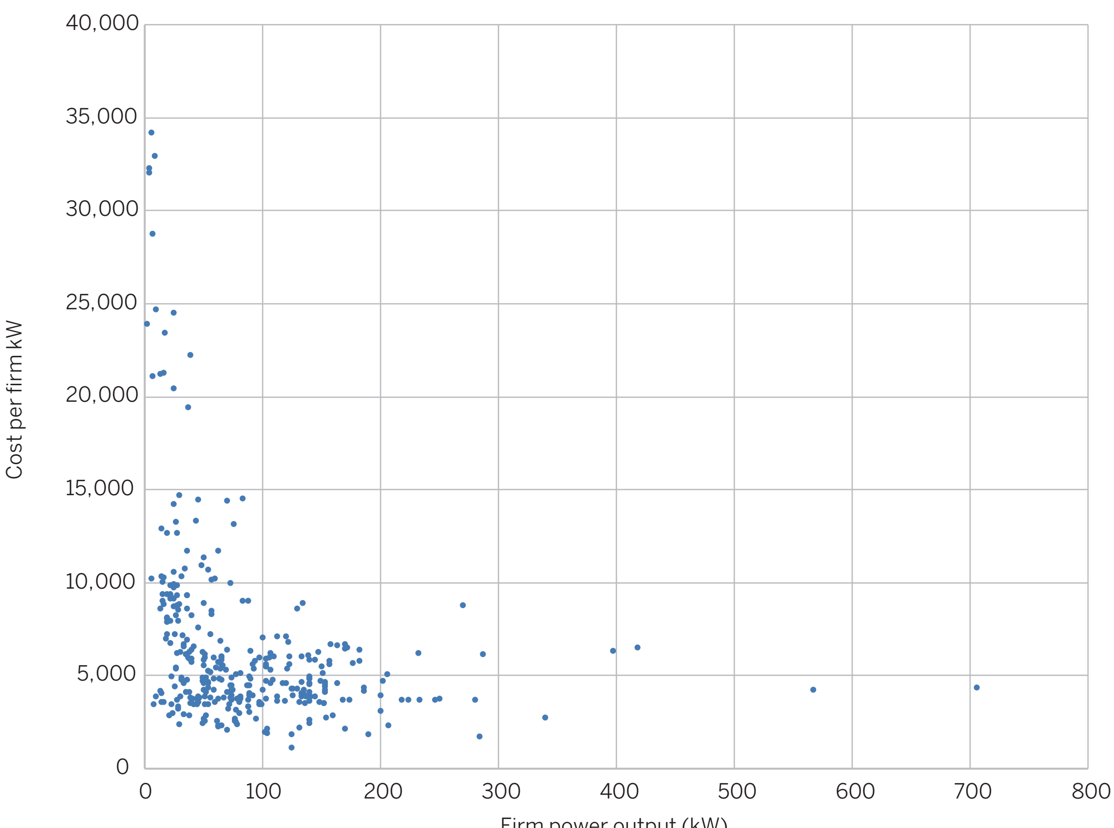
This definition assumes that the battery is sized large enough to store sufficient solar electricity to redistribute it over periods with inadequate sunlight, accounting for inefficiencies. But in some areas, especially those with a prolonged rainy season, this will not be possible. The definition also assumes that diesel supply is not constrained. Thus, mini grids with large diesel generators seem to have greater capacity than mini grids with strong solar investment, despite the fact that operating a diesel generator for anything other than backup generation is not cost effective. The definition also ignores the effects of temperature on PV power output, as well as power lost through efficiencies in energy storage and conversion. On the other hand, the definition underestimates power available during sunlight hours, which could reach as high as the sum of the generator output, the PV array output (technically, the AC output from the PV inverter), and the battery inverter capacity.

Despite these shortcomings, we find the metric useful because it is easily calculated with available data, and gives an indication of the rough magnitude of a constant load that could be powered by the mini grid for many days, if not indefinitely, if adequate diesel supply were available. The premise is that the provider of the electricity service can guarantee electricity delivery upfront for any time the consumer wants it. The definition is useful for contemporary solar mini grids that are basically designed as solar-storage systems that have a diesel generator backup for less than 10 percent of annual energy. For the other 90 percent or more of annual energy, solar panels or solar plus storage are sufficient. The low marginal cost of a diesel genset's installed capacity makes it affordable for it to carry the entire load. However, given high fuel costs, there is strong incentive to operate generator only when there is absolutely no other choice. Within this context, the firm power metric delivers valuable information on the ability of a system to power a load for days or even weeks. Outside these contexts, the kW_{firm} metric should be treated with caution.

Of 356 mini grids, there are wild cost variations per kilowatt of firm power (kW_{firm}) output (figure 1.4). The median economic cost was $5,084 per kW_{firm}, while the 25th and 75th percentile economic costs were $3,760 and $6,953 per kW_{firm}, respectively. Most mini grids below 200 kW_{firm} have costs around or below $5,000 per kW_{firm}. The economic cost of a best-in-class mini grid in 2021 was $3,659 per kW_{firm}.

As expected, in general mini grids display economies of scale in generation, with smaller mini grids costing more per kW_{firm} than larger mini grids. Most of the highest cost per kW_{firm} projects are built as individual projects and often lacked backup diesel generators. Many of these mini grids represent early efforts to understand the marketplace and experiment with new technologies with less focus on cost

FIGURE 1.4 • Total economic cost of mini grids per kW_{firm} as a function of firm power output



kW = kilowatt.

reduction. Data on financing sources were not collected, but it is likely that these costlier projects had larger shares of grant funding. While generally only small projects (under 50 kW_{firm}) had exceptionally high costs per kW_{firm}, many small projects also had low costs in this metric. We should note that the lowest-cost mini grids from an LCOE perspective are not necessarily the lowest cost in terms of firm capacity. If a low LCOE is desired, high solar utilization is required, whereas mini grids with large diesel generators tend to score low on the $\$/kW_{firm}$ metric because diesel generators provide cheap capacity, albeit expensive to fuel. With this in mind, it is worth emphasizing that the $\$/kW_{firm}$ metric is *not* the design parameter for optimization—but this indicator is useful when estimating investment.

Some high $\$/kW_{firm}$ projects appeared to follow a deliberate strategy of overbuilding their distribution network (in terms of both quality and scale), to easily accommodate upgrades in generating capacity as the load grows. Other factors explaining the wide variation may be the amounts and ways in which project development costs are internalized into a project or absorbed by a company and not reported as a mini grid development cost, the cost of doing business in the country in question, and a lack of competitive tendering.

> Mini grid costs vary across projects and countries, with a median cost per kilowatt of firm power output of about $5,000. A low cost relative to firm capacity points to the likelihood of the mini grid having a large diesel generator relative to its solar array, which could, in turn, raise the levelized cost of energy if it is dispatched often.

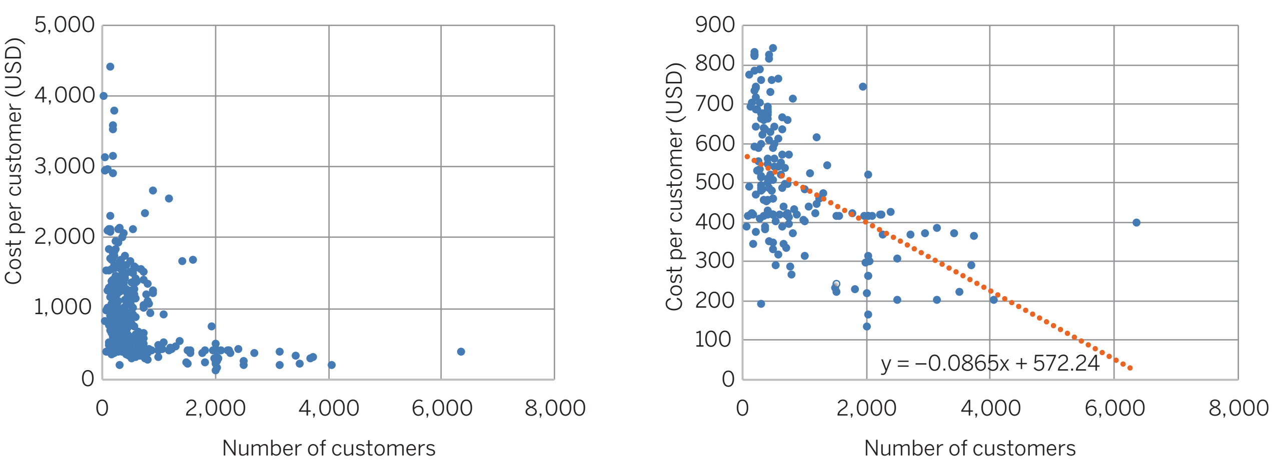
INVESTMENT COSTS PER CUSTOMER

The median cost per customer for village mini grids was $846, with 25th and 75th percentile costs of $468 and $1,413, respectively. As figure 1.5 shows, however, there are notable and unsurprising outliers—many from 2020 and 2021 mini grids reporting only a few customers—among newly commissioned mini grids. Others were relatively costly pilot projects, sometimes one of a kind, built with less emphasis on cost reduction.

The total costs per customer reflect economies of scale, as mini grids serving more customers have lower costs per customer on average. If only those mini grids with per customer costs below the median are included, every additional 100 customers lowers the per customer cost by about $9.

Of the 411 mini grids in the database, a majority (217) had between 200 and 600 customers; 82 mini grids had fewer than 200 customers, and 112 had more than 500 customers. The preference for mini grids under 500 customers may be because mini grids beyond this scale, both in terms of distance and cumulative consumption, require transformers and medium-voltage lines to distribute power. Lack of regulatory certainty regarding grid arrival may also be a factor: in the absence of regulation, project developers may be choosing small sites farther from the main grid that are less attractive for potential grid expansion. When a version of this study was conducted in 2018 with 53 mini grids, the most popular size (28 mini grids) served under 200 customers, likely reflecting relatively early preferences by developers to limit risk by testing the waters with smaller communities.

FIGURE 1.5 • Mini grid economic costs per customer (left) and costs per customer for mini grids below median cost (right)



Source: ESMAP analysis.

The data suggest that, on average, for every additional 100 customers a mini grid serves, its per customer costs fall by about $9. Whereas in 2018 most mini grids had fewer than 200 customers, today most serve between 200 and 600 customers.

The largest cost components of the mini grids in our data set were distribution (27 percent of total capital expenditure), batteries (15 percent), import duties and taxes (12 percent), and installation (13 percent).

COST OF INDIVIDUAL COMPONENTS

Solar mini grid components include solar panels, batteries, generators, inverters, other electronics, the distribution network, powerhouse, shipping and logistics, and installation. Mini grid total costs also include soft (but very real) business and project development costs, such as site identification, demand assessment, design, and the process of obtaining necessary approvals. Table 1.4 provides a summary of the costs and characteristics of individual mini grid components from 351 mini grids in our database. The sections below unpack the details of these components.

In addition to the summary data reported in the table above, sufficient data were available from 294 mini grids to determine the average share of mini grid cost attributable to each component (figure 1.6). The largest cost components were the distribution grid (26.6 percent), batteries (14.9 percent), installation (11.3 percent), PV modules (9.7 percent), and taxes and import duties (11.5 percent).[19] Taxes and import duties were back-calculated based on tax and import duty rates provided by developers for the countries they build and operate mini grids in, and vary considerably from country to country and from component to component. The profit margin (reported at only 0.3 percent of economic costs in our data set) merits unpacking and further research. On the one hand, most mini grid projects earn revenues on electricity sales and it is difficult for anyone to tell, especially early on in a project's life cycle, how profitable the project will be and thus what the ultimate profit margin will be. For mini grids that were constructed as engineering, procurement, and construction contracts, our data are derived from bid responses and in this case the profit margin is not explicitly stated, but rather is blended into line items (equipment costs, management, installation, and so on).

It is important to note that the portion of reported costs that each component accounts for ranges widely across mini grids (table 1.5). PV solar panels in a mini grid in Nepal, for example, were reported to cost nearly twice what they did in neighboring India. Li-ion batteries cost more than double on a per kWh basis in Indonesia in 2017 than what they cost in Ethiopia for a 2021 mini grid. Distribution costs per customer were more than five times higher on a per customer basis in a 2016 Côte d'Ivoire project than reported in a 2021 project in India.

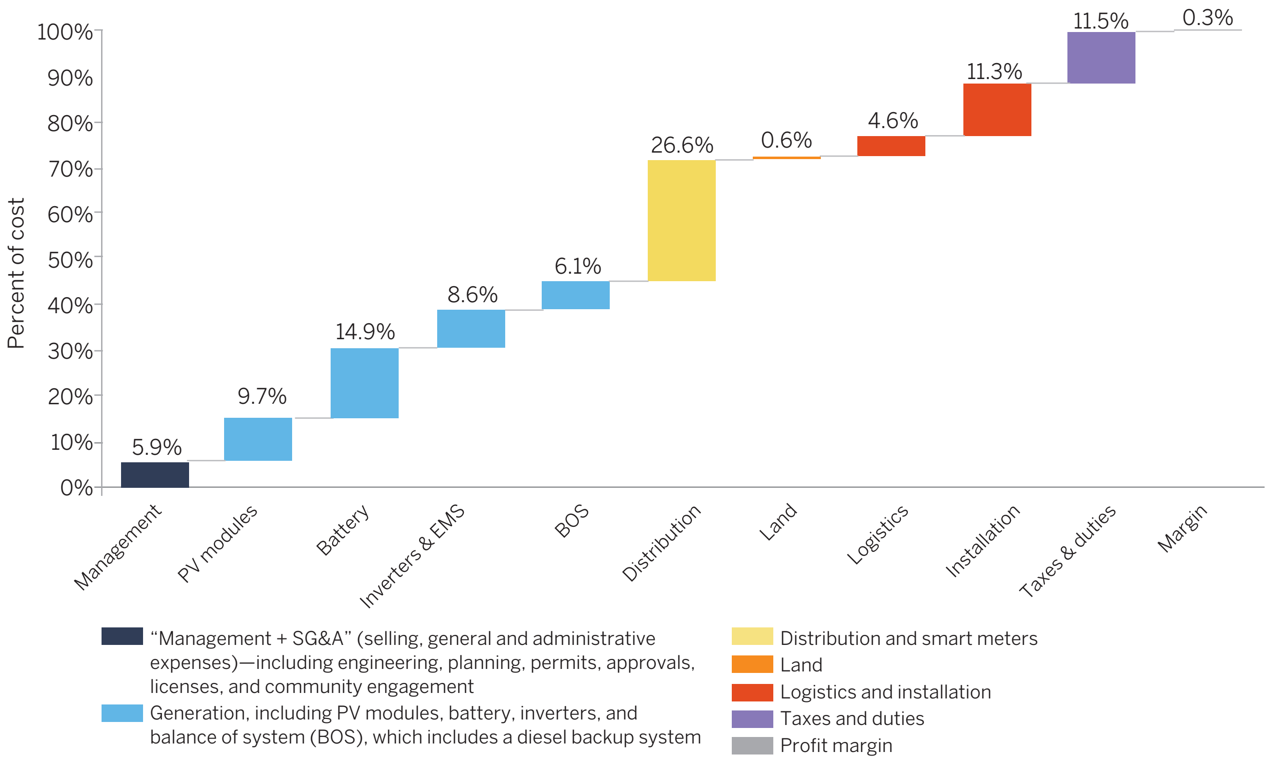
There are likely multiple reasons for these differences. Most pronounced is that costs have come down over time for major components, yet the data in the table above do not distinguish the year of project commissioning. This remarkable change in cost over time is discussed below. Another factor is that developers in different countries fold the profit margin into component costs in various ways. Other reasons may include differences in interpretation by mini grid developer respondents to the surveys and

TABLE 1.4 • Mini grid components: A summary of costs and characteristics

		Technical characteristics			Costs		
Component	**Number of mini grids with available data**	**25th percentile**	**Median**	**75th percentile**	**25th percentile**	**Median**	**75th percentile**
Solar panels (including PV inverter)	351	45 kWp	76 kWp	125 kWp	$388/kWp	$441/kWp	$599/kWp
Battery	Lead-acid: 133	144 kWh	288 kWh	432 kWh	$154/kWh	$193/kWh	$224/kWh
	Lithium ion: 217	102 kWh	180 kWh	312 kWh	$271/kWh	$314/kWh	$414/kWh
Inverter + EMS	313	30 kW	63 kW	118 kW	$325/kW	$415/kW	$716/kW
Distribution and meters	317	N/A	N/A	N/A	$163/kWp	$250/cust	$331/cust
Customers	350	238	404	644	$480/cust	$836/cust	$1290/cust

Source: ESMAP analysis. Note: percentile technical characteristics and unit costs are for each component separately. The rows should not be read together and interpreted in aggregate to represent the component capacities of a "25th percentile" or "median" mini grid.

FIGURE 1.6 • Average share of component economic costs in total capital costs of mini grids



Note: For costing purposes, PV inverters and PV controllers are grouped together.
BOS = balance of system; EMS = energy management system; PV = photovoltaic.

TABLE 1.5 • Average economic costs of key mini grid hardware components, by country

	Solar panels $/kWp	Lead-acid battery $/kWh	Lithium-ion battery $/kWh	Battery inverter $/kW	Distribution $/customer
Bangladesh	622	185	—	1,242	355
Ethiopia	504	—	285	—	385
Ghana	798	143	—	1,011	520
Guinea Bissau	801	129	—	1,612	283
India	445	115	—	1,225	155
Indonesia	601	—	625	1,017	316
Ivory Coast	688	106	—	707	933
Kenya	834	142	—	928	307
Myanmar	497	231	422	467	321
Nepal	865	152	—	870	392
Nigeria	477	180	331		206
Palestine	656	158	—	1,181	303
Tanzania	585	159	614	1,431	496
Vanuatu	464	141	—	641	704
Minimum	**445**	**106**	**285**	**467**	**155**
Average	**631**	**153**	**455**	**1,028**	**405**
Maximum	**865**	**231**	**625**	**1,612**	**933**
Delta	***94***	***119***	***119***	***245***	***504***

Source: ESMAP analysis.
— no data available; kVA = kilovolt-ampere; kWh = kilowatt-hour; kWp = kilowatt-peak.

queries that solicited this information. In the distribution case, some projects may have needed only upgrades to existing distribution networks, whereas most others built new distribution networks, and there are considerable cost differences in distribution networks that are underground vs. above ground, and for different sizes of poles and conductors.

The following sections explore in more detail some of the components that account for large fractions of the total investment cost.

Solar panels (including racking and PV inverter)

Based on data from 351 projects, solar panel economic costs for mini grids have been decreasing by about $32/kWp per year on average since 2012 (figure 1.7). Based on data from 278 projects built between 2019 and 2021, these more recent installations had a median cost of $413 per kWp, with a 25th percentile cost of $354 per kWp and a 75th percentile cost of $599 per kWp.

In our data groupings, solar panel costs include not only the solar panels, but also the PV inverters.[20] Both are consistent with, yet not strictly comparable with, the module-level pricing that we discuss among global PV module cost trends later in this chapter.

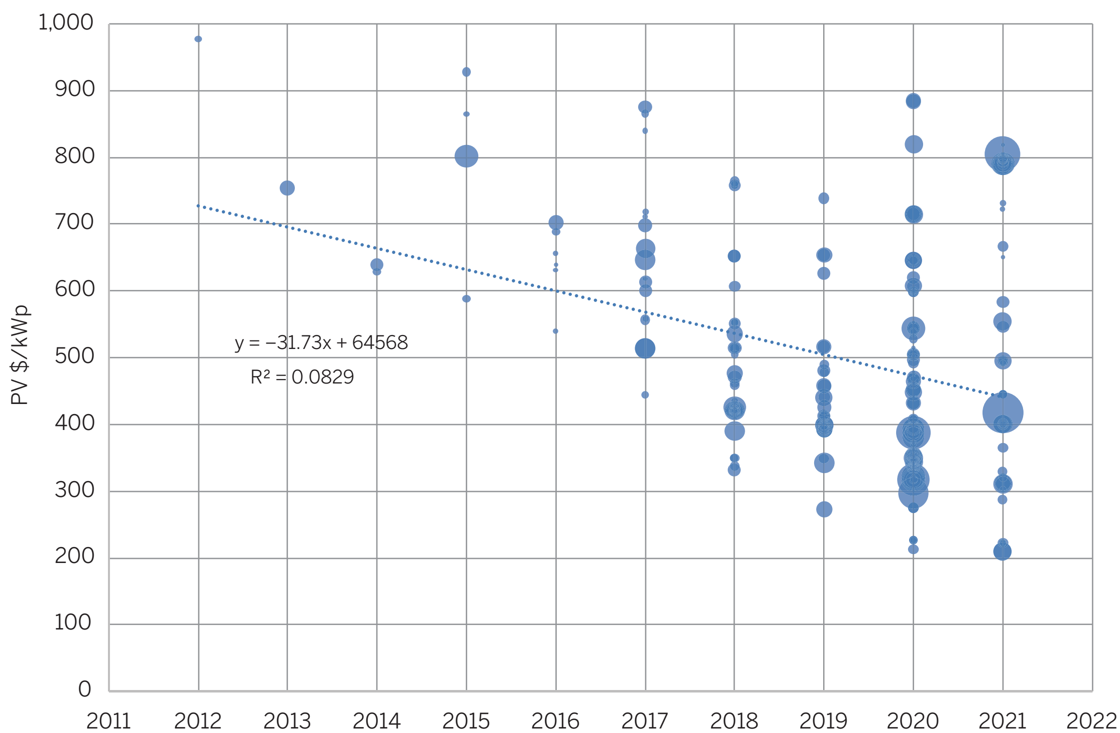
> Mini grids benefit from decreasing global solar module prices, reflected in cost declines in the solar portion of mini grids of around $32 per kilowatt-peak per year.

Batteries

Batteries are a huge story in mini grids in the past several years. Li-ion batteries are rapidly becoming the dominant choice for new mini grids, driven by lower costs enabled by their increasing use in consumer appliances, electrical vehicles, and utility power storage. Of 211 mini grids under construction or commissioned in 2020 and 2021, 145 (69 percent) used Li-ion batteries while 66 (31 percent) used lead-acid batteries.

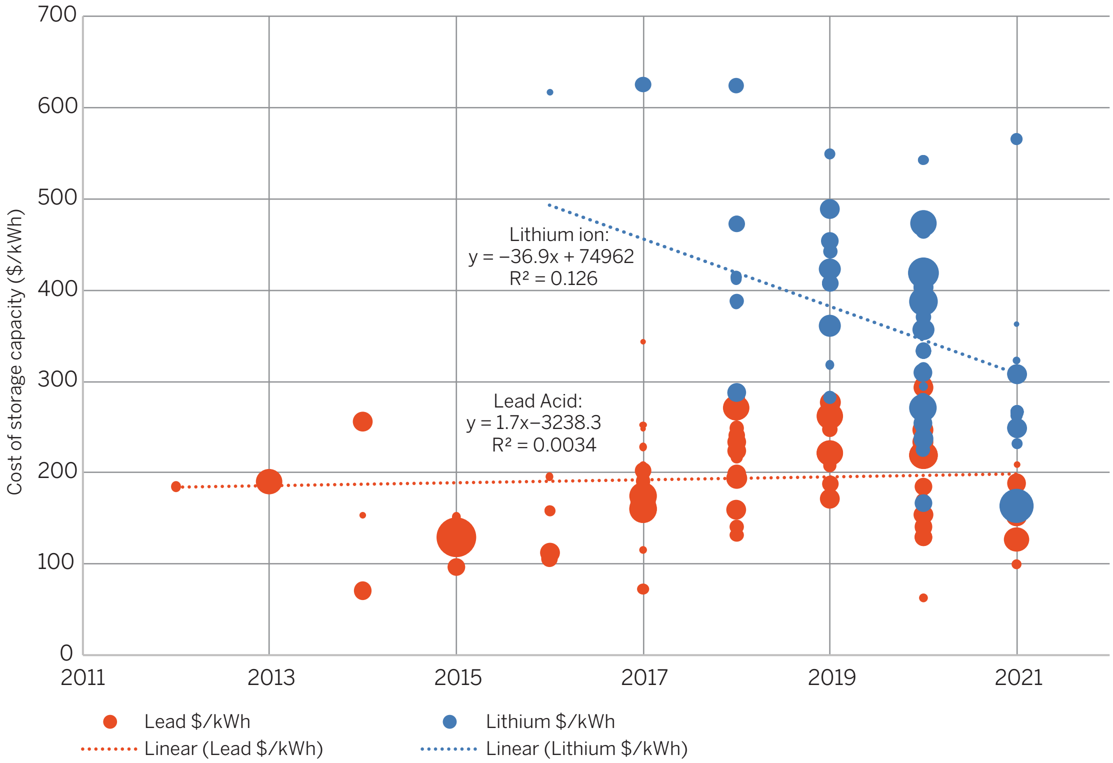
The common metric for battery pricing is $/kWh of battery storage capacity. Figure 1.8 indicates economic cost trends for mini grid Li-ion (blue) and lead-acid (red) batteries. The graph shows lead-acid battery costs slightly increasing from our earliest project data in 2012 but holding roughly steady at about $200 per kWh. Increasing lead-acid battery costs are consistent with global trends driven by the

FIGURE 1.7 • Costs of solar panels (including PV inverters) for mini grids, by year, 2012–21



Source: ESMAP analysis.
Note: The relative capacity (kWp) of the solar array is indicated by the relative size of the dot.
kWp = kilowatt-peak.

FIGURE 1.8 • Economic cost trends for the storage capacity ($/kWh) of lithium-ion and lead-acid batteries used in mini grids between 2012 and 2021



Source: ESMAP analysis.
Note: The nameplate capacity (kWh) of the battery is indicated by the relative size of the dot.
kWh = kilowatt-hour.

increase in the commodity price of lead, especially since mid-2015 (Trading Economics 2022).

Li-ion batteries appeared first in 2016 among the mini grids we tracked, and by 2018 were in 28 new projects. In 2019 they were included in 60 new projects and this number has grown every year since. Costs have been declining substantially for Li-ion batteries and their battery management systems at a rate of nearly $37 per kWh per year.

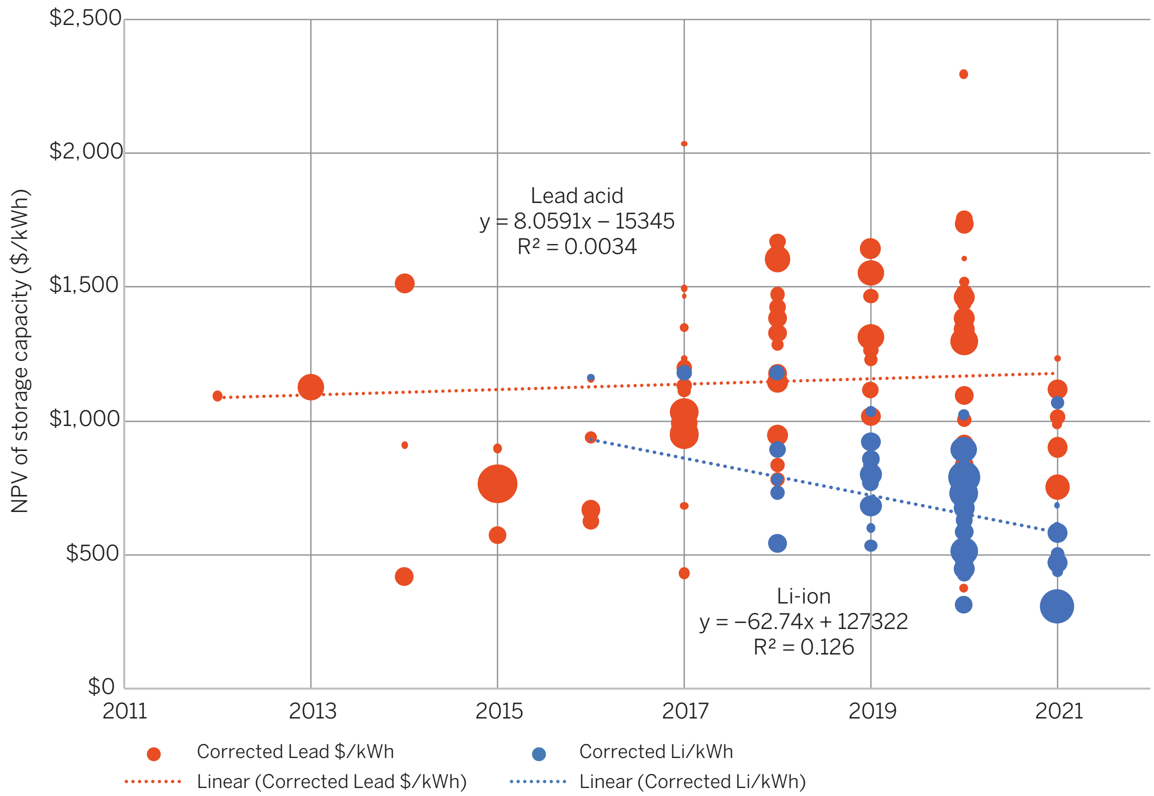
A casual glance at figure 1.8 would suggest that while Li-ion batteries are decreasing in price, they are still more costly overall than lead-acid. But this would be an incorrect interpretation of the data, as the nameplate kWh capacities of lead-acid and Li-ion batteries are not comparable.[21] For a given kilowatt-hour of nameplate capacity, Li-ion batteries can be more deeply discharged[22] and thus have a larger usable kilowatt-hour capacity. Moreover, Li-ion batteries have superior cycle lifetimes (the quantity of kilowatt-hour of electricity that can be charged and discharged into the battery before failure), higher efficiencies, as well as decreased temperature-related degradation, which is problematic for lead-acid batteries in tropical countries.[23] Differences in lead-acid and lithium batteries as modeled in the HOMER LCOE calculations in the first half of this chapter are shown in table 1.6.

TABLE 1.6 • Performance characteristics of lead-acid and lithium-ion batteries as modeled in HOMER levelized cost of energy calculations

	Unit	Lead-acid	Lithium-ion
Cycle life (throughput)	kWh throughput before failure	800	3,000
Maximum depth of discharge	%	60	80
Roundtrip efficiency	%	80	90

The implication of these performance differences is that a single 1 kWh lead-acid battery will, over the course of its lifetime, be able to cycle 800 times to 60 percent depth of discharge at 80 percent efficiency, storing and releasing 800 x 0.6 x 0.8 = 384 kWh of electricity before it must be replaced. A single 1 kWh Li-ion battery, on the other hand, will cycle 3,000 x 0.8 x 0.9 = 2,160 kWh of electricity, over five times more.

FIGURE 1.9 • Net present value of storage capacity for lithium-ion and lead-acid batteries, 2012–21



Source: ESMAP analysis.
Note: The relative nameplate capacity (kWh) of the battery is indicated by the relative size of the dot.
kWh = kilowatt-hour.

To account for these differences, figure 1.9 compares the net present value (NPV) per kWh of energy storage capacity among these mini grid projects. This calculation takes into account the factors listed in table 1.6 in a discounted cashflow calculation that accommodates the battery's replacement schedules as predicted by the HOMER project modeling for mini grid projects serving the same load profile.

The revised figures ("Corrected Lead" and "Corrected Li" in figure 1.9) show that Li-ion batteries, despite their higher sticker price, have proven to be cost-competitive with lead-acid batteries since at least 2018.

The shift to Li-ion batteries is remarkable considering that most subsidies for mini grids are for capital, per connection (performance-based grants), and therefore mini grid developers must shoulder the higher upfront cost of Li-ion batteries at a time in the project cycle when revenue is not yet generated. Moreover, lead-acid batteries were the incumbent technology and benefit from over a hundred years of tried and tested operation; whereas Li-ion batteries are a new arrival accompanied by unknown technical risk as well as the need to develop new supply chains.

Despite a higher sticker price, lithium-ion batteries have replaced lead-acid batteries due to their superior longevity, efficiency, and deeper discharge capabilities. Lithium-ion battery costs are falling while the cost of lead-acid batteries is slowly increasing over time, in line with global increases in the price of lead. Mini grids with lead-acid batteries remain competitive, however, especially where strong supply chain relations can procure quality lead-acid batteries at high-volume pricing, and where discount rates are high.

Although our data set indicates that Li-ion batteries are now the battery of choice in most mini grid projects, their dominance is not complete. Our data set includes developers, particularly in Nigeria and India, who are building very competitive mini grids using lead-acid batteries at scale. Developers who have established lead-acid battery supply chains and low pricing through large volumes of orders will likely find it competitive to continue using lead-acid batteries, at least in the short term. Moreover, high discount rates reflecting high capital costs will, all things being equal, favor lead-acid batteries since their upfront capital costs are lower. The country of battery manufacture is also a consideration. Currently China dominates Li-ion battery manufacture, whereas countries where lead-acid batteries remain popular for mini grids (India and Bangladesh, for example) have well-established and historically competitive lead-acid battery industries.

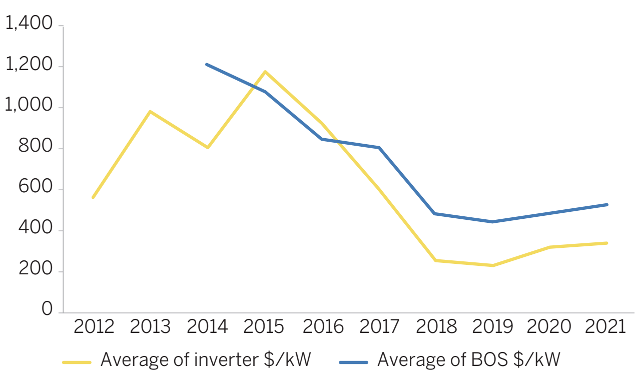
Battery inverters, energy management systems, and monitoring

Battery inverters, energy management systems, and monitoring compose on average 8.6 percent of project costs. Based on data from 327 mini grids, over time, these costs have been trending downward on a per kW basis (figure 1.10), dropping from an average of $1,204 per kW in 2014 to $524 per kW in 2021, a decrease of nearly $100 per kW each year. This reflects the global decreases in the cost of power electronics, as well as economies of scale both from larger mini grid sizes over time as well as bulk purchases through expanded deployment.

Balance of system

Balance of system (BOS) costs compose a catch-all category for the remainder of generation costs not captured in the main categories of PV panels, batteries, and inverters. The BOS comprises the diesel generator, solar support structures, fencing, foundations, lighting, civil works, powerhouse, and air conditioning system for the batteries, if installed. Based on data from 349 mini grids, average BOS costs are broadly trending downward (figure 1.10). BOS costs are shown here on a per kilowatt-peak basis because many (solar support structure, fencing, civil works) are proportional to the size of the solar array. Somewhat low costs in 2012 and 2014 may reflect shortcomings in data collection in these categories. Likely contributors to declining costs are larger economies of scale through larger mini grids and clustering.

FIGURE 1.10 • Unit costs for inverters, energy management systems, and monitoring (blue), and balance of system (orange)



Source: ESMAP analysis.
Note: Balance of system (BOS) comprises the diesel genset, solar support structure, fencing, foundation, lighting, civil works, powerhouse, and cooling.

kW = battery inverter rated kilowatt capacity. kWp = kilowatt peak of the solar PV array.

Data collected in the survey circulated for the 2018 version of this analysis distinguished between conventional masonry powerhouses and powerhouses made from shipping containers. When a shipping container is repurposed as a powerhouse, typically equipment arrives on site prewired in the shipping container, which is also used to transport the PV modules and racking materials to the site. Measured in absolute costs, shipping containers as powerhouses were, on average, the lowest cost, with an average cost of $6,922 and a median cost of $7,235; powerhouses constructed on site averaged $29,700, with a median cost of $26,253. We have anecdotal evidence, however, to the contrary. Some developers have found working with local masons to be cost-efficient, particularly in areas where roads are poor, increasing shipping costs and challenges.

Shipping containers as powerhouses (figure 1.11) were also the lowest cost on a per kilowatt basis, accounting in the 2018 version of the study for the five mini grids with lowest powerhouse cost, while conventional buildings accounted for the most expensive five. For mini grids with shipping containers, the average powerhouse cost/kW_{firm} was $153, whereas buildings constructed on site averaged $494/$kW_{firm}$.

A recent innovation is to use weatherproof cabinets for the battery and energy management system enclosure, placed under a PV-paneled roof without the need for any additional structure for a powerhouse. Even though the CAPEX of the system is only slightly lower than its alternatives, the major savings occur with the transportation and installation costs. These cabinets can be transported in lower-cost and more agile pickup trucks (figure 1.11, photo 6).

Distribution

For 349 mini grids with comparable data, the distribution costs of recent mini grids tend to cluster between $100 and $500 per customer, with wide variation. Broadly, the distribution costs appear to be trending downward slightly year

> Shipping containers as powerhouses were the lowest cost on a per kilowatt-hour basis, accounting for the five mini grids with the lowest powerhouse costs.

FIGURE 1.11 • Powerhouse innovations can lower costs and expedite deployment

1. **Power house: Remote Power Unit (RPU) 40-foot shipping container under PV array**
   Location: Bunjako Island, Uganda
   Developer: Winch Energy
   Photo credit: © Winch Energy. Used with permission by Winch Energy. Further permission required for reuse.

2. **PV and battery inverters Inside the RPU**
   Location: Bunjako Island, Uganda
   Developer: Winch Energy
   Photo credit: © Winch Energy. Used with permission by Winch Energy. Further permission required for reuse.

3. **Power house: 20-foot shipping container kiosk**
   Location: Katiko, Turkana North, Kenya
   Developer: Renewvia
   Photo credit: © Jon Exel. Used with permission by Jon Exel. Further permission required for reuse.

4. **Brick power house**
   Location: Kangitan Kori, Kenya.
   Developer: Renewvia
   Photo credit: © Jon Exel. Used with permission by Jon Exel. Further permission required for reuse.

5. **Micro-grid in a box (MIB)** is the taller structure on the right. The diesel generator stands alone outside on a platform (left). Elevating equipment protects against flooding, increases natural cooling, and reduces risk of damage from dust, insects and animals.
   Location: rural India
   Developer: TPRMG
   Photo credit: © TPRMG. Used with permission by TPRMG. Further permission required for reuse.

6. **Power equipment in outdoor rated cabinets**
   Location: Danchitagi, Niger state, Nigeria.
   Developer: PowerGen
   Photo credit: © PowerGen. Used with permission by PowerGen. Further permission required for reuse.

by year, with larger systems in recent years appearing to have lower such costs per customer.

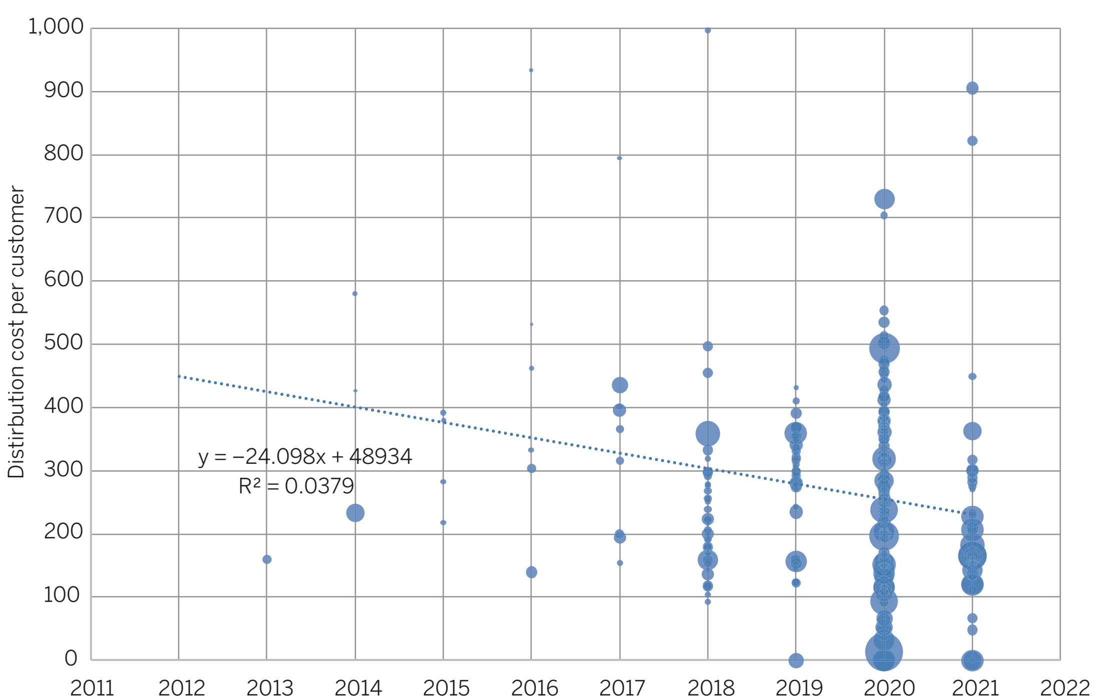
Distribution costs include poles, conductors, service drops, and meters, and customer wiring (or prewired "ready boards" that contain a couple of light switches and one or two outlets). Included in this list are smart meters that can send and receive data to and from the internet, and generally incorporate pay-as-you-go features by which customers prepay for electricity (similar to prepaid minutes on a cell phone). Smart meters can help substantially reduce ongoing costs and increase revenues by lowering electricity theft; remove the costs of meter reading and postpay billing and collections; and, in some cases, provide data to mini grid operators on vital mini grid technical parameters that help operators and engineers identify and address problems before they become larger and more expensive.

Variations in cost and the technical sophistication of metering explain some of the wide variation in distribution costs per customer (figures 1.12 and 1.13). Other variation may be attributable to the fact that some mini grids provide inhouse wiring while others do not. Though not tracked in the survey, it is nevertheless worth noting that the connection fees charged to customers do not necessarily have a one-to-one relationship with the connection costs per customer. Indeed, many mini grid developers choose to recoup the connection costs through a small upfront connection charge and then small monthly installments added to their customers' bills for the first several months of service. While this strategy helps customers overcome what would otherwise be a prohibitively expensive one-time connection charge, implementing it adds an administrative burden—and cost—to the mini grid developer. From the customer's perspective, though, this pricing model is often familiar because a similar pricing model is used for most smartphones, where customers do not pay the full price of the phone up front but instead a portion of their monthly bill goes toward the cost of the phone.

Intuition would suggest that increasing the number of customers served would lead to decreases in costs per customer. Each increase of 100 customers per mini grid lowers costs by about $3 per customer, but the data suggest only a weak correlation (figure 1.13).[24] For mini grids with low consumption needs, a DC mesh can offer lower costs per customer (box 1.2).

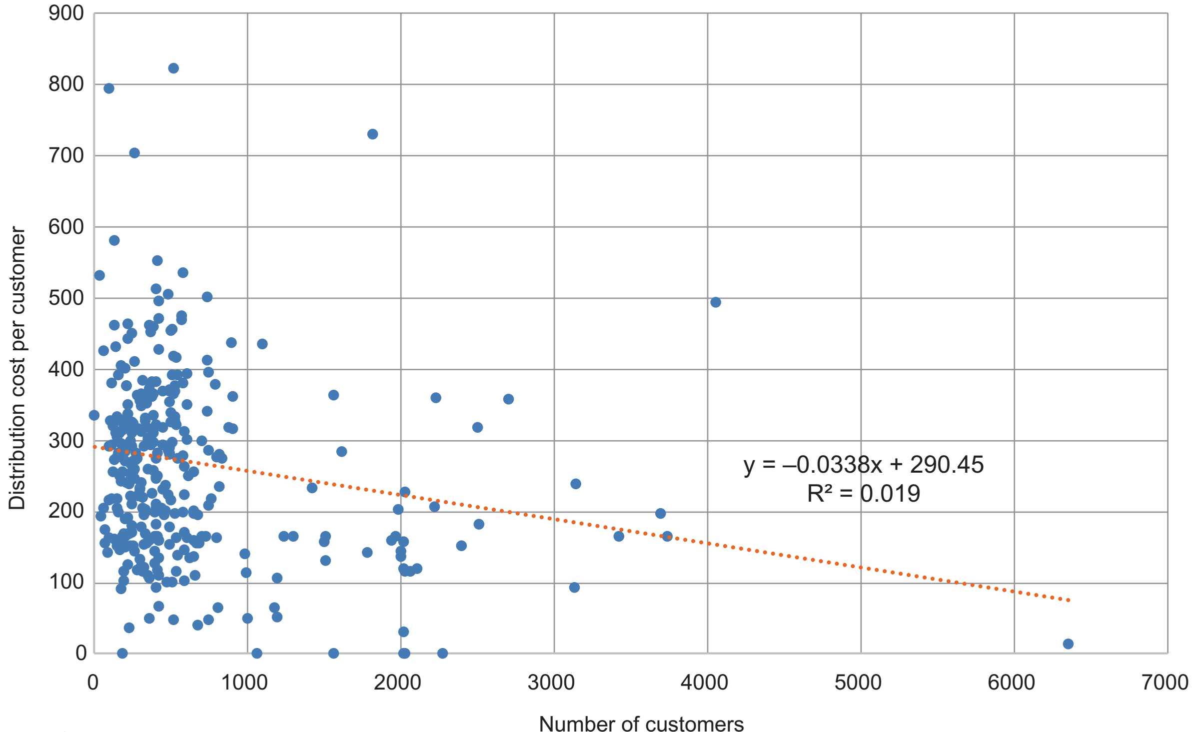
Each additional increment of 100 customers correlates with declines in distribution costs per customer of about $3. But the data only weakly support this relationship.

FIGURE 1.12 • Distribution costs per customer, 2012 to 2021



Source: ESMAP analysis.
Note: The size of the installation (number of customers) is indicated by the relative size of the dot.

FIGURE 1.13 • Distribution costs per customer as a function of customers served



Source: ESMAP analysis.

BOX 1.2

DIRECT CURRENT MESH GRIDS

Although mesh grids are not included in our analysis, they nevertheless hold promise for some communities and states affected by fragility, conflict, and violence, with lower electricity needs.

Mesh grids—or "skinny grids"—distribute DC electricity for lighting, electronics, and small appliances like fans and even efficient refrigerators or electric rickshaws. They take the form of clusters of solar home systems made up of solar panels affixed to customers' premises and connected in a mesh network. Specialized controllers allow surpluses to be shared. Examples include Okra Solar, with installations in Cambodia, the Philippines, and Haiti; and SOLshare in Bangladesh.

In the rural Haitian province of Artibonite, Alina Enèji has built direct current (DC) mesh grids that electrify 300 households and small businesses using Okra Solar's platform and equipment. Households start with systems that provide electricity for small, efficient DC appliances, but they can upgrade to AC appliances by requesting an inverter. Larger productive use AC appliances and higher-consumption households can also be accommodated through networks of interconnected customers. Approximately 90 percent of Alina's customers are interconnected with at least one other customer; only the remotest 10 percent of customers are served with isolated systems.

Alina encourages productive uses of electricity. The company partners with a local appliance supplier and conducts multiple community visits and workshops prior to the arrival of the mesh grid arrival and as it expands.

The mesh grids in Haiti typically have a capital cost about $800 per connection, about half of the cost for conventional AC mini grids in Haiti. The modularity of the systems makes for quick installation and capacity upgrades as needed.

a. Okra Solar, https://okrasolar.com/.
b. SOLshare, https://me-solshare.com/

Land

Land comprised only a small portion (0.7 percent) of the mini grid sample's average economic costs. Of 356 mini grids that provided plausible cost data, only 193 reported land costs, and only 103 projects reported land costs over $5,000. We are not sure to what extent this reflects limitations in data reporting. Land is often provided gratis by communities or local governments as part of agreements at project inception, although we have anecdotal evidence that obtaining rights to suitable land is often a challenge. A 100 kWp solar array requires about half an acre of land, or a square about 20 meters on a side.

Figure 1.14 shows two examples of solar arrays for mini grids, illustrating the relatively small amount of land required. The array on the left is a 30 kWp mini grid developed by Mandalay Yoma in Myanmar, with the powerhouse and diesel generator under the green roof at upper right. The array on the right is a 40 kWp mini grid developed by Winch Energy in Lamwo District in northern Uganda. The solar array is built over the powerhouse to reduce land requirements, though with additional racking costs.

Sales, general and administrative expenses, senior management, logistics, and installation

The data collected for this chapter illustrate how soft costs (project development, logistics, and installation) might be an area where economies of scale can lower investment costs.

> Mini grids built as part of a portfolio saved $81,000 in soft costs on average, compared with mini grids built as one-off projects.

In particular, our data show how building a portfolio of mini grids can help lower costs by bundling approval processes and exploiting economies of scale in project management, shipping, equipment procurement, and installation.

Project developers reported management costs (including project development, general administration, planning, engineering, partnership, public relations, permits, approvals, licenses, community engagement) for 309 sites. Logistics (transportation) and installation costs were reported for 327 and 297 sites, respectively.

Though mini grids built separate from a portfolio tended to have fewer customers (single mini grids average 405 customers, while clustered projects averaged 657 customers), they had substantially higher average soft costs ($208,900, compared with $127,400 for portfolio projects).

Governance requirements and developers' internalized prefeasibility assessments, technical standards, and accounting and reporting requirements may give rise to widely varying soft costs across similar projects.

REPLACEMENT COSTS

Replacement costs are for repairing worn-out or broken equipment as the mini grid ages. These costs were not explicitly reported in the data that underlie this study, but are nevertheless essential. For long-term sustainability, it is critical to ensure that sufficient funds are available to cover replacement costs. Battery replacements in particular are problematic because it is generally necessary to replace the entire pack in order to ensure that new batteries are not electrically compromised by older batteries to which they are electrically connected. In this regard, the transition from lead-acid to Li-on batteries is important. As discussed above, although Li-on batteries have much higher upfront

FIGURE 1.14 • A 30 kWp Mandalay Yoma mini grid in Myanmar (left) and a 40 kWp Winch Energy mini grid in Uganda (right)

Photo credits: Left © Mandalay Yoma; used with permission; further permission required for reuse. Right: © Winch Energy; used with permission; further permission required for reuse.

costs, they last much longer than lead-acid batteries, delaying the need for, and ultimately reducing, a project's long-run replacement costs.

While many projects are too young to report out their replacement costs, they are built into HOMER optimization and LCOE modeling. The replacement of many components (PV panels, inverters, monitoring equipment) is based on years in service, diesel generators' replacement is based on hours operated, and battery replacement is dictated by the total throughput in kilowatt-hours based on battery type.

OPERATING COSTS

A mini grid's operational expenses are important, especially from the perspective of long-term sustainability. OPEX includes all costs associated with operating mini grid equipment, including fuel costs, maintenance, repairs,[25] payment collection, and security.

OPEX was reported for 137 systems (113 in Myanmar, 4 in other Asian countries, and 20 in Africa). Reported OPEX per customer varied widely from a low of $2 a year in Myanmar to $267 a year in Kenya.

Among the 19 mini grids (12 of them in Bangladesh) that reported a breakdown of staff, fuel, and other O&M costs, fuel on average accounted for 30 percent of O&M, staff accounted for 49 percent, and other O&M accounted for 21 percent. Within this data set, there were considerable variations. In some, fuel or staff accounted for 0 percent; in others, 100 percent.

Some of the large variation in reported OPEX may reflect differences in staffing needs. Did the sale of electricity require staff, or was it accomplished automatically through a cellphone-based prepayment system? Does the site require security guards? How is the O&M of the mini grid plant accomplished? Are some staff responsibilities conducted on an unpaid basis? Did the mini grid initially not work properly and therefore require more intense support until the system was operating robustly? How was OPEX allocated on a component basis? The data set does not provide sufficiently detailed information to answer these questions.

Developers face choices between CAPEX-intensive and low OPEX installations (for example, a contemporary solar hybrid system) versus those involving low CAPEX and high OPEX (for example, diesel-fueled mini grids). With the availability of subsidies to help cover CAPEX for renewable energy mini grids, effort is often made to set affordable tariffs that cover OPEX and replacement costs.

Further research to revisit the OPEX costs of the analyzed mini grids would be useful to understand how OPEX changes over time, and how staff, fuel, and other OPEX components evolve. Further research is also necessary to understand whether revenues are sufficient to cover OPEX and other costs, such as debt service and equipment replacement.

THE OUTLOOK FOR MINI GRID CAPITAL AND OPERATING COSTS

As discussed in the sections above, mini grid costs have declined substantially on an LCOE basis, including a 31 percent decline of LCOE in best-in-class mini grids since 2018. In addition, as discussed above, our data show that the costs of key components (especially PV modules, batteries, and electronic components) reported by mini grid developers have been steadily declining.

This section draws on research on costs in related global industries such as solar panels and batteries to better understand what levels component costs for mini grids may reach by 2030. Industry trends suggest that component costs in most key areas of generation, storage, metering, and power conversion can be expected to continue to decline thanks to their increasing deployment and spillover effects from technological development in much larger sister industries. Table 1.7 and the sections in this chapter that follow provide details of the expected cost declines for key mini grid components.

The best-in-class 2030 component price assumptions used in the HOMER LCOE modeling discussed in the beginning of this chapter used the following approach: we started with the costs for each component in the best-in-class mini grid from 2021, and then applied the same percentage drop to that component that is expected industry-wide. For example, PV costs in the best-in-class, representative mini grid were $596 per kWp in 2021. Global industry PV, with a 2020 benchmarked cost of $198 per kWp, is expected to drop another 42 percent to $114 per kWp by 2030. For the 2030 mini grid cost estimate, the same 42 reduction is applied to the 2021 best-in-class price, yielding a 2030 estimate of $343 per kWp (including PV inverters). This is still several times higher than the industry benchmark price, reflecting the realistic cost multipliers that translate an industry spot market price into the cost at a remote mini grid site far from a factory.

PV MODULE TRENDS

Mini grids benefit from decreasing solar module prices, driven mostly by large grid-connected installations. PV prices have fallen faster and lower than nearly any forecast. As of April 2021, global spot prices averaged $198 per kWp for poly-crystalline modules (Energy Trend 2021).[26] By the time PV modules arrive on the project site and are included with PV inverters they cost considerably more than global

TABLE 1.7 • Mini grid component cost benchmarks and price projections

Component	Unit	Share of total capital cost (%)	Median cost in ESMAP survey	Best-in-class 2021 LCOE modeling assumption	Mainstream industry benchmark in 2010	Mainstream industry benchmark in 2020 (% change from 2010)	Mainstream industry estimate by 2030 (% change from 2020)	Best-in-class 2030 LCOE modeling assumption (% change from 2020)
PV module	$/kWp	9.7	$441	$596	$1,589	$198 (–88)	$114 (–42)	$343 (–42)
PV inverter	$/kWp	*	*	*	$320	$80 (–75)	$70 (–12.5)	*
Battery (Li-ion)	$/kWh	14.9	$314	$297	$1,160	$126 (–89)	$58 (–54)	$137 (–54)
Battery inverter	$/kVA	8.6	$415	$303	$565	$113 (–63)	$99 (–12.5	$265 (–12.5)
Smart meters	$/ customer	†‡	‡	‡	$106	$40 (–62)	$35 (12.5)	‡

Sources: ESMAP analysis; Bloomberg New Energy Finance Solar Spot Price Index; National Renewable Energy Laboratory U.S. Solar Photovoltaic System Cost Benchmark: Q1 2020; Feldman and others 2021; Kairies 2017.

* PV inverter is included with PV module cost.

† Battery inverter is grouped with EMS and monitoring equipment.

‡ Smart meters are included in distribution cost. Average, median, minimum, and maximum costs are all expressed in inflation-adjusted dollars.

kVA = kilowatt-ampere; kWh = kilowatt-hour; kWp = kilowatt-peak; Li-ion = lithium-ion; PV = photovoltaic.

spot prices. The median cost of PV (with PV inverters) for all mini grids in our database was $441 per kWp. Just counting those mini grids commissioned between 2019 and 2021 gives us a median cost of $413 per kWp, with 25th and 75th percentile costs of $354 and $599 per kWp, respectively.

Module prices have been roughly following Wright's Law,[27] falling 18–22 percent for every doubling of installed capacity (Yu 2018). With growth rates averaging about 40 percent a year through 2017,[28] production doubled about every 1.8 years. In recent years, growth slowed to about 24–27 percent, reflecting a doubling every 2.8 years.

At the end of 2021, a cumulative total of 843 GWp of PV had been deployed, with 133 GWp commissioned in 2021 alone (IRENA 2022). Bloomberg New Energy Finance (BNEF) projects that solar PV prices will drop to $114 per kWp by 2030 (BNEF 2020a), with a cumulative 2.4 terrawatts-peak (TWp) of PV installed by that year. This reflects a compound average 13 percent annual growth rate for solar PV, a considerable decrease from contemporary growth levels.

There are wide variations in estimates of total PV that will be added by 2030. As of 2020, new builds of solar PV farms are competitive with the marginal cost of existing conventional generation such as coal, nuclear, and combined cycle natural gas (Lazard 2020). With decreasing PV costs and increasing electrification of transportation, heating, and industry, some scientists are envisioning that PV's current annual percentage growth will be maintained for the next decade, hitting 10 TWp of PV by 2030. To accommodate this level of PV would require considerable utility-level storage and expanded ability to dispatch load (Haegel and others 2019). If Wright's Law continues to hold, expansion to 10 TWp is consistent with a price drop to below $90 per kWp.

From a materials perspective, new cell technologies like perovskite cells promise to radically reduce the amount of highly pure silicon material required in solar cells, as well as improving efficiencies, paving the way to lower production costs (US DOE n.d.). Currently about 41 percent of the world's supply of high grade polysilicon for solar panels comes from Xinjiang, China, a region where human rights groups and numerous governments have reported ongoing forced labor violations, specifically against the Uyghur ethnic minority (Jenkins 2022).

PV INVERTER TRENDS

PV inverters used in mini grids are similar (or in many cases identical) to those used in residential and commercial grid-connected installations, which are projected to increase by about 200 GW in China alone between 2021 and 2026 (IEA 2021). PV inverters used in mini grids are also smaller cousins to the grid-tie PV inverters used in utility-scale PV installations that account for the lion's share of the 204 to 252 GW of PV expected in 2022 (BNEF 2022). These large volumes, together with cost declines associated with rapid expansion of other power electronic markets, such as motor drives for electric vehicles, will continue to drive down costs for PV inverters and controllers.

A study by the National Renewable Energy Laboratory (Feldman and others 2021) identifies a benchmark price of $80 per kW_{AC} for three-phase string inverters (including the cost of monitoring equipment, in 2019 US dollars) in the first quarter (Q1) of 2020 for commercial scale PV (100 kW to 2 MW). Inverters are less than a third what they cost a decade ago: in Q1 of 2010, three-phase inverters cost about $270 per kW_{AC} (also in 2019 US dollars).

Assuming a conservative slowdown in the rate of decrease in costs between 2021 and 2030, ESMAP estimates that PV inverter costs could reach $70 per kilowatt-peak by 2030.

BATTERY TRENDS

Costs for Li-ion batteries have declined dramatically since 2010 and are expected to continue to decrease substantially. BNEF reported in December 2020 that Li-ion (pack level) battery benchmark costs were at $126 per kWh on a volume-weighted average basis, down from $1,100 per kWh in 2010. Even with rising commodity prices in the wake of COVID, BNEF predicts an average cost below $100/kWh for batteries by 2024 (BNEF 2021). It predicts an average cost of $58/kWh in 2030 (BNEF 2020b), reflecting a cost reduction of 54 percent from 2021 benchmark prices.

Many Li-ion batteries used in high-end electric cars use cobalt in their cathodes to increase their energy density to provide greater ranger or power output. Lower-end electric vehicles (such as those increasingly sold in Chinese markets) and stationary power applications such as mini grids or utility storage use lithium iron phosphate (LFP) batteries, which are less expensive, and less exposed to the risk of supply shortages for cobalt. Bloomberg found that LFP cells were almost 30 percent cheaper than batteries with cobalt (BNEF 2021). Cobalt is a rare metal and the Democratic Republic of Congo accounted for 70 percent of global production in 2019, and substantial concerns have been raised concerning child labor and other human rights abuses in cobalt mines in that country (Sanderson 2019).

The industry benchmark cost for lead-acid batteries is $143 to $147/kWh (Kairies 2017; Wagman 2020). Lead-acid technology is largely developed, but the industry makes improvements every year. For example, carbon added to the negative electrode will reduce sulfation and increase charge rates. ESMAP was unable to find cost projections for lead-acid batteries by 2030, but efforts to increase their life cycles beyond 800 and into the thousands would have the effect of reducing lead-acid battery storage costs even if nominal costs remain the same. Even so, lead-acid batteries are unlikely to reclaim the mantle of battery of choice from Li-ion based on expected cost decreases in Li-ion batteries.

Other battery chemistries promise long-term energy storage that may allow solar mini grids to remove diesel generators entirely and yet maintain high reliability. Recent innovations in iron air batteries have led to price targets for this technology at less than $20/kWh for 100 hours of storage. Because of their lower-current, higher internal impedance, and longer-duration chemistry, iron air batteries would not replace but could complement Li-ion batteries, allowing mini grids to weather a week or more of cloudy weather (Plautz 2021).

BATTERY INVERTER TRENDS

Decreasing battery inverter costs are consistent with broader trends in power electronics, driven by synergies with PV inverters and electric vehicle motor drives. While broader industry data were not available for battery inverters, using PV inverter costs as a proxy, ESMAP estimates that battery inverter costs will reach $99/kVA by 2030, assuming the same 12.5 percent decline by 2030 expected for PV inverters.

SMART METER TRENDS

The global market for smart meters has seen rapid growth in recent years, driven by strong policy support in China and Europe. European utilities are projected to install 182 million smart meters between 2016 and 2020, totaling nearly $38 billion in investment. Likewise, in Japan, 55 million meters costing $16.6 billion were installed between 2016 and 2020. Globally, the smart meter industry is a $20 billion a year market, expected to reach $30 billion by 2026 (Smart Energy International 2018; Global Industry Analysts 2022). Smart meters used in mini grids are in some cases identical to those deployed in large numbers by utilities. In other cases, they are built specifically for the mini grid market, with functionalities such as load dispatching, which are included to optimize mini grid load factor by reducing peak demand but still benefit from technology improvements and component cost reductions driven by the larger smart meter industry.

Competition among prepayment metering manufacturers and increasing scale will allow development costs to be spread over a larger product base. BNEF tracks smart meter installations and investments globally and found that the global average cost per smart meter in 2010 was about $106 per unit; 2021 benchmark costs per smart meter in low-income countries were around $40. ESMAP expects costs to continue to decline at a rate equal to inverters, reaching unit costs of $35 in 2030.

TRENDS IN OTHER CAPITAL COSTS

One cost-saving trend in low-voltage distribution is the increase in local factories that build hollow reinforced concrete poles.[29] These poles are manufactured through a process in which concrete is poured into a mold together with reinforcing steel. The mold is spun, while centrifugal force compacts the concrete into a smooth hollow cylinder (Taizhou Amity Care 2013). Spun poles have higher strength per unit weight than solid poles and require much less concrete, lowering transportation costs by 25 percent or more compared with solid concrete poles. Developers from Myanmar report that depending on local availability of sand and gravel, on-site construction of concrete poles may also lower costs (Zaw Min 2019).

For powerhouses, though the data on shipping container powerhouses appear promising, more research is needed to understand whether the construction cost savings of shipping containers outweigh the thermal management issues that arise from their use in hot, sunny environments, and the other engineering issues (for example, stackable batteries) required to repurpose these containers. Another option, still in its infancy, is building mini grids that need no powerhouse, in which components are sheltered under the solar array. The Rockefeller Foundation–supported Smart Power India program has partnered with the Institute for Transformative Technologies in an approach that combines a 10 kW PV array with all necessary electronics into modular units that can be scaled up, depending on the situation. In India, Tata Power Renewable Microgrids has targeted the installation of 10,000 microgrids using standardized equipment packages built around a mass-produced "micro-grid in a box" (figure 1.11). Increased factory integration of components in a "utility in a box" model will lower on-site assembly requirements. Through these economies of scale, the Rocky Mountain Institute expects these other CAPEX components to drop by 15 percent (Carlin and others 2018).

Meanwhile, the next generation of diesel generator incorporates power electronics in ways that allow engines to operate at variable speed as needed, increasing energy efficiency (AP News 2018). Variable-speed generators, together with a dump load and short-term battery storage buffer, can accommodate up to 100 percent renewable energy penetration (Innovus 2015). One approach uses a fast-acting clutch that can disengage the motor from the alternator when the renewables can fully support the load. The alternator remains spinning, providing reactive power and voltage and frequency regulation (Danvest Energy 2019).

Local production of relatively low-tech items like PV racks has the advantage of low labor costs, low shipping costs, and local economic development. The mass production of these items in large factories can, however, take advantage of economies of scale. As mini grids scale up and competition intensifies, mini grid developers in each country can be expected to find context-specific solutions that optimize the costs of these components.

In addition, preparation and planning costs have declined. In the past, multidisciplinary teams prepared electrification plans, scoped sites, and conducted prefeasibility studies, at considerable cost. Today, most of this work,[30] all the way up to feasibility-level analysis—including compiling bills of quantity and bid documents or purchase orders—can be done from behind a desk, thanks to the following factors:

- The availability of big data that provide geotagged points of interest that can be used to prepare a detailed demand assessment of prospective load centers
- Affordable high-resolution satellite imagery
- Easy-to-use but sophisticated software that can be used to design hybrid generation systems together with the design of the distribution network
- Data-driven web-based platforms that compile large amounts of geotagged market intelligence that can be configured in different ways to be useful for mini grid developers, financiers, and government agencies

The introduction of geospatial and other digital technologies has decreased the cost of preparation and planning by an order of magnitude (see chapter 2 for more details on geospatial planning). In the past, the unit cost per site was more or less the same, irrespective of the number of sites—about $30,000 per site—because each site required a high level of on-site analysis. Today, portfolios of mini grids can be prepared to the point where they are ready for full feasibility assessment and community engagement at a cost of about $2,300 per site, based on the World Bank's recent experience in Nigeria.

The socioeconomic surveys and energy audits (looking at demand and willingness/ability to pay) make up 58 percent of per-site costs, which are largely linear since human resources are the primary drivers. The time required for a household survey will not change with the scale of the exercise, although streamlined travel logistics might produce savings. Nevertheless, technology can expedite these labor-intensive tasks—for example, through the use of drones to map out a village and sequence household visits by enumerators. Tablet-based software can swiftly and accurately capture survey data. Partnerships with cell-phone-based electronic payment companies can obtain market data from targeted rural customers on appliance purchases or other spending patterns.

TRENDS IN OPERATING COSTS

The introduction of remote-controlled, prepay smart meters has slashed labor costs. Reaching delayed or nonpaying customers can now be done remotely. Consumption patterns can also be tracked and analyzed remotely. Smart meters and cell-phone carrier-based, real-time data collection enable detailed monitoring of system parameters. When parameters exceed programmable thresholds, alarms alert technicians of problems that are much easier to address before they grow and cascade into expensive equipment failures and prolonged downtime. In addition, smart meters enable developers to easily collect and analyze their performance data, which can be aggregated and anonymized to share with development partners, industry associations, investors, and other stakeholders. Data uploaded to the cloud can be analyzed by machine learning algorithms, and allow early identification of problematic patterns. Some companies are planning to respond to customer inquiries with artificial intelligence systems.

Replacement costs have also fallen. Projects installed with lead-acid batteries that last three to six years can, if the battery inverters are compatible, be replaced with Li-ion batteries with a life of ten or more years. Developers building mini grids would be wise to choose battery inverters (and battery chargers in the case of DC-coupled systems) compatible with Li-ion batteries. Replacement costs for electronics, such as PV inverters and battery inverters, are also falling as they are manufactured at larger and larger scales.

Other costs are incurred in dealing with bureaucratic processes, such as obtaining licenses, approvals, and permits. These costs depend on a country's enabling environment. Several governments have incorporated mini grids as part of their energy policy, giving them and the industry a place in the energy sector. Some countries have adopted mini grid regulations that allow for a light-handed approach. In some countries, e-government has streamlined the process for obtaining location and building permits. Even though these costs are important, they are not expected to change much over the next decade in countries with high energy deficits, not unless enabling environments are introduced in these countries.

THE IMPACT OF ECONOMIES OF SCALE

In addition to the benefits of decreasing spot market prices from the deployment of PV panels and batteries in large global industries like solar farms and electric vehicles, mini grids themselves benefit from economies of scale due to increasing portfolio size and from industry scaling at the country level. As mini grid developers scale their portfolios from 10 to 100 and then to 1,000 or 10,000 mini grids, fixed costs like administration and management are spread over more units of production; sometimes a company can negotiate lower per-unit costs enabled by bulk purchases.

To explore this effect, we analyzed mini grid cost data to discern changes across categories arising from portfolio and in-country market sizes. Categories included hardware (PV modules, batteries, inverters, and so on), management, logistics, and installation. We also made estimates of the net present value of the ongoing costs of O&M, major equipment replacements, and engaging with customers. To align portfolio-scale projections with declines in equipment spot prices (see above), we assumed a representative portfolio size of 100 mini grids and doubled this at each time interval to 200, 400, 800, and 1,600 mini grids per portfolio. We also had the portfolio grow by orders of magnitude to stress-test the boundaries of the different cost categories.

The results show that with economies of scale, significant shifts are taking place in the three cost categories (table 1.8). Overall, the portfolio development and management cost category remains small, with less than 5 percent of the cost over the lifetime of the portfolio. This indicates that additional cost reductions will have limited impact on the overall LCOE of the portfolio. What is not incorporated in the calculation is the cost of delay in processing for permits, licenses, approvals, and other red tape. More surprising, perhaps, is the minimal difference between the extended CAPEX and OPEX. On average the CAPEX contributes a little more than half the cost of the LCOE, while the OPEX is close to 45 percent, suggesting that the LCOE is sensitive to the makeup and design of the cost structure of O&M and major repairs over the lifetime of a project. In

TABLE 1.8 • Net present value broken down by category with economies of scale

Portfolio size (number of mini grids)	Portfolio development and management (%)	Procurement, construction, installation, and customer engagement (%)	Operation, maintenance, major replacements, and customer engagement (%)
100	4.8	53.0	42.2
200	4.0	53.3	42.7
400	4.0	53.1	43.0
800	3.7	52.9	43.4
1,600	3.5	52.6	44.0
100	4.8	53.0	42.2
1,000	3.6	52.5	43.9
10,000	3.4	56.8	39.8
100,000	2.9	48.3	48.8

Source: ESMAP calculations and analysis using costing data described in this chapter.

part due to difficulties in obtaining OPEX data, this topic has not received the same level of attention in this handbook and deserves more scrutiny in future work.

Closer scrutiny of unit costs reveal important changes (table 1.9). When doubling the size of the portfolio stepwise, from 100 to 1,600 mini grids per portfolio, unit costs plunge across categories. Also, the LCOE falls from $0.36/kWh with a load factor of 22 percent for a portfolio of 100 mini grids to $0.21/kWh for a portfolio with 1,600 mini grids. A load factor of 40 percent produces a similar trend.

The analysis suggests that all component costs of mini grids will see declines, but as imported equipment costs (PV modules, batteries, electronics) tumble downward through spot markets, the remaining components will assume more of the share of overall costs. The NPV of ongoing major replacements such as batteries benefits from the future size of portfolios: they will be larger and unit costs lower. For example, the batteries installed at year 7 to replace a failing pack will be part of a scaled-up battery purchase to build 5,000 mini grids.

When moving from 100 to 100,000 mini grids in a portfolio, the marginal gain diminishes in terms of percentages. The largest gain is made from 100 to 1,000 and from 1,000 to 10,000 systems per portfolio. Growing beyond this scale might call for closer scrutiny; perhaps multiple, smaller portfolios (several of 10,000 mini grids) might be optimum. Additional research will need to be conducted to obtain more specific insights for the industry.

REASONING FROM FIRST PRINCIPLES

To further break down the complex setup of a solar mini grid, we tried to reason from first principles and analyze the system's basic elements. This analysis is a first attempt to determine the cost asymptote for the hardware of a solar mini grid. It is also an invitation to interested experts, students, and professionals to elaborate further. We took the typical system (see box 1.1) that consists of a 285 kWp solar system, a 690 kWh Li-ion (LiFePO4) battery, and a 285 KVA back-up generator set.

As the generator set is expected to phase out over time due to economic forces, and optimization of this system has been ongoing for more than a century, we have used a specific cost for the full system of $100/kW. For the solar and battery systems we looked into the composition of the basic elements and found on the commodity market the estimated cost for each material.

A typical solar mini grid system needs an estimated 20 tons of glass, 16 tons of steel, 13 tons of concrete, 5 tons of aluminum, 2 tons of silicon, 2 tons of copper, 2 tons of plastic; the Li-ion batteries require an estimated 650 kg of aluminum parts, 450 kg of graphite, 400 kg of copper parts, 250 kg of iron, and about 50 kg of lithium. Adding value to these raw materials resulted in a total cost of $157k for a solar-battery-genset power plant. This is a 53 percent cost reduction from what is reported in box 1.1 ($333,000 for the generation system).

TABLE 1.9 • Change in unit costs with economies of scale, by cost category

Portfolio size (# of mini grids)	Portfolio development and management per mini grid (US$, thousands)	Procurement, construction, installation, and customer engagement per mini grid (US$, thousands)	Total NPV per mini grid (US$, thousands)	LCOE with 22 percent load factor ($/kWh)	LCOE with 40 percent load factor ($/kWh)
100	23	251	473	0.36	0.20
200	17	220	412	0.31	0.17
400	14	192	363	0.27	0.15
800	18	168	319	0.24	0.13
1,600	10	148	281	0.21	0.12
100	23	251	473	0.36	0.20
1,000	11	163	310	0.23	0.13
10,000	6	106	187	0.14	0.08
100,000	4	69	143	0.11	0.06

Source: ESMAP calculations and analysis using costing data described in this chapter.

NPV = net present value; LCOE = levelized cost of energy; kWh = kilowatt-hour.

When maintaining the rest of the upfront cost (management, distribution system, land and logistics, installation cost, taxes, and duties), the cost reduction is 21 percent of the total upfront cost for the power plant. Carrying this forward into the LCOE calculation, assuming a 75 percent CAPEX, 20 percent OPEX and 5 percent for preparation costs, the power plant cost savings lowers the LCOE by 15 percent, from $0.38/kWh to $0.32/kWh. If we use the breakdown as found in a database of 440 projects (CAPEX, 64 percent; OPEX, 31 percent; and 5 percent for preparation costs), the reduction of the LCOE is less, and when we use the breakdown as calculated in the "economies of scale" analysis (CAPEX, 52 percent; OPEX, 44 percent; and 4 percent for preparation costs), the impact of the power system's cost reduction on the LCOE falls to 11 percent.

As also mentioned under the "economies of scale" analysis, the overall reduction in power plant costs is essential for an overall competitive product in the marketplace. Equally important, and a topic that has not received the same level of attention in this handbook, is the innovation necessary to also reduce the OPEX, including the cost of major replacements.

CONCLUSION

Best-in-class mini grid costs have plummeted in the past few years. In 2018 ESMAP conducted a cost analysis of 53 mini grids published in the executive summary of Mini Grids for Half a Billion (ESMAP 2019). At that time, the "best-in-class" mini grid produced electricity with a (financial) LCOE of $0.55 per kWh. In the three years since this analysis, best-in-class costs have dropped nearly 31 percent to only $0.38 per kWh, thanks to decreases in the cost of solar panels, batteries, inverters, and efficiencies through economies of scale.

SUMMARY OF POTENTIAL COST REDUCTIONS

The trends in CAPEX and OPEX highlighted above will lead to major cost reductions in four areas for third-generation mini grids through 2030:

- **Increasing income-generating uses of electricity can decrease the LCOE by 25 percent or more** and, when combined with the expected cost declines described below, will bring the economic cost of mini grid electricity to almost $0.20/kWh by 2030. The baseline load factor for mini grids of 22 percent reflects low levels of income-generating uses of electricity. Mini grids that can increase their load factors to 40 percent through significant daytime consumption by local businesses and commercial clients, can reduce their LCOE by up to 30 percent. When combined with the expected declines in CAPEX and OPEX, the cost of electricity from a best-in-class third-generation system will be $0.20 per kWh by 2030. This is for mini grids with productive applications that enable a 40 percent load factor.
- **Expected decreases in component costs can reduce upfront investment costs to less than $2,500/kW$_{firm}$ by 2030.** In improving the design of a race car, a designer might find it impossible to shave 1 kg off in a single location but could identify 20 places in the car where she could reduce 50 grams. Cost reductions in mini grids work the same way, with cost reductions in many different components adding up to a substantial overall cost reduction. If the prices that mini grid developers pay for the PV array, Li-ion batteries, and inverters and associated electronics decline by the same proportion as mainstream industry benchmarks between 2020 and 2030, the upfront capital cost per kW$_{firm}$ of a solar hybrid mini grid would fall by almost 25 percent.
- **Economies of scale will reduce the LCOE of mini grids even further.** As developers build portfolios of mini grids instead of one-off projects, they benefit from increased economies of scale—primarily as a result of bulk purchases of components and increased efficiencies through standardized processes and increased know-how. Analysis of the data collected in ESMAP's survey of mini grids in Africa and Asia indicates that economies of scale can greatly reduce capital costs. As we describe in this chapter, for every additional 100 customers a mini grid serves, its cost per customer falls on average by about $9. Cost reductions from economies of scale complement the downward effect on costs from greater recourse to productive uses of electricity.
- **Using geospatial and other digital tools to develop portfolios of mini grids will also reduce costs.** Geospatial analysis allows developers to assess mini grid sites at a fraction of the cost of traditional site assessment activities—from around $30,000 per site without using geospatial analysis, to approximately $2,300 per site using geospatial analysis. A number of established mini grid developers in Sub-Saharan Africa use geospatial and other analytical software to plan their portfolios remotely. They prioritize sites for mini grid development and use technology-enabled processes to estimate demand, allowing them to optimize system design across their portfolios. Where government or donor entities are conducting the portfolio-level analysis, the data can be analyzed and disseminated to developers on a web-based platform like Odyssey Energy Solutions.

GOVERNMENT'S ROLE IN REDUCING MINI GRID COSTS AND CATALYZING INNOVATION

Governments can help keep the path open for mini grid component technology innovation and cost decreases by designing and implementing regulatory frameworks and mini grid programs that provide light-handed regulation and exempting mini grid components from import taxes (see chapter 9 for a detailed discussion of mini grid regulations). It is important to design standards that leave open opportunities for innovation and not to assume (and thus lock in) a particular technology or configuration.

Rural electrification agencies can harness these cost savings by designing programs that provide opportunities for capable developers to develop multiple nearby sites as part of a larger, comprehensive program. Doing so allows for economies of scale in project identification (especially harnessing geospatial information), engineering and design, site assessment and community negotiations, equipment procurement and installation, O&M, and tariff collection.

Ensuring a competitive marketplace for mini grids will be important to promoting innovation and continued cost declines. The data presented in this chapter show sizable cost variations, implying in part the ability of mini grid developers to procure equipment at internationally competitive prices.[31] In cases where costs are on the high end of the mini grids we analyzed, the systems were clearly overbuilt, designed to meet a load that may not materialize for years. Some subsidy programs, particularly those that subsidize a portion of renewable energy generation investments, incentivize oversizing mini grids. Costs reported at the low end in this study indicate the best possible practice at the frontiers in a competitive market, keeping in mind the need to specify minimum customer-service levels and not stint on quality. As mini grids are deployed in larger quantities and markets become more competitive, costs will trend downward toward, and beyond, the best-in-class cost and performance benchmarks revealed in this study.

THE IMPORTANCE OF COORDINATED COLLECTION OF DATA ON MINI GRID COSTS

Data collection on mini grids is at an early stage. Better and more uniform data will produce more useful results and observations. More effort should be spent on standardizing data collection and integrating data collection into reporting requirements into mini grid programs. One branch of this effort could take the form of a plug-in into a standardized mini grid bidding and accounting software package that provides developers front-end geospatial information on prospective villages and markets, optimizes mini grid system design, helps link developers with equipment suppliers and financiers, helps keep track of key milestones in project development, and provides suitably anonymized costing data for use in understanding detailed mini grid costs as they evolve in different markets.

More data are also needed on the standards to which mini grids are built. For example, are poles and wires built to standards that a utility would use? Or are cheaper, untreated wooden poles used to save costs? What is the expected life cycle of the battery? Mini grids built to different standards will naturally report different costs, reflecting these different standards. Without improved knowledge of the underlying standards for each mini grid, variations that currently appear to be noise in data could more meaningfully and accurately reflect the realities on the ground and help identify areas where action is warranted to reduce mini grid costs, improve quality, or both. This chapter and the underlying database should be viewed as living documents, which will benefit from better, and more, data over time.

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NOTES

1. This chapter uses the terms solar and photovoltaic interchangeably to mean generation of electricity from sunlight.
2. For some 2021 mini grids, contracted costs were used rather than post-commissioning costs.
3. Not included for detailed analysis in this chapter, but nonetheless promising (especially for communities with needs for smaller amounts of electricity) are lower-cost direct current (DC) "mesh grids" or "skinny grids" that distribute DC electricity for lighting,

electronics, and small appliances like fans and even efficient refrigerators or electric rickshaws. See box 1.2.

4. In the world of grid-connected power plants, LCOE is used to compare on an apples-to-apples basis the cost of energy delivered to the grid network from generating assets that have different capital costs, fuel costs, and lifetimes. LCOE is typically expressed in currency per kilowatt-hour.
5. In these three countries we restricted our analysis to mini grids with lithium-ion batteries because they are the most common type (accounting for 76 percent of battery types in mini grids from our data set in Nigeria, 50 percent in Myanmar, and 100 percent in Ethiopia), and also have lower LCOE, on average, than mini grids with lead-acid batteries.
6. Bolivia, Ethiopia, Indonesia, Myanmar, Nigeria, and Tanzania.
7. Bangladesh, Bolivia, Chad, Ethiopia, Ghana, Guinea Bissau, India, Indonesia, Ivory Coast, Kenya, Liberia, Myanmar, Nepal, Nigeria, Palestine, Sierra Leone, Tanzania, Vanuatu, and Vietnam.
8. In addition to 20-year project economic life, we have also modeled the impact of 15- and 25-year lifetime assumptions on LCOE. Adding five years decreases LCOE by about 2.2 US cents per kWh in the 22 percent load factor / 0 percent subsidy case, with a smaller reduction in other cases. Subtracting five years increases LCOE by about 2.7 US cents per kWh for the same case, with lesser impact in other cases.
9. The weighted average cost of capital of a capital structure comprising 40 percent equity at 12 percent return and 60 percent debt at 8 percent interest is 9.6 percent. Assumptions consistent with Lazard (2021).
10. The combination of a 9.6 percent nominal discount rate and 3 percent inflation yields a real discount rate of 6.41 percent.
11. The World Bank tracks pump prices for diesel from Sub-Saharan Africa at https://data.worldbank.org/indicator/EP.PMP.DESL.CD?end=2016&locations=ZG&start=2010. Corrected for inflation, the most recent (2016) pump price is $1.08 per liter. The fuel cost sensitivity analysis investigated $0.75 and $1.50 per liter of diesel fuel in addition to the base case of $1.00 per liter. Because the mini grids have high penetrations of renewable energy, the cost of diesel had a relatively small effect on LCOE. In HOMER sensitivity runs with diesel fuel costs of $0.75 and $1.50 per liter, the variation in LCOE was less than +6 percent of the $1.00 per liter base case. The project lifetime analysis considered project economic lifetimes of 15 and 25 years in addition to the base case of 20 years. The +5 year project lifetime assumptions affected LCOE by less than +7 percent, with the strongest impacts in the 22 percent load factor case.
12. Diesel generators' nonfuel OPEX is estimated at $0.03 per kWh; solar PV OPEX, at $10 per kW a year; and battery OPEX, $10 per kW a year. These variable O&M assumptions are held constant across all HOMER modeling runs.
13. The prices that developers pay for individual components are typically higher than the wholesale price direct from the factory. Even as third-generation mini grid developers build larger portfolios, all but the very biggest developers will still pay higher prices than those available at the factory door. As a result, we conservatively assumed that by 2030, the typical third-generation mini grid developer would be able to purchase components at their 2020 factory spot prices.
14. In our data set, the average cost of PV modules in mini grids built with Li-ion batteries (mostly built in 2019 to 2021) was $534 per kWp, reflecting the fact that our best-in-class mini grid, while best-in-class overall and for other equipment costs, had higher than average PV module costs. For our 2030 calculations we used average cost of PV modules in these Li-ion battery mini grids and then applied industry-projected cost declines discussed in the "PV Module Trends" section of this chapter.
15. Because of Li-ion batteries' ability to discharge energy more deeply, they can have a nameplate capacity that is 25 percent smaller than if lead-acid batteries were used.
16. Somewhat counterintuitively, the optimum renewable energy fraction decreases slightly in some of the cases as the load curve shifts from normal to sun-following. For example, for cases 3 and 4 (Ethiopia and global Li-ion, respectively), the renewable energy fraction falls from a 22 percent load factor to a 22 percent sun-following scenario. Why would the renewable energy fraction decrease when shifting to a more solar-coincident load? The answer lies in the component sizing of the optimal mini grid in each case. Moving more solar-coincident loads allows the system to rely less on battery storage, with the consequence that the system becomes a bit more reliant on backup diesel during occasional rainy periods.
17. Generators are often rated in apparent power (kVA). The generator's real power output (kW) is the apparent power multiplied by the power factor, typically assumed to be 0.8 for design purposes.
18. Peak power output of a solar panel is the power output at a solar irradiance of 1,000 watts per square meter, 1.5 air mass, and a temperature of 25º C.
19. In 2019 an early version of ESMAP's Mini Grids for Half a Billion included a similar waterfall graph based on data from 36 mini grids commissioned between 2012 and 2018. A comparison of the 2019 graph with this 2022 version reveals that PV costs (including for PV inverters) plummeted, from 16 percent to about 10 percent of total project costs, reflecting lower PV costs in recent years. Battery and battery inverter + EMS costs remained the same. Distribution and meters as a portion of total project costs increased from 21.0 percent to 26.6 percent as other costs fell, as did installation, which increased to 11.3 percent from 8.0 percent. On the other hand, project development costs dropped from 9.0 to 5.9 percent, which likely reflects benefits of clustering and perhaps also a trend in more recent projects to fold project development costs into reported equipment costs.
20. PV inverters convert the direct current (DC) electricity produced by the solar array into alternating current (AC) power on the mini grid's network.
21. Battery nameplate capacity is typically indicated in ampere-hours (Ah). Battery nameplate kWh is calculated as the Ah multiplied by the battery's nominal voltage.
22. Lead-acid batteries are typically not discharged more than 50–60 percent, whereas lithium-ion batteries can be discharged to 80 percent depth of discharge.
23. For an apples-to-apples comparison across different battery chemistries, it is useful to compare the levelized cost of storage (LCOS). LCOS is analogous to the levelized cost of energy (LCOE) but uses the discounted cost of purchasing and operating the battery over the course of its lifetime (in lieu of the cost of generating and distributing electricity), divided by the discounted discharged electricity. It is the levelized cost associated with storing and withdrawing one kWh of electricity. The data set does not provide sufficient data for an LCOS calculation. Lazard (2018) finds that for US applications in 2018 at the scale of 40 kWh of storage capacity ("residential scale" in their analysis, equivalent in storage capacity to the smallest mini grids considered in this chapter), the LCOS for lithium-ion batteries was $0.476–$0.735/kWh. Lead-acid batteries have a comparable range of LCOS values at this scale, of $0.512–$0.707/kWh. For proj-

ects at the scale of 2 megawatt-hours of energy storage (Lazard's "Commercial & Industrial scale," about twice as much storage as the largest village mini grids studied in this chapter), the LCOS for lithium-ion batteries was $0.315–$0.366/kWh, several cents lower than the $0.382–$0.399/kWh LCOS for lead-acid batteries. The analysis assumed a 20:80 percent debt to equity ratio, with debt at 8 percent and the cost of equity at 12 percent (Lazard 2018).

24. Parameters not captured in the distribution network cost data are the standards to which the low-voltage distribution network is built. Projects built to a high standard or a grid-ready standard will have much higher costs per customer and per kilometer than those built to lower standards (for example, using untreated wooden poles, low pole heights, and undersized conductors and hardware), as will distribution grids that are deliberately oversized to accommodate future growth. Other factors influencing the wide variations in cost per kilometer and per customer that are not captured in the survey likely include whether poles for distribution were constructed of local materials and not costed as part of the project, accounting practices related to in-kind labor and materials supplied by local communities, whether service is single phase or three phase, and whether public lighting costs were bundled into this category by a developer.
25. Replacement of large assets such as batteries is not included in these O&M costs. These costs are included, however, in LCOE calculations earlier in this chapter.
26. With high commodity prices for polysilicon, aluminum, and other raw materials due to post-COVID supply bottlenecks prices were pushed higher for PV modules in 2021 and the first part of 2022 (Stevens 2021). As of April 2022, the global average spot price for PV was $230 per kWp for 330–335 W multi-crystalline modules. Industry experts expects these bottlenecks to be transitory (Energy Trend 2022).
27. Wright's Law posits that every cumulative doubling in the cumulative amount of a product produced leads to a consistent percentage cost decline.
28. PV deployment has been growing at an average of 40 percent in recent years (50 percent in 2016, 29 percent in 2017) (Solarpower Europe 2018) and a compound average growth rate of more than 40 percent over the past 15 years (Jäger-Waldau 2017).
29. See http://haiyuindustry.sell.everychina.com/p-101752826-concrete-spun-electric-pole-production-machine.html for photos and a more detailed description of this process.
30. Field visits at the preparation stage are needed to engage with communities to discuss agreements, such as the terms of land purchases or leases, and to verify the geospatial analysis data—and they can be handled by a much leaner team.
31. A related issue more germane to the data is that some companies appear to report project development and business development costs explicitly, others blend them into equipment costs in the form of markups, and still others internalize these costs and do not report them at all. The background study carried out for this chapter did not include data gathering on subsidy amount or in-kind accounting (for local materials and community contribution) or address competition in markets.

CHAPTER 2

NATIONAL STRATEGIES AND DEVELOPER PORTFOLIOS: THE ROLES OF GEOSPATIAL ANALYSIS AND DIGITAL PLATFORMS

CHAPTER OVERVIEW

This chapter discusses geospatial analysis and other digital tools that can support electrification planning at both the national and portfolio levels. Drawing on real-world examples from Nigeria and Ethiopia, and leading mini grid developers, the chapter lays out how to use cutting-edge technologies like geospatial software and online platforms to develop large portfolios of mini grids. It also introduces some of the leading technology providers for such planning tools.

Thanks to new geospatial analysis technologies, a portfolio approach to mini grid development is becoming mainstream in the industry and in national electrification planning. This is occurring at the national level for least-cost electrification planning and among mini grid companies themselves. Geographic information system (GIS) software and geospatial data are becoming key tools for planning electrification at the national level and performing rapid site assessments. Mainstream digital tools are expediting technological advances and cost reductions, including:

- Satellite imagery and spatial products
- Big data and cloud-based computing
- More sophisticated algorithms and analytical solutions (for example, heuristics and machine learning)
- Global positioning system devices and the proliferation of web-based and mobile technologies
- Higher-quality open-source software

A geospatial approach ensures that national electrification is mapped cost-effectively on the existing grid network and its attributes digitalized. Demand and supply of electricity can be geolocated by overlaying demographic data (such as population density and growth patterns) on social infrastructure (for example, schools, health centers, administrative offices) and the economic landscape (such as household income, poverty, commercial activities, willingness to pay). Spatial modeling delivers a least-cost plan by identifying beforehand the technology best suited to local circumstances—technically feasible and economically viable. At the same time, geospatial plans can also identify communities requiring decentralized solutions (mini grids) as they wait for the grid.

Geospatial plans are essential in siting mini grids and signaling the likelihood of grid arrival, information that curtails asset stranding. The identification of communities for which mini grids offer the optimal technology solution requires at least the following:

- Electricity demand estimates, including for productive uses;
- The location of existing infrastructure and modeling of grid rollout; and
- Estimation of local renewable generation potential.

Using geospatial analysis in planning mini grid portfolios could cut the time spent on deployment.

Geospatial planning cannot replace field-based feasibility studies, but it can determine mini grid potential. It does this by evaluating current and anticipated service needs (including productive use) and the time frame for grid arrival. This exercise prepares engineers and policy makers for planning electricity services and allocating public funding, ensuring that public interventions (where and why) are done with equity foremost in mind. System optimization, network design tools, and online platforms analyze data, develop project proposals, select developers, solicit financing, and monitor and verify implementation.

This chapter assesses the market potential for mini grid sites selected by geospatial data. It then looks at tools and analyses that support least-cost electrification and planning exercises. We then assess how geospatial and other digital tools are being used to save both time and costs in mini grid project development, from site prospecting and analyzing demand to right-sizing solutions, packaging projects, and taking them to market. Examples from the "frontier" of these planning exercises, particularly the World Bank's Nigeria Electrification Project and its Ethiopia project, Access to Distributed Electricity and Lighting in Ethiopia, illustrate their practical application.

ASSESSING THE MARKET POTENTIAL FOR MINI GRIDS

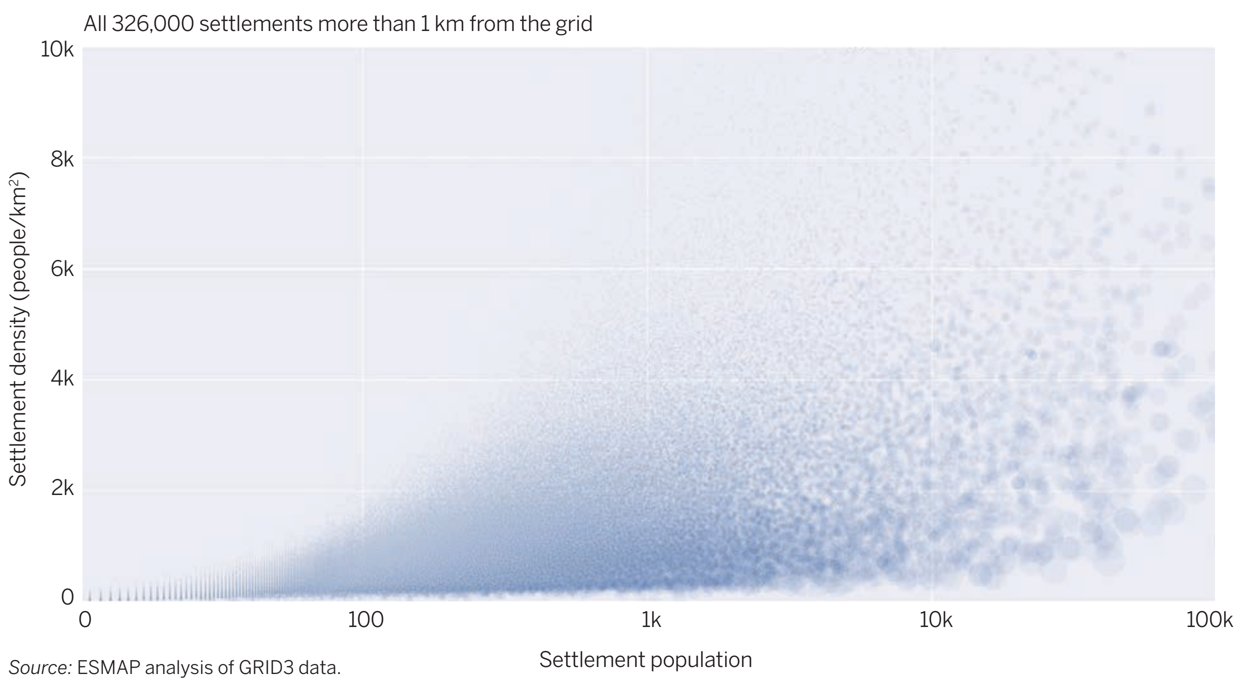
With programs ramping up worldwide as countries seek to meet their Sustainable Development Goal (SDG) 7 targets, what roles do mini grid systems play in that process? Different stakeholders come at this question from various standpoints. Governments and policy makers want to understand how mini grids could support a speedy rollout of electrification; how many people or households can mini grids serve with high-quality and sustainable electricity over the long term? Investors and financiers, on the other hand, are interested in the addressable market and the economically viable potential of mini grids in Sub-Saharan Africa. This section briefly describes how new spatial data and analysis can help address these questions, providing qualitative and, to the extent possible, quantitative data.

The single most critical data set required for this analysis is the settlement distribution—that is, the location of settlements or buildings over the area of interest. Over the past few years, several data sets have been developed in this regard, based on high-resolution satellite imagery and processing techniques (for example, machine learning). We describe and use some of them below.

SIMPLE EXPLORATORY SPATIAL DATA ANALYSIS FOR SUB-SAHARAN AFRICA USING GRID3

In the first example, we explore the settlement distribution layer for Sub-Saharan Africa provided by GRID3 (CIESIN 2020). The layer constitutes a comprehensive set of settlement polygons classified into built-up areas, small settlement areas, and hamlets; 326,000 settlements were found to be more than 1 kilometer (km) from the existing grid[1] (figure 2.1), including a preponderance of settlements in the 100–1,000 population range. Extracting additional information about the settlements to facilitate site selec-

FIGURE 2.1 • Scatter plot of settlement population vs population density in Sub-Saharan Africa



Source: ESMAP analysis of GRID3 data.
Note: Point size reflects the area of the settlement.

tion, the following criteria were thus set to define a settlement suitable for mini grid electrification:

- Number of people: more than 100 and less than 100,000
- Distance from the existing grid: more than 1 km
- Population density: more than 1,000 people/km^2

Settlements with populations of more than 100,000, or any settlements located less than 1 km from the grid, are considered either already electrified or candidates for grid electrification and thus excluded from this analysis. On a similar note, any settlement with less than 100 people is considered a better candidate for solar home systems (SHSs) than mini grids. The density assumption was set as such to satisfy mini grid design criteria; that is, to avoid the selection of settlements that have sparse populations. These criteria reflect the prevailing view of what constitutes a good candidate site for a mini grid; they were based on past projects and experience on the ground. The results presented below are bound to these selection criteria and should be interpreted with caution accordingly.

As table 2.1 indicates, about 23.7 percent of Sub-Saharan Africa's population (that is, 276.9 million of 1.17 billion people) lives in settlements that in theory could be markets for mini grids. Assuming an average size of 5 people/household, about 55.4 million households on the subcontinent, or about 291,000 clusters, could be served by mini grids.

As an initial assessment of the potential for standardization in the rollout of mini grids in Sub-Saharan Africa, we also explored whether we could find convergence around certain sizes of mini grids to serve the clusters described above. The growing pipeline of mini grid projects under development under the World Bank's Nigeria Electrification Project provided some data on the sizing of private-sector-led mini grids vis-à-vis the customer base or settlement size, indicating an average firm power allocation of roughly 100 watts (W) per connection. We used this as a benchmark, while acknowledging variations from project to project, including in the ratios of commercial and productive end users to residential customers, and associated power requirements. We anticipate that mini grids of 20 kilowatts (kW), 80 kW, and 200 kW may be best suited to serve the settlement sizes listed in table 2.1. Custom solutions will continue to be the preferred option for settlements of 10,000 to 100,000 people, likely requiring mini grids at the 500 kW to 1 megawatt (MW) scale.

Settlement population distribution is presented by country in figure 2.2, with the estimated addressable market for mini grids presented in absolute numbers atop the bars for each country. The height of the bars represents the share of this segment as a percentage of the total population of the country. This addressable market for mini grids is further disaggregated into the same settlement sizes as described in table 2.1.

Using the same selection criteria and settlement sizes, figure 2.3 maps and visualizes their population distribution.

THE GLOBAL ELECTRIFICATION PLATFORM AND LEAST-COST ELECTRIFICATION ANALYSIS FOR SUB-SAHARAN AFRICA

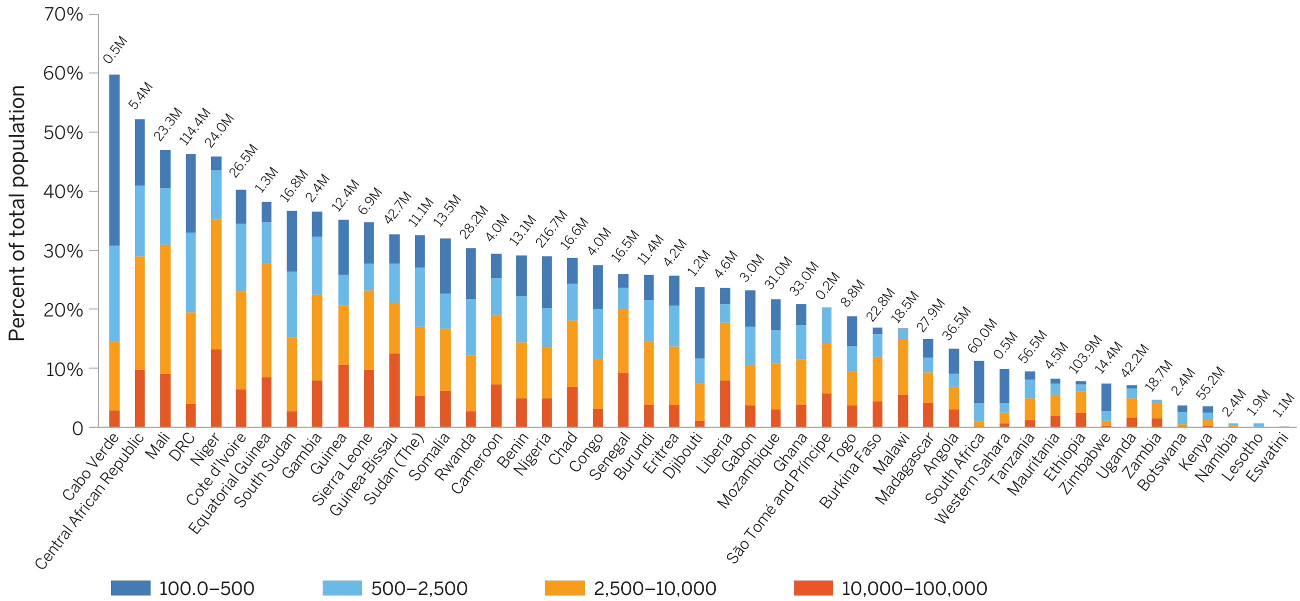
The Global Electrification Platform (GEP) is an open-access, interactive, online platform that models and visualizes pathways toward universal access, split into an intermediate strategy for 2025 and full electrification by 2030, for countries marked by severe access deficits. The current version, GEP V.2.0, officially launched in April 2022, explores 96 unique scenarios. The set of results was modeled with a modified version of the Open Source Spatial Electrification Tool (OnSSET). This is a flexible and modular GIS-based energy modeling tool developed to support electrification planning and decision making by estimating, analyzing, and visualizing the most cost-effective electrification strategy. In doing so, it takes into account spatially explicit characteristics related to energy, such as population density and distribution, proximity to transmission and road network, night-time lights, and local renewable energy potential, among others.

The GEP considers current and projected values of key parameters such as population growth, demand level, technology costs, and other policy/planning limitations in generating electrification scenarios. Results indicate the least-cost electrification technology per settlement (or cluster)[2] across millions of clusters in 46 countries of Sub-Saharan Africa. The addressable market for mini grids falls within a range that depends on the input parameters and assumptions, with the key parameter being the level of demand for unelectrified households. Usually, the

Table 2.1 • Characteristics of Sub-Saharan African settlements suitable for electrification via mini grid

Size (average pop.)	100–500	500–2,500	2,500–10,000	10,000–100,000	Total:
Settlements	177,087	95,702	15,188	2,948	290,925
Population total	46,886,543	97,073,397	67,627,653	65,303,591	276,891,184
Share of total population (%)	4.01	8.31	5.79	5.59	23.71
Optimum mini grid sizing (kW)	20	80	200	Custom	

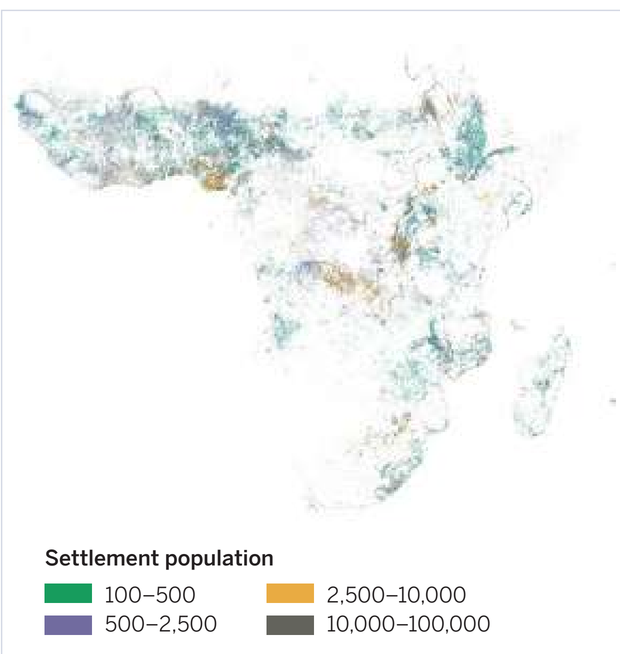
FIGURE 2.2 • Sub-Saharan Africa's addressable market for mini grids



Source: ESMAP analysis of GRID3 data.

Note: Total country population shown in values atop each bar. Results indicate the percentage of people located in settlements (clusters) that fulfil the selection criteria for mini grid candidacy (that is, between 100 and 100,000 people, located more than 1 km from the main grid, with a distribution of more than 1,000 people/km^2). Clusters derived from GRID3 (CIESIN 2020).

FIGURE 2.3 • Sub-Saharan Africa's addressable market for mini grids, mapped by settlement population



Source: ESMAP analysis of GRID3 data.

Note: Results indicate the number of people located in settlements (clusters) that fulfil the selection criteria for mini grid candidacy (that is, between 100 and 100,000 people, located more than 1 km from the main grid, with a distribution of more than 1,000 people/km^2). Clusters derived from GRID3 (CIESIN 2020).

greater the targeted demand, the greater the share of mini grid potential. Table 2.2 presents how three different levels of demand can dictate the share of mini grids in the least-cost mix.

When demand is low, mini grids are the least-cost option for about 66.0 million people (or 13.2 million connections). Intermediate demand pushes mini grid potential to about 87.2 million people (17.5 million connections), while with high-demand scenarios, the potential is estimated at about 131 million people (26.2 million connections).

Mini grids can also serve as pre-electrification solutions, which is to say, they could be least-cost options for settlements expecting the arrival of the main grid. Political, economic, and other considerations will ultimately determine if and when the grid reaches these communities. On the one hand, the newer mini grids mostly meet code and could connect to the main grid once it arrives. On the other hand, falling costs and decentralized renewable technologies tell us that not every community may need to connect to the main grid.

Including pre-electrification, in the low demand scenario, mini grids are cumulatively the least-cost option for 66 million people (or 13.2 million connections)—the same as the count in 2030. In the bottom-up and high-demand scenarios, we see huge increases in the population served at least-cost by mini grids once we account for mini grids that are eventually connected to the grid: 105 million people (or 21 million connections) and 325 million people (or 65 million

TABLE 2.2 • Selected electrification results for 2030 retrieved from the Global Electrification Platform, aggregated for 46 countries in Sub-Saharan Africa

Demand target[a]	Mini grid potential		Mini grid potential (including pre-electrification role)	
	People	Connections	People	Connections
Low demand	66,004,359	13,200,872	66,004,359	13,200,872
Bottom-up demand	87,249,707	17,449,941	104,716,450	20,943,290
High demand	131,052,705	26,210,541	325,025,815	65,005,163

Source: ESMAP analysis of Global Electrification Platform results.

Note: GEP V.2.0 released in April 2022.

a. Low demand reflects targets equivalent to Tier 3-4 for urban households and Tier 1 for rural households. High demand indicates Tier 4-5 for urban households while Tier 2-3 for rural. Tier values differ per country depending on the current electrification status and/or goals. The bottom-up value reflects an intermediate level of demand that is based on the combination of socio-economic indicators that vary spatially (poverty rate and GDP).

TABLE 2.3 • Breakdown of electrification results from bottom-up demand scenario

	<10 kW	10–100 kW	0.1–1 MW	1–10 MW	10–100 MW	>100 MW	Total
Settlements	36,914	136,465	19,313	1,056	94	3	193,845
Population	1,781,648	39,190,271	35,259,640	17,100,927	9,281,040	2,102,924	104,716,450
Households	356,330	7,838,054	7,051,928	3,420,185	1,856,208	420,585	20,943,290
Percentage of total new connections in Sub-Saharan Africa	0.19	4.16	3.75	1.82	0.99	0.22	11.13

Source: ESMAP analysis of OnSSET data and Global Electrification Platform results.

connections) respectively. Note that all values are inclusive of population growth and reflect aggregated data for all modeling years between 2020 and 2030.

Looking more closely at the bottom-up demand scenario, we see that least-cost mini grids serve close to 200,000 settlements, numbers that correspond to the aforementioned 105 million people (or 21 million households). Table 2.3 displays the distribution of this population by the size of the mini grids projected to serve them. One can see that most settlements (and their mini grids) fall in the 10 to 100 kW range, while mini grids in the 10 kW to 1 MW range serve about 7.9 percent of all newly electrified population in Sub-Saharan Africa.

Based on the estimated new capacity in settlements where mini grids are the least-cost option for all or part of the expected population between 2020 and 2030

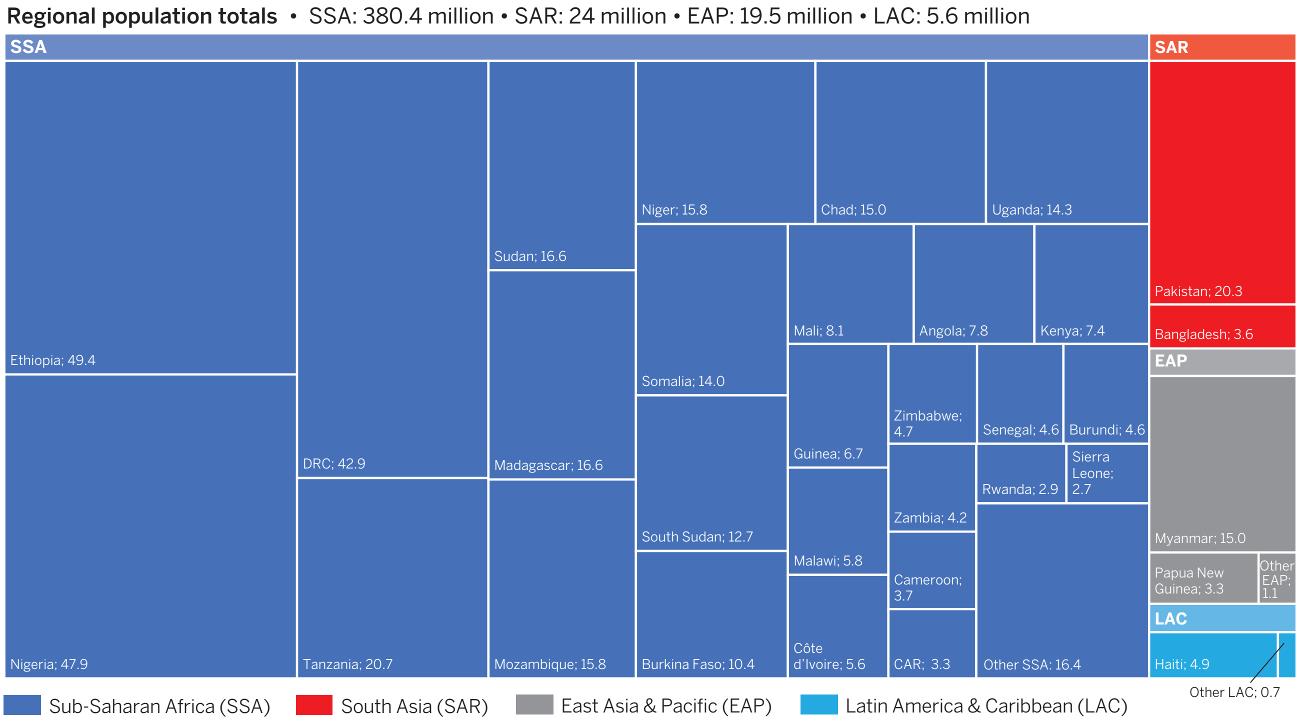
MAXIMAL MINI GRID DEPLOYMENT MODELED IN THE GLOBAL ELECTRIFICATION PLATFORM

Rather than selecting a particular demand scenario (low, bottom-up, or high) and modeling results for all countries for that scenario, we use the GEP to review which of the 96 modeled scenarios for each country deploys the most mini grids. While high-demand scenarios tend to favor mini grids as the least-cost solution, they also tend to label grid densification or extension as the least-cost option. Besides, other parameters, like those referring to generation for grid electricity and the cost of solar photovoltaic (PV) systems, affect the least-cost option and together account for the 96 unique scenarios modeled in the GEP. The scenario most favorable for the deployment of mini grids as the least-cost solution thus varies from country to country.

The finding from this exercise is that 430 million people can receive access at least cost via mini grids. This includes 380 million people in Sub-Saharan Africa living in the 58 access-deficit countries covered by the GEP, which represent nearly 40 percent of all new connections achieved in these countries. See figure 2.4 for a breakdown of this population by region and country, and table 2.4 for the GEP scenario codes for readers interested in exploring country-specific scenarios.

For those interested in electricity access or the mini grid industry, it will come as no surprise that Sub-Saharan Africa is by far the most important market for mini grid electrification. While three African countries—Ethiopia, the Democratic Republic of Congo, and Nigeria—stand out for their massive mini grid potential (49.4 million, 47.9 million, and 42.9 million people, respectively), one can also see from figure 2.4 that many others have huge populations that could be served by mini grids. Elsewhere, the electrification potential is vast: 20 million people in Pakistan, 15 million in Myanmar, and, in Haiti, almost 5 million people could gain least-cost electricity by mini grid.

FIGURE 2.4 • Distribution by country of 429.5 million people served at least cost by mini grids in 58 access-deficit countries



Source: ESMAP analysis of Global Electrification Platform results.

Note: Under the scenario most favorable for mini grids. Data from the Global Electrification Platform. SSA: Sub-Saharan Africa; SAR: South Asia; EAP: East Asia & Pacific; LAC: Latin America & Caribbean. *Other SSA:* Ghana (2.5); Eritrea (2.3); Benin (2.2); Liberia (1.9); Congo (1.5); Mauritania (1.4); Togo (1.1); Guinea-Bissau (1.0); Gambia (0.9); Lesotho (0.5); Equatorial Guinea (0.3); Comoros (0.2); South Africa (0.2); Eswatini (0.2); Namibia (0.1); Djibouti (0.1); Gabon (0). *Other LAC:* Nicaragua (0.4); Honduras (0.3). *Other EAP:* Cambodia (0.6); Solomon Islands (0.4); Vanuatu (0.1).

TABLE 2.4 • GEP scenario codes for each country's maximum number of new mini grid connections by 2030

Region	Country Name	GEP Scenario	People newly connected to mini grids (millions)
SSA	Ethiopia	et-2-2_0_1_0_0_0	49.4
SSA	Nigeria	ng-2-2_1_1_0_1_0	47.9
SSA	Democratic Republic of Congo	cd-2-2_1_1_0_1_1	42.9
SSA	United Republic of Tanzania	tz-2-2_1_1_0_0_0	20.7
SSA	Sudan	sd-2-2_1_1_0_1_1	16.6
SSA	Madagascar	mg-2-2_1_1_0_1_0	16.6
SSA	Mozambique	mz-2-2_0_1_0_0_0	15.8
SSA	Nigeria	ne-2-2_1_1_0_0_0	15.8
SSA	Chad	td-2-2_0_1_0_0_0	15.0
SSA	Uganda	ug-2-2_1_1_0_1_1	14.3
SSA	Somalia	so-2-2_0_0	14.0
SSA	South Sudan	ss-2-2_0_1_0_0_0	12.7
SSA	Burkina Faso	bf-2-2_1_1_0_1_0	10.4
SSA	Mali	ml-2-2_1_1_0_1_0	8.2
SSA	Angola	ao-2-2_1_1_0_1_0	7.8
SSA	Kenya	ke-2-2_1_1_0_1_1	7.4
SSA	Guinea	gn-2-2_1_1_0_1_1	6.7
SSA	Malawi	mw-2-2_1_1_0_0_0	5.8

continued

TABLE 2.4, *continued*

Region	Country Name	GEP Scenario	People newly connected to mini grids (millions)
SSA	Côte d'Ivoire	ci-2-2_1_1_0_1_0	5.6
SSA	Zimbabwe	zw-2-2_1_1_0_1_1	4.7
SSA	Senegal	sn-2-2_1_1_0_1_0	4.6
SSA	Burundi	bi-2-2_1_1_0_0_0	4.6
SSA	Zambia	zm-2-2_1_1_0_1_1	4.2
SSA	Cameroon	cm-2-2_1_1_0_1_0	3.7
SSA	Central African Republic	cf-2-2_0_1_0_0_0	3.3
SSA	Rwanda	rw-2-2_0_1_0_1_0	2.9
SSA	Sierra Leone	sl-2-2_1_1_0_1_0	2.7
SSA	Ghana	gh-2-2_1_1_0_1_0	2.6
SSA	Eritrea	er-2-0_0_1_0_0_0	2.3
SSA	Benin	bj-2-2_1_1_0_1_0	2.2
SSA	Liberia	lr-2-2_1_1_0_0_0	1.9
SSA	Congo	cg-2-2_1_1_0_1_0	1.5
SSA	Mauritania	mr-2-0_1_1_0_1_0	1.4
SSA	Togo	tg-2-2_1_1_0_0_0	1.1
SSA	Guinea Bissau	gw-2-2_1_1_0_1_0	1.0
SSA	The Gambia	gm-2-2_1_1_0_1_1	0.9
SSA	Lesotho	ls-2-2_1_1_0_1_0	0.5
SSA	Equatorial Guinea	gq-2-2_1_1_0_1_0	0.3
SSA	Comoros	km-2-2_0_0_0_0_0	0.2
SSA	South Africa	za-2-2_0_0_0_1_1	0.2
SSA	Eswatini	sz-2-2_0_1_0_1_0	0.2
SSA	Namibia	na-2-0_1_1_0_1_0	0.1
SSA	Djibouti	dj-2-2_0_1_0_0_0	0.1
SSA	Gabon	ga-2-0_1_1_0_1_1	0.0
SSA	Botswana	bw-2-2_1_1_0_0_0	0.0
SSA	Sao Tome and Principe	st-2-0_0_0_0_0_0	0.0
SAR	Pakistan	pk-2-2_1_1_0_1_0	20.3
SAR	Bangladesh	bd-2-0_0_1_0_1_0	3.6
EAP	Myanmar	mm-2-2_1_1_0_1_1	15.0
EAP	Papua New Guinea	pg-2-0_1_1_0_1_1	3.3
EAP	Cambodia	kh-2-2_1_1_0_1_1	0.6
EAP	Solomon Islands	sb-2-0_0_0	0.4
EAP	Vanuatu	vu-2-0_0_0	0.1
EAP	Timor-Leste	tl-2-2_0_0_0_0_0	0.0
EAP	Federated States of Micronesia	fm-2-0_0_0	0.0
LAC	Haiti	ht-2-2_0_1_0_0_0	4.9
LAC	Nicaragua	ni-2-2_1_1_0_0_0	0.4
LAC	Honduras	hn-2-0_0_1_0_0_0	0.3

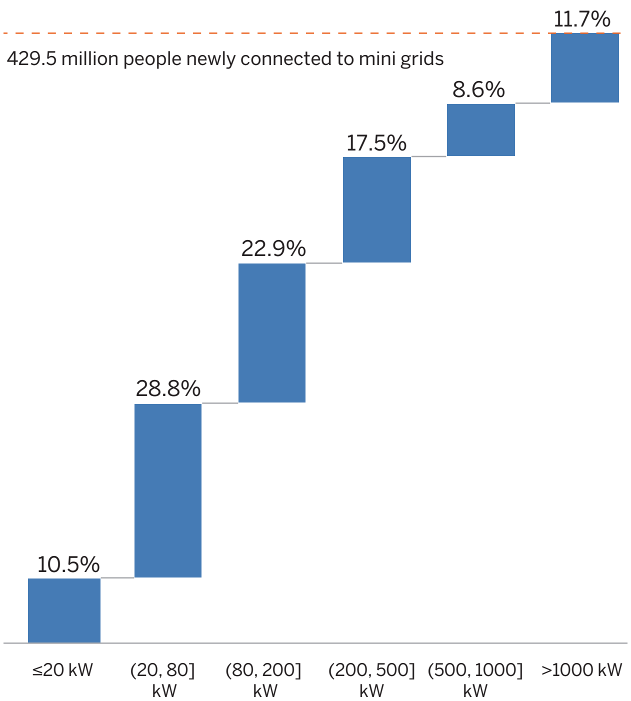
Source: ESMAP analysis of Global Electrification Platform results.

GEP Scenario code definition:

cc-: two letter country code
2-: default value indicating GEP V.2.0
1st value: [0: "Bottom up", 1: "Top-down low", 2: "Top-down high"] for "Electricity demand target"
2nd value: [0: "Social and productive uses demand included", 1: "Residential demand only"] for "Productive uses inclusion"
3rd value: [0: "Estimated", 1: "High"] for "Grid generation cost"
4th value: [0: "Estimated", 1: "High", 2: "Low"] for "PV cost"
5th value: [0: "No connections cap", 1: "Capped connections in 2025"] for "Intermediate investment & Grid connection Cap"
6th value: [0: "Least-cost nationwide", 1: "Only grid within 2 km"] for "Rollout Plan"

What size mini grids could deliver electricity to these 430 million people? Figure 2.5 displays the population distribution by applicable mini grid size. For example, systems of less than 20 kW are expected to serve 10.5 percent of new mini grid connections. Mini grids roughly corresponding to 20 kW, 80 kW, and 200 kW systems can serve about 52 percent of all new mini grid connections, which generally accords with most mini grids built to date. The GEP analysis also suggests there is a great deal of scope for mini grids in the 200 to 500 kW range, which could serve 17.5 percent of all new mini grid connections. There is also potential for 8.6 percent and 11.7 percent of new mini grid connections to be served by systems in the 500 kW to 1 MW and 1 MW+ range, respectively, which corresponds to more than 87 million people and aligns with discussions about so-called metro grids in some markets.

FIGURE 2.5 • Distribution by mini grid size of 429.5 million people served at least-cost by mini grids in 58 countries with severe access deficits



Source: ESMAP analysis of Global Electrification Platform results.

Note: Under the scenario most favorable for mini grids. Data from the Global Electrification Platform.] means up to and including; (means greater than but not equal to.

The GEP also estimates the investment required at about $100 billion, or 66 gigawatts (GW) of installed capacity, almost all of it solar hybrid, with over 90% of both this installed capacity and investment needed in Africa. The GEP, however, defines[3] the installed capacity of solar hybrid systems as the PV capacity plus diesel generator capacity, which results in a higher measure of installed capacity than if measuring firm power as defined in chapter 1. Table 2.5 presents the number of settlements, electricity connections (or households), population, installed capacity in MWs, and the investment requirement to realize the delivery of electricity to 430 million people by mini grid system size.

NATIONAL ELECTRIFICATION PLANNING

Geospatial plans represent a data-driven approach to planning for the efficient and effective deployment of limited resources, particularly aimed at supporting countries with low rates of electrification. Spatial modeling delivers a least-cost plan that identifies the optimal grid or off-grid technology tailored to local circumstances (including local cost parameters) and appropriate in its technical feasibility and economic viability. It also integrates social and economic planning objectives, like equity, which may target universal service delivery or priority access for schools and clinics. The (local) costing associated with the deployment of different technology solutions (for example, grid, mini grid, or SHS) is triangulated and compared across various dimensions. The most important of these are population (or institutional) density, distance, and isolation from the main grid, in addition to current and forecasted demand.

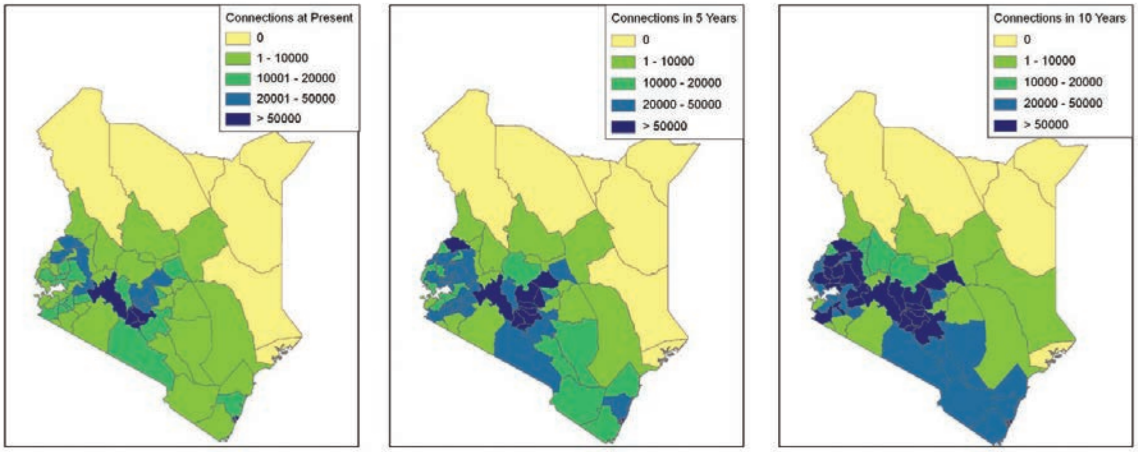
TABLE 2.5 • Distribution by mini grid system size of 429.5 million people served at least-cost by mini grids in 58 countries with access deficits

	<20 kW	20–80 kW	80–200 kW	200–500 kW	500–1,000 kW	>1,000 kW	Total
Settlements	622,061	421,358	104,279	33,202	7,322	3,634	1,191,856
Connections	8,986,188	24,767,050	19,694,967	15,035,819	7,384,990	10,024,393	85,893,408
Population	44,930,942	123,835,249	98,474,836	75,179,094	36,924,951	50,121,965	429,467,039
Capacity (MW)	5,617.70	16,817.20	12,646.50	9,878.00	4,972.60	16,063.10	65,995
Investment (US$, millions)	14,513.80	28,311.50	20,408.40	15,261.70	7,296.80	14,412.80	100,205

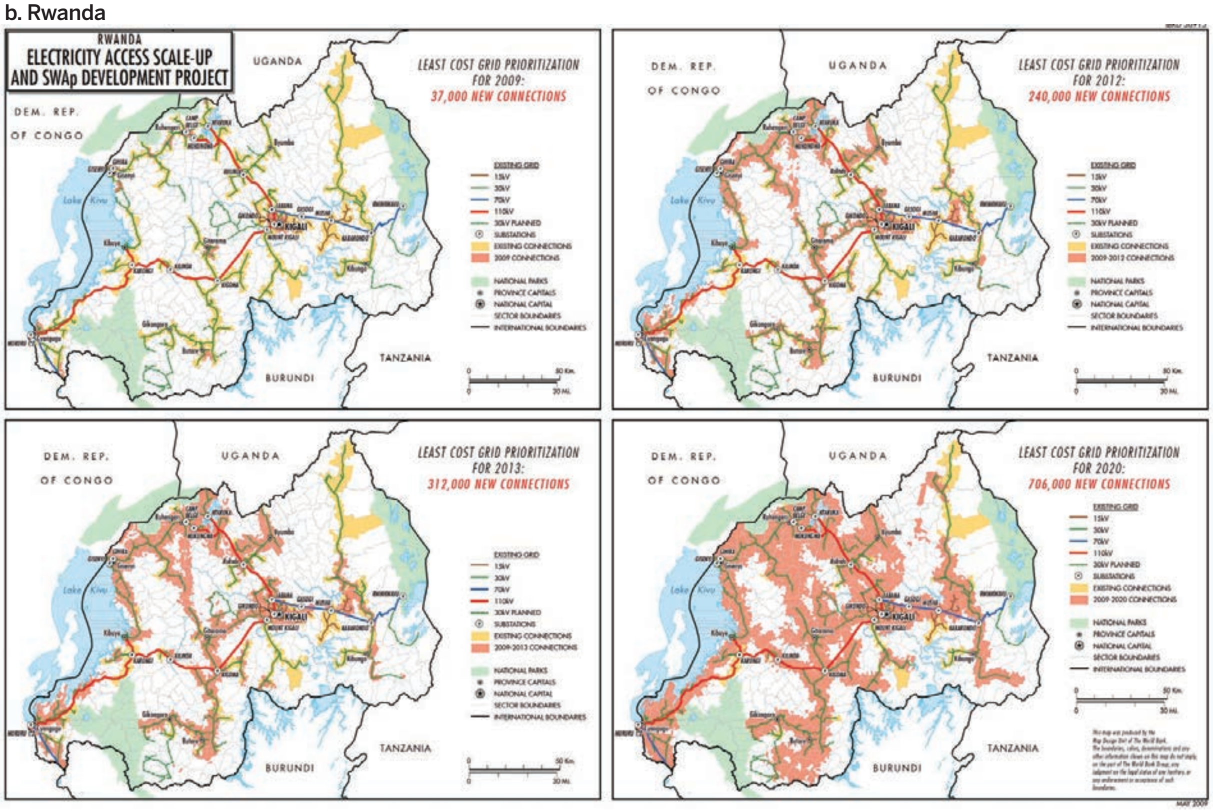
Source: ESMAP analysis of Global Electrification Platform results.
Note: Under the scenario most favorable for mini grids. Data from the Global Electrification Platform.

FIGURE 2.6 • Geospatial least-cost rollout plans in Kenya and Rwanda

a. Kenya



b. Rwanda



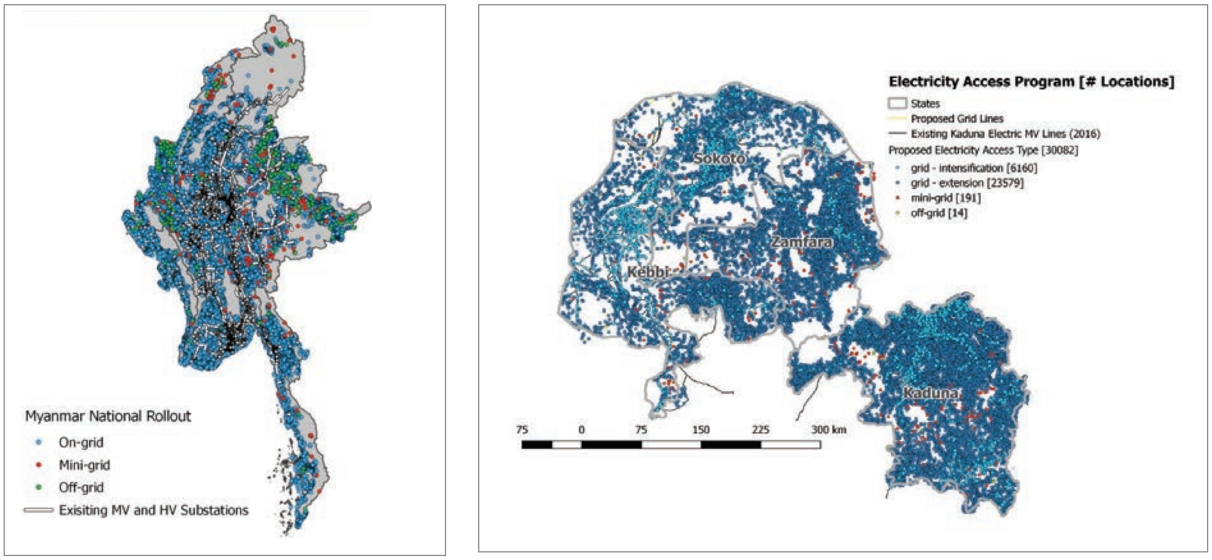
Sources: Kenya: World Bank 2007; Rwanda: World Bank 2009.
GIS = geographic information system; km = kilometers; kW = kilowatt; mi = miles.

Geospatial analysis surfaces the most efficient technology solution by using not only location (where do prospective beneficiaries reside?) but also over time. Hence the focus on off- and mini grid programs. Even if the grid may, in some cases, be the least-cost solution, decentralized solutions have a role in providing nationwide access in the short term, making up for what could be halting progress in network extension, and providing backup solutions. National least-cost electrification planning can therefore help rural electrification agencies and mini grid developers define the addressable market for mini grids both as interim and permanent electrification solutions in the country.

Examples of geospatial planning exercises for least-cost electrification can be drawn from Kenya and Rwanda (figure 2.6) and Myanmar and Nigeria (figure 2.7). Their experiences led to the development of the GEP, also presented below in more detail.

FIGURE 2.7 • Geospatial least-cost electrification plans for Myanmar and Nigeria by 2030, by technology component

Myanmar | Nigeria (with a focus on 4 states)



Source: Castalia 2014; World Bank 2015.
HV = high voltage; MV = medium voltage.

OPERATIONAL EXPERIENCE AND THE GLOBAL ELECTRIFICATION PLATFORM

Kenya and Rwanda were early adopters in the use of GIS tools for electrification planning. Electrification programs in both countries were informed in 2009 by investment prospectuses relying on the results of geospatial analysis. These early experiences with least-cost electrification planning focused on the least-cost rollout for grid extension without giving explicit insights about the size and space for off-grid solutions. In particular, transitional off-grid solutions (whereby no distinction was made between mini grids and stand-alone solar) were assumed to be inversely proportional in terms of required space and time to progress in grid expansion, while the long-term targets for off-grid electrification were presumed to lie in areas not expected to be connected to the grid even in the long term.

Since then, several countries have undertaken geospatial least-cost planning, with accurately sized components of electrification programs, which helps countries update their existing plans or develop new ones. Initially, the location and sizing of decentralized electrification were based on short-term grid extension. For example, a five-year rollout plan for grid densification and extension (prospectuses typically have a five-year overview) indicates the space for transitional off-grid solutions, whereas a long-term plan for the rollout of connections indicates the space for long-term off-grid solutions.

Gradually, least-cost geospatial plans have achieved further sophistication in geospatial planning by going beyond an on-grid/off-grid distinction and indicating least-cost solutions between mini grids and SHSs. Figure 2.7 shows the least-cost access solutions for Myanmar and four states in Nigeria by 2030, broken down by technology component. Such analyses provide first-order estimates of potential sites for mini grid projects or SHS programs.

Building on this momentum, the World Bank has engaged in national least-cost electrification planning with its Global Electrification Platform (GEP), a multiphase project.[4] It will improve, standardize, and simplify the use of geospatial tools in least-cost electrification planning. To achieve this, it is designed and developed at two levels, briefly described below.

The GEP Explorer

The GEP Explorer (figure 2.8) is an open access, interactive, online platform that provides overviews of electrification investment scenarios for all countries with less than 90 percent electrification, which now includes 58 countries worldwide. The GEP Explorer allows the user, in two steps, to navigate nearly 100 electrification scenarios to meet access goals in those countries. The first step is an outlook for an intermediate investment strategy (up to 2025). The second explores full electrification by 2030. The number, type, and parameters of investment scenarios, along with their inherent assumptions, are presented in the form of six levers designed to reflect different socio-techno-economic assumptions about the country context.

All scenarios indicate the least-cost option, investment, and capacity required to achieve full electrification at

FIGURE 2.8 • The GEP Explorer

Source: https://electrifynow.energydata.info/.

both settlement and national levels. Results include three types of technologies, namely grid extension, mini grids, and stand-alone systems. The user can also apply filters to narrow results as well as toggle on different base layers (for example, distribution network, location of health facilities, MapBox satellite) that can help better assess the modeling results.

The GEP Explorer targets high-level decision makers in addition to policy and investment analysts that can use its output to assess geo-infographic electrification investment for an area of interest. It does provide some flexibility through scenario selection, but all scenarios are pre-run with no option to customize on the fly.

The GEP Toolbox

The backbone of the GEP initiative, the GEP Toolbox, offers a range of tools and material that support reproducibility, replicability of the GEP Explorer, as well as capacity building, dissemination, and inter-organizational collaboration.[5] A few components are described below.

The GEP-OnSSET code. The GEP Explorer displays results developed in conjunction with the Royal Institute of Technology (KTH), building on a special version of the Open Source Spatial Electrification Tool (OnSSET). This is called GEP-OnSSET and is available on GitHub along with online documentation that supports its installation, setup, and use.

The GEP Generator. This open access, user-friendly Jupyter notebook allows a user to reproduce and customize the electrification models behind GEP Explorer. The notebook requires little to no programming experience to operate; it hides coding complexities and presents only key input decision parameters to the user. The GEP Generator allows users to discover the values for the levers outside the prescribed values in the GEP Explorer and to investigate the many variables not exposed as levers.

Other code modules. A number of modules can be used to further customize GEP elements. Examples include the backend code here, the code for estimating custom demand for settlements here, the code for population cluster generation here, the code for GIS data extraction to those clusters here, and the code for a high-level result analysis here. The list is expected to expand as the project evolves.

Training/teaching hub (access here). Online videos, presentations, short lectures, and training material (for example, exercises) support capacity-building activities around the GEP. The GEP team has run four capacity-building events and has established an annual training in Trieste, Italy, every June. Recently, the training material has been bundled into a self-paced, online, open course offered by **Open University**[6] (access here). The course seeks to introduce trainees to geospatial electrification modeling and planning by providing lectures on theoretical concepts and practical exposure through hands-on exercises.

Finally, it is worth mentioning that the GEP is part of a continuous data and model discovery process. To ensure that new data and models can easily be integrated into the GEP ecosystem, guidelines for its form and description, as well as handling protocols, have been developed more here. Based on these, expect annual updates of the GEP to reflect advances in algorithms and models, better data input, and more scenarios defined by increasingly relevant and available levers.

INDICATIVE WORKFLOW FOR THE DEVELOPMENT OF A GIS-BASED NATIONAL ELECTRIFICATION PLAN

As described above, a spatial least-cost electrification scheme could support planning undertaken by various stakeholders; it could help form policy and design around nationwide pathways for electrification. Such modeling activities—and the plans they might inform—should be based on rigorous models and analytics as well as good governance principles. The literature indicates some overarching principles to guide such initiatives—for example, U4RIA (DeCarolis and others 2017; Howells and others 2021).

ESMAP has adopted those principles and, based on its operational experience, converted them into a more practical, five-step workflow presented in figure 2.9. The activities are often linear; however, in reality, the process depends on country-specific conditions, including feedback loops and reiterations. For example, in some cases, capacity building may take priority over analytical work.

Diagnostic and preliminary analysis

The first step in the workflow includes a thorough investigation of data availability and know-how over the area of interest. Any existing and/or past applications of electrification planning techniques should be reviewed. The public or private stakeholders involved in the project should be listed; their capacity in the use of GIS-based analytics to support electrification planning should likewise be assessed. The status of the assessment should be documented in greatest possible detail (for example, data types, quality, metadata, level of knowledge, etc.) as this will determine the level of effort required in the following steps. Therefore, the diagnostic and preliminary analysis should delineate any analytical gaps and guide the project structure. This is usually presented in a short yet concise inception report that guides the project thereafter.

Data collection, mapping, and database preparation

The next step involves the collection, review, and compilation of the best readily available data required for the geospatial analysis. These data may come from national agencies, such as the Census Bureau, public statistics, the survey department, and other departments/ministries; international agencies such as the World Bank, IEA, UN, FAO, IRENA, EU JRC, WRI, and so forth; open access databases such as ENERGYDATA.info, OpenStreetMap, HOTOSM and so forth; and in some cases proprietary sources (for example, satellite imagery, Maxar's building footprint).

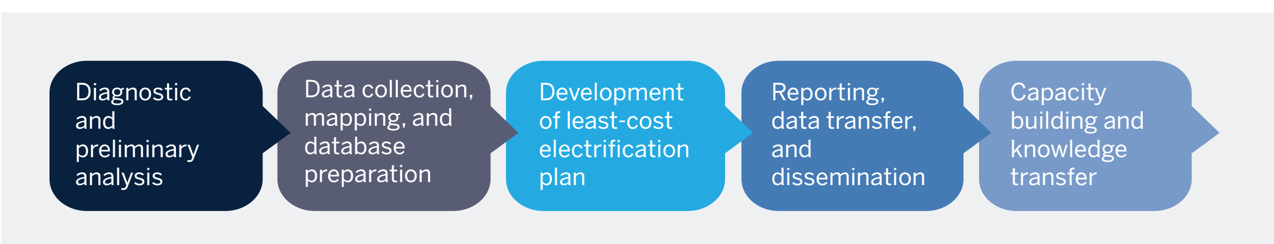
The type of data required depends on the modeling framework, but usually it covers infrastructure (for example, the power network, roads, settlements, public facilities), natural resources (solar irradiation, wind speed, hydro resources, land cover, protected land) and socioeconomic activity (night lights, population, travel time, gross domestic product, electricity demand, affordability). Note that non-GIS data are also collected at this stage in order to support model calibration. These may include population growth, urbanization, and electrification rates; household size; electrification targets; and so on. Finally, planners should collect the technical and costing parameters for the technologies used—namely, medium-voltage (MV) lines, mini grids, and SHSs—as well as cost curves/projections, and discount rates.

Once collected, cleared, and compiled, all data and information should be reported to and shared with stakeholders. Wherever technically feasible with regard to security and privacy, data should be shared on an open-source data repository such as ENERGYDATA.INFO. Any missing data, like the locations of productive activities (potential and existing), energy expenditure, and ability to pay may be collected by site visits, geolocated surveys, or top-down sector-based analysis working through regional government and private organizations and commercial associations.

Development of least-cost electrification plan

Here, the information collected in the previous step(s) informs the analytical work. To bound the least-cost planning exercise, planners must identify the constraining parameters. Then they need to explain how each parameter is defined or measured. Such parameters may include

FIGURE 2.9 • Typical least-cost electrification planning sequence (best practice)



Source: ESMAP analysis.

definitions for (1) starts, plateaus, and endpoints; (2) electricity demand targets and projections; (3) costs and service standards for networks and individual systems; (4) availability of renewable energy resources; (5) ability of consumers to afford upfront investments (such as connection charges) and recurring expenditures (such as monthly tariffs); and (6) criteria for temporal and spatial prioritization. These parameters are just indicative and depend on the scope of the analysis. The combination of those parameters creates scenarios that can be used to assess the sensitivity of results to different input values. Typical sensitivity analyses examine the impact of various electrification targets (following the Multi-Tier Framework) or demand levels (based on demand sensitivity); different commodity prices; economic forecasts; and other variables (such as grid supply cost, technology costs, and service standards).

The analytical work provides a basis for the systematic rollout of a least-cost national electrification program for both urban and rural areas and aims to either maximize coverage for a given investment level or minimize investment for the targeted coverage. The objective function depends on the model used or the scope of the analysis. Key outputs include the following:

- A technology mix (grid connections, mini grids, and stand-alone systems) that fulfils the objective function and is subject to parameters and/or constraints.
- System components' characteristics (for example, size, capacity, investment, service quality, and other operational features) required to implement the least-cost technology mix.

The results of the least-cost model can be overlayed with some of the input data (or other information) and provide a greater level of analysis as per need. The following paragraphs show how this can further support on- and/or off-grid rollout plans in particular.

Detailed analysis of on-grid solutions. Building on the least-cost electrification, planners could articulate the need to expand generation capacity (or electricity trading with neighboring countries) and upgrades to grid infrastructure needed to support the stated targets. Doing so might require access to data, such as installed generation capacity, existing transmission network, geotagged on-grid demand and demand projection, potential generation capacity, reserve constraints and operational constraints, and interconnections with neighboring countries. The sequencing of new connections (and related costing) and extensions, along with other needed changes to the supply system (namely, network reinforcement, increased generation, and transmission), can be elaborated at this stage. A power-flow analysis might also reveal needed grid infrastructure upgrades to support targets and potential integration of variable renewable energy. The output is a prospectus with details on the upgrades necessary to achieve on-grid targets and the associated financing requirements.

Analysis of mini grid and off-grid solutions. Alongside this probe of on-grid solutions, an economic analysis of the potential for mini grid and stand-alone systems (namely, SHS, diesel gensets, and so forth) is recommended as part of least-cost electrification planning. Aimed at securing sector-wide support, the study might look at representative samples of high-potential off-grid sites, using data and comparisons from existing sites. This analysis can help articulate the most important considerations for both private and government stakeholders in pursuing the off-grid sector, such as the potential profitability of different business models and technologies, the tariffs and subsidies required to achieve profitability, and promising sites for public-private partnerships. Prospectuses could be developed using the results of this analysis.

Reporting results, including technical model, data transfer, and dissemination

The national least-cost electrification planning exercise usually produces the following output:

- A well-structured and -informed database that includes input and output data (both GIS and non-GIS)
- An electrification model built and customized for the country (or area of interest)
- Documentation related to the project; this might include an inception report, an intermediate report or a final report that describes the methodological framework, key assumptions, results of the analysis, lessons learned, and recommendations. It may also include any user guide for data processing or model running.

The output must comply with global best practices and ensure the project's long-term sustainability. The U4RIA framework is highly recommended. Its output and processes can be retrieved, repeated, and rebuilt. They can be audited and are interoperable. All stakeholders should be consulted before recommending any institutional and organizational arrangements. This will help to ensure that the GIS database is maintained and regularly updated and that the GIS electrification planning exercise can be replicated. Determining the appropriate institutional and organizational arrangements involves identifying the organization responsible for hosting the national power sector GIS database and the arrangements by which stakeholders will update their database. Furthermore, which organization will house the electrification planning models? Who will be responsible for replicating the geospatial electrification planning exercise in the future? These decisions will need to be made.

Capacity building and knowledge transfer

Finally, all output, as described above, should be transferred both to the government (or its designated counterparts) and to the institution funding the geospatial work. Those who are analyzing the least-cost electrification planning should be asked to:

- Train professional staff throughout the assignment;
- Familiarize them with the capabilities of the models;
- Teach them about the methodology and analysis framework for updating the geospatial high-level analysis in the future; and
- Explain the key variables, such as technology costs, for future sensitivity analysis.

The consultant should list any licenses needed to ensure the functionality of the GIS planning platform and provide estimated costs for acquiring them and also instructional materials for ongoing capacity building and knowledge transfer efforts.

ANALYTICAL INSIGHTS AND GENERIC OBSERVATIONS

Although geospatial electrification plans are country and context specific, some insights with general application can be gleaned from experience. They are presented below.

Estimated (or targeted) electricity demand of beneficiaries shapes the cost-effectiveness of various technologies. Varying demand also affects the type of system recommended by electrification modeling tools: household/customers with strong demand typically favor grid extension if the load centers are close to the grid, and mini grids if they are farther away, whereas low demand favors off-grid/SHSs.

The different balances of initial and recurring technology costs affect how economies of scale are leveraged. To illustrate: grid electrification has relatively high initial costs but lower recurring costs. By way of contrast, SHS has lower initial costs, at least for small, remote communities, as they do not require distribution networks. But its recurring costs are relatively steep because of battery storage needs over the long term. Mini grids typically offer an intermediate option to serve demand levels that are too high for SHS but not great enough (or too remote) to justify connection to the main grid. (See chapter 1 for more on mini grid costs.)

Unlike stand-alone solar systems, mini grids and grid extension both require the installation of an electrical distribution system throughout the village in addition to a minimum density of customers to justify this installation. Table 2.6 shows the maximum distance justifying the customer-connection cost as a function of the level of service that the customer requires. For example, for a mini grid or main grid distribution system to be cost-effective, a group of customers requiring Tier 1 service would have to be densely co-located (within approximately 3.3 meters of one another). By way of contrast, a group of customers requiring Tier 5 service can be about 1.7 kilometers (km) distant from the other group members for a distribution system to make economic sense.

In practice, communities that require only Tier 1 service can almost never justify a distribution system, and communities requiring only Tier 2 service will rarely justify a distribution system unless one or more customers require Tier 4 or 5 service. Distribution systems, whether powered by mini grids or the main grid, are generally justified for areas that require Tier 3 and higher levels of service.

Figure 2.10 presents the indicative results from a simulation run using the Hybrid Optimization Model for Multiple Energy Resources (HOMER) planning tool. It indicates that large loads close to an existing grid are more cost-effectively served by a grid extension. Small loads far from an existing grid are more cost-effectively served by a mini grid. For this exercise, the same level of service was assumed from both approaches, and the same cost for the distribution system and for operation and maintenance.

Both electricity demand and customer density thresholds presented above refer to residential loads. The addition of

Least-cost electrification planning at the national level using geospatial analysis tools typically follows a five-step process: (1) diagnostic and preliminary analysis; (2) data collection, mapping, and preparation of the database; (3) development of least-cost electrification planning, including detailed analyses of main grid, mini grid, and off-grid solutions; (4) reporting results; and (5) capacity building and knowledge transfer.

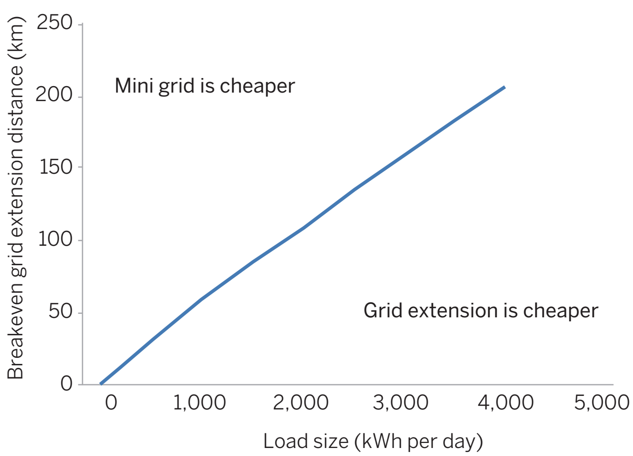
Mini grids are rarely justified from an economic standpoint in areas with demand for electricity that correspond to Tiers 1 and 2. In contrast, distribution systems, whether powered by mini grids or grid extensions, generally make sense from an economic standpoint for Tier 3 and higher levels of electricity demand, all other things being equal.

TABLE 2.6 • Maximum cost-justified distance for connecting a customer as a function of the required level of service

Service tier	1	2	3	4	5
PV size (Wp)	10	100	1,000	3,000	10,000
Energy requirement (kWh/month)	1	10	100	300	1,000
Generation and storage technology	Solar Lantern	Solar home system	PV, battery, inverter	PV, battery, inverter, backup generator	PV, battery, inverter, backup generator
Capital cost	$50	$300	$3,000	$9,000	$25,000
Maximum distance between customers to cost-justify a distribution system (meters)	3.3	20	200	600	1,667

Source: HOMER Energy.
kWh = kilowatt-hour; PV = photovoltaic; Wp = watts peak.

FIGURE 2.10 • Distance as a function of load size: Break-even grid extension



Source: HOMER Energy.
km = kilometer; kWh = kilowatt-hour.

productive activities could change those dynamics. That is, communities where households have low levels of power demand but are close to productive loads might also be good candidates for mini grids or grid extension. Therefore, electrification technologies should be compared not only according to the number of households they serve but also according to the productive uses and community services they enable. Productive uses have only recently been incorporated into geospatial electrification modeling efforts; thus, their impact on national least-cost electrification plans is not yet directly quantifiable.

It should also be noted that estimating the required level of service of unelectrified beneficiaries can be difficult, as demand for energy tends to grow once energy becomes available. But the rate of growth varies and depends on whether and how productive uses are promoted. Outreach efforts that demonstrate productive appliances and commercial opportunities enabled by reliable electricity are therefore crucial in efforts to boost the rate of load growth (IEG 2015). Chapter 3 discusses this topic in further detail.

The quality of services that beneficiaries receive is another useful parameter when comparing the technologies in the least-cost plans.

Stand-alone solar systems tend to have smaller capacity (10–200 watts [W]) and provide on average 1–20 kilowatt-hours (kWh) per month. Within the Multi-Tier Framework for measuring household electricity access, this is Tier 1 or 2 access. Stand-alone systems generally don't use an inverter or a backup generator. This means that they provide direct current (DC) power whose availability on any given day may be determined by the weather. The supply of electricity may be sufficient for households that need only light-emitting diode (LED) lighting and cell phone charging or possibly some other small DC appliance, such as a radio.

By way of contrast, the national grid extension can supply 24-hour power. In practice, however, many of these grids, particularly those in low-income countries, cannot meet this level of reliability, and their customers suffer frequent outages and load shedding. Third-generation mini grids, on the other hand, can provide high-quality electricity service. Members of the Africa Minigrid Developers Association (AMDA) report an average of 97 percent system uptime. Both the main grid and mini grids can also supply sufficient alternating current (AC) power for productive use (for example, grain milling, water pumping, sewing, woodworking), businesses (for example, telecommunications towers; local, small and mid-size enterprises), and public services like schools and hospitals.

Note that the cost of electrification can vary widely depending on local subsidies, but the true unsubsidized cost of power is the appropriate metric for comparing options. As mentioned before, the reliability of grids in many low-income countries can vary significantly. In most places, outages are a common occurrence, and mini grids are often deployed in areas already connected to an unreliable main

> Because of the vast differences in the quality and reliability of the energy service provided by mini grids, solar home systems, and the main grid, it is not appropriate to compare them according to their respective costs for the provision of electricity to the same groups of customers.

grid to ensure reliable electricity service. The mini grids operated by OMC Power in Uttar Pradesh offer one such example. They serve villages where a government-owned distribution utility is already present, but with low service reliability, particularly during peak evening hours.

Amid wild variations in the quality and reliability of the energy service provided by mini grids, SHSs, and the main grid, comparisons based solely on their respective costs for energy provision are inappropriate. Any comparison should—to the extent possible—internalize costs associated with the reliability of supply (for example, value of lost load).

LESSONS LEARNED AND CHALLENGES AHEAD

Drawing on new developments in geospatial analytics, many countries are updating their geospatial least-cost plans, taking stock of the results achieved so far with grid extension, and analyzing the off-grid space to inform their electrification programs. These updated programs can provide more guidance on the design of implementation frameworks and modalities for scaling up off-grid solutions, as they will be more specific about location and sizing of off-grid and mini grid potential in the country; the location and sizing of long-term off-grid beneficiaries; and the preliminary location and sizing of mini grid solutions (to be followed by feasibility studies on the ground), based on population density and loads (including their forecasting), and local renewable generation resources.

Previous national least-cost geospatial planning exercises have taught us the need to engage the private sector during the diagnostic and preliminary analysis phase of a project. As early least-cost planning activities have demonstrated, projections of the costs of mini grid electricity, main grid expansion plans, and demand growth in areas not expected to be connected to the main grid in the near to medium terms have underestimated—by far—the actual potential for mini grids. Engaging with the private sector early in a national least-cost electrification plan can enable the integration of more realistic assumptions about mini grids, SHSs, and the main grid.

Most modeling frameworks available at the moment have evolved to provide an explicit analysis of electricity access by technology, location, and sizing of the different components of electrification programs. In addition, a plethora of spatial data is increasingly available and continues to improve in quality, coverage, and availability.

> Early experiences with least-cost electrification planning have demonstrated the importance of engaging with the private sector during the diagnostic and preliminary analysis phase of a project. This ensures that realistic assumptions about costs and demand growth over time, among other assumptions, are built into the least-cost model's calculations.

Nevertheless, there is always room for improvement. For example, better MV line mapping and improved demand estimation are essential in order to improve the sophistication of planning and tailor services to beneficiaries' needs.

From a planning perspective, knowledge of existing electricity infrastructure is fundamental to ensuring that the results of geospatial modeling tools reflect conditions on the ground. Knowing the reach of electricity infrastructure is critical if developers are to, first, identify who already has a connection and, second, to cost the investment necessary for access provision. This knowledge is based on the location of the beneficiaries and their distance from existing infrastructure. In the absence of this information, planning tools may overestimate the number of beneficiaries. Mapping of MV lines is not yet common in most developing countries. Analysts may infer the extent of the MV network from other parameters, but this approach would result in more errors in determination of electrification status than if reliable maps of MV networks are available.

Demand forecasting is perhaps the single most critical modeling parameter for electrification planning, from geospatial least-cost plans to power sector planning, although the willingness and ability of customers to pay for electricity are also critical from the developer/investor point of view. Improved demand estimates are also crucial to support existing economic centers (and maximize the economic returns of electricity access) through adequate access to electricity services and to forecast locations for productive uses (and future economic growth potential) that may be prioritized by electrification programs.

Finally, the models themselves need to improve constantly in order stay current with new data and policy/planning needs. Better methods could help internalize the costs of reliability (for example, the value of lost load) and other policy mandates (like energy access equity or equality tariff and subsidy schemes). They could also better accom-

Looking ahead, the next critical advances in geospatial planning are improvements to network mapping and demand estimation, which will further increase the accuracy of national least-cost electrification plans.

Geospatial analysis provides a broader picture of communities' locations and characteristics a portfolio can consider, a picture that enables mini grid developers to exploit economies of scale and prepare quicker, more cost-effective rollout plans and plans for service and maintenance.

modate new configurations like hybrid or biomass-based systems and climate aspects (for example, resilience to climate change or disasters).

MINI GRID PORTFOLIO PLANNING

OVERVIEW

Geospatial analysis can also be used as part of a portfolio planning approach for mini grid development, to complement a comprehensive national least-cost electrification planning framework and, in the absence of such a framework, where grid extension is expected to be limited or unlikely because of political considerations, insolvency of the distribution companies, and so forth. If national least-cost electrification planning exercises have carved out areas that mini grids can serve as the least-cost solution, mini grid developers and electrification agencies may wish to focus their time and resources on investigating the potential for developing mini grids to serve communities in these areas.

Developers would do well to remember that political and other considerations may affect the likelihood of grid extension regardless of the underlying economics. The grid may be extended to areas where it might make more sense to pursue decentralized solutions and, inversely, distribution companies may not be in a position to extend the grid to areas even when it may be the least-cost solution. Nevertheless, national least-cost electrification plans can serve as a guide and a starting point when prospecting for suitable sites for mini grid deployment.

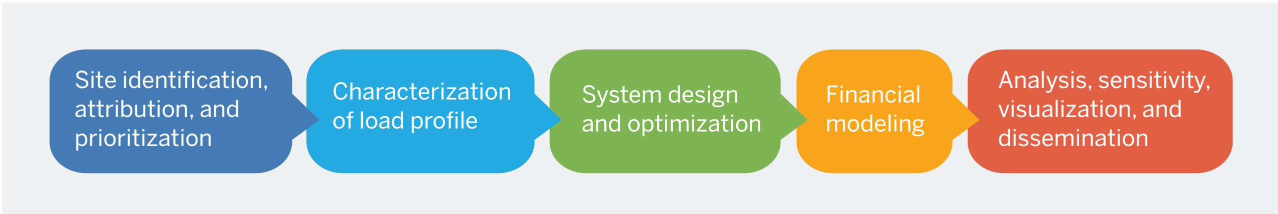
Geospatial portfolio planning, which is already being used by a number of established mini grid companies in Sub-Saharan Africa, greatly reduces the pre-investment cost associated with preparing sites for mini grid development compared with traditional approaches, which rely heavily on the deployment of full multidisciplinary teams to villages to explore the scope for mini grid electrification. Geospatial portfolio planning does not eliminate the need to conduct feasibility studies or engage with beneficiary communities, but it does provide guidance on where communities suitable for mini grid electrification are located and reduces the time and resources spent on prospecting for such communities, and it can mitigate the risk of demand uncertainty by incorporating a larger number of customers in a single investment (the portfolio) as compared with a single mini grid.

Without geospatial tools, developers must often rely on anecdotal suggestions from local governments to identify promising communities to visit and investigate further for consideration. While such human intelligence is still useful and can complement or be used to validate the recommendations from geospatial portfolio planning, a broader picture of the locations and characteristics of communities that can be considered at a portfolio level will enable mini grid developers to exploit economies of scale and prepare quicker, more cost-effective rollout plans and plans for service and maintenance. At a more micro level, geospatial tools can be used for mini grid generation sizing and distribution network planning.

Technological advances and cost reductions in satellite imagery and in machine learning, increased sophistication of algorithms and analytical approaches, and the proliferation of web-based technologies have made available a host of new digital tools to improve the efficiency of mini grid development. This section examines how some of these tools can expedite the process of identifying potential sites for mini grids; collecting, estimating, and analyzing customer data; optimizing mini grid system designs; and finding and selecting developers and investors, using innovations from the frontier as examples. These examples from the frontier include private developers, who are using geospatial and other digital technologies to improve preparation of portfolios of mini grid projects, as well as public-sector programs that are taking advantage of such disruptive technologies to facilitate implementation of mini grid projects.

Figure 2.11 presents an indicating sequence of activities (workflow) involved in geospatial portfolio planning for mini grids. The rest of this chapter describes each of these steps and looks at how disruptive technologies are helping governments and private developers prepare and implement mini grid portfolios. The Access to Distributed Electricity and Lighting in Ethiopia (ADELE) project and the Nigeria

FIGURE 2.11 • Geospatial portfolio planning sequence



Source: ESMAP analysis.

Electrification Project (NEP), a flagship initiative of the federal government of Nigeria, supported by the World Bank, are two especially apt exemplars of geospatial portfolio planning. Lessons from studies of these two projects are used interchangeably, hereafter, to illustrate the implementation of the suggested workflow in the real world.

THE WORKFLOW PHASES FOR MINI GRID PORTFOLIO PLANNING: SPATIAL DATA AND ANALYTICS

PART 1. Site identification

The initial phase of the workflow involves the collection and processing of geospatial (and other) data and information for the identification of sites with potential for mini grid development. The process is split into three main activities: namely, the generation of population clusters and the attribution of those clusters and their prioritization based on a set of criteria. This activity produces a list of possible mini grid sites.

CONVERTING RAW GIS DATA AND SATELLITE IMAGERY INTO POPULATION CLUSTERS

A key input for electrification planning and projects is to understand where people live. The location of settlements and their boundaries is therefore the baseline for any geospatial planning exercise.

In Nigeria, the administrative areas (from higher to lower levels) are federal states, local governmental areas (LGAs), and wards. Population statistics and administrative boundaries are well known at the LGA level, but not at the ward level. But having the exact population figure and boundaries for wards is not sufficient for designating suitable sites for mini grid electrification. That exercise would require having the exact locations of the buildings and settlements. So a cluster identification algorithm was developed for the NEP to automatically identify the location and boundaries of population settlements.[7]

Based on the data sets described in box 2.1, it is possible to identify clusters with great accuracy following the process illustrated in figure 2.12. First, the HRSL buildup raster is vectorized, buffered, and dissolved to define boundaries. The cluster data set improves when it is merged with OSM land-use and mapped-buildings data.

This process identified nearly 200,000 clusters across the country—188,014 clusters, to be precise—occupying from 1.1 hectares to 48,500 hectares. Figure 2.13 visualizes the distribution of these clusters across Nigeria, and represents their distribution by size (in hectares).

More recently, alternative methods have been generating population clusters with vector data (polygons or centroids) that show the distribution of buildings (or rooftops). One example is the building data set developed by NRECA as part of the USAID Distribution Systems Strengthening Project. This visualizes digitized housing structures in Ethiopia based on satellite imagery (NRECA 2019). In addition, the Digitize Africa building footprint data set has been produced for Sub-Saharan Africa by Ecopia.AI and Maxar with funding from the Bill and Melinda Gates Foundation (Ecopia AI and Maxar Technologies 2021) (figure 2.14). The first data set identified about 13.7 million buildings across Ethiopia; the latter identified about 32.8 million rooftops in the country with a high estimated accuracy (>95 percent valid precision and recall).

The new methods grouped rooftops into clusters using density-based clustering (DBSCAN) and three parameters. Rooftops in proximity are called "core," whereas dispersed single rooftops are called "noise" and omitted from the cluster. This identifies more populous areas (clusters) with enough density to justify mini grid development.

The DBSCAN algorithm is based on two parameters. The first is the maximum distance between rooftops (or, eps), and the second is either the density threshold (or, minPts) or the minimum number of neighboring rooftops each building needs to have within the maximum distance in a potential cluster. The process is iterative; the clustering algorithm needs to be run for different parameter combinations in order to identify those yielding the most representative results.

Note that there is a modified version of the DBSCAN algorithm (bounded DBSCAN suggested by Village Data Analytics, VIDA) that includes an optional parameter

BOX 2.1

DATA SOURCES FOR CLUSTER DEFINITION IN THE NIGERIA ELECTRIFICATION PROJECT

A population cluster is an area that could be supplied by a single distribution network. All households that are "relatively" close to one another form one cluster. A cluster, in principle, could be as small as a hamlet, or as large as a city. Key data sets were used for cluster identification:

- OpenStreetMap (OSM) data (contains vector layers with buildings, residential land use, roads, waterways, and so forth)[a]
- A high-resolution settlement layer (HRSL)[b]
- Administrative boundaries[c]

A HRSL population raster estimates population distribution accurately.[d] Spatial processing of the HRSL can thus help roughly delineate where population settlements are located. Combining those estimates with OSM building features presents a clearer picture of the settlement boundaries and building counts within them. Note that some of these data sets are incomplete—for example, in Nigeria, Niger state is mapped more precisely than its neighboring states. So additional sources of data should complement the methodology, when and if they are available.

For example, the WorldPop's peanutButter web application, a more recent development, allows the custom generation of gridded population estimates at 100-meter spatial resolution.[e] The application builds on the high-resolution building footprint data set and complements both population and building counts in the candidate sites.

a. In the case of Nigeria, OSM data sets were retrieved from the open access Geofabric Server, available at https://download.geofabrik.de/africa/nigeria.html. Vector data list coordinates that define points, lines, or polygons.

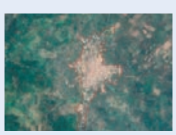
b. The HRSL layer was retrieved from the Facebook Connectivity Lab and Center for International Earth Science Information Network (CIESIN), Columbia University, available at https://www.ciesin.columbia.edu/data/hrsl/.

c. In the case of Nigeria, administrative boundaries have been retrieved from the Database of Global Administrative Areas (GADM), available at https://gadm.org/download_country_v3.html.

d. Raster data consist of pixels (or cells) where each pixel has an associated value.

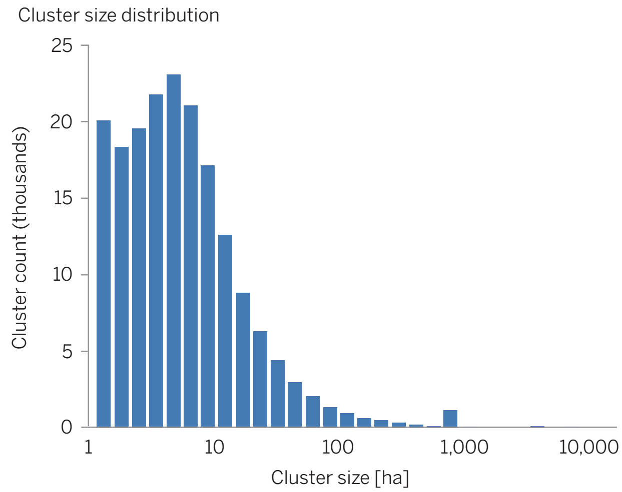
e. The WorldPop's peanutButter web application is available as a beta version at https://apps.worldpop.org/peanutButter/

FIGURE 2.12 • Methodology for the generation of population clusters in Nigeria, using the HRSL and OSM data

Input data		Processing	Result
Built-up raster data Pixels with presence of built-up structures are depicted in light colors		**Vectorizing, buffering, and dissolving** in order to indicate precise settlement boundaries	**Settlement clusters** Outline of settlement structures result from merging the three input data types 
OSM land use Land use types are colored individually (residential in red, industrial in blue)		**Filtering, buffering and dissolve** Extracting residential land use and reducing polygon count	
OSM buildings Open source mapped polygons . . .		**Clipping and clustering** Finding additional buildings not covered in other data sets	

Source: Integration and Reiner Lemoine Institut 2016.
Note: OSM = OpenStreetMap.

FIGURE 2.13 • Nigeria's population clusters: Spatial distribution (left) and size histogram, in hectares (right)

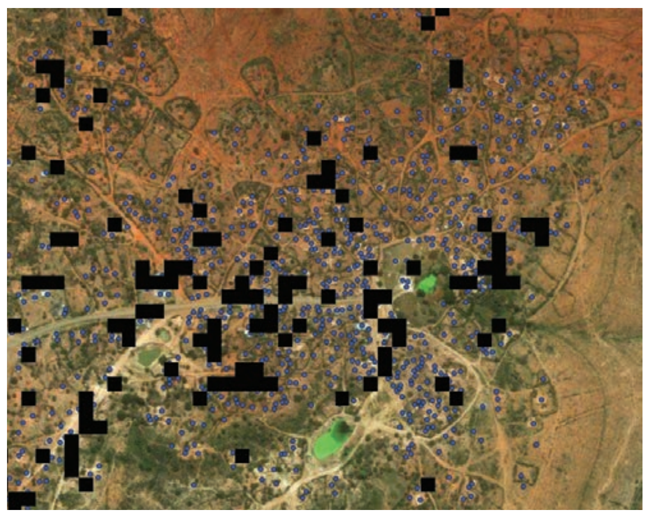


Source: Integration and Reiner Lemoine Institut 2016.
ha = hectare.

FIGURE 2.14 • Sample outputs from the Digitize Africa building footprint data set

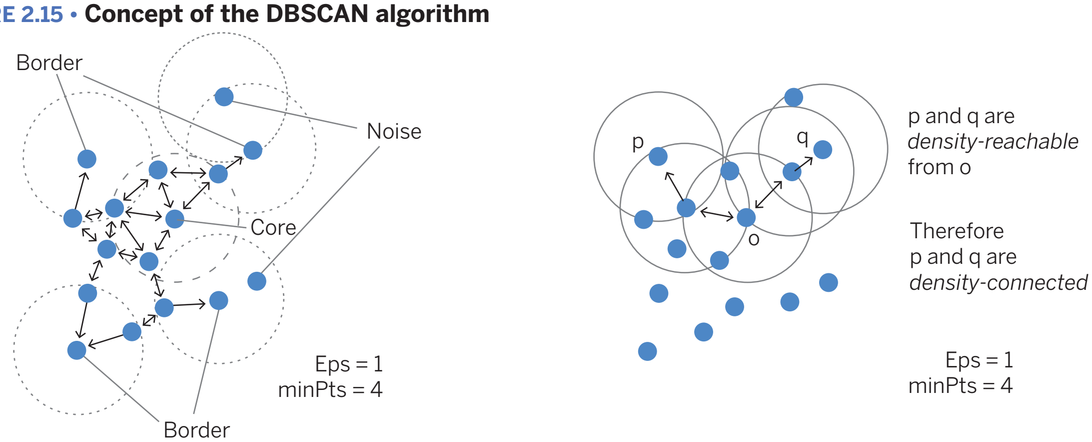
a. Maxar's building footprint (blue polygons) and NRECA's building centroid (red dots)

b. Maxar's building centroids and HRSL's population distribution (raster data set)



Source: VIDA 2021.

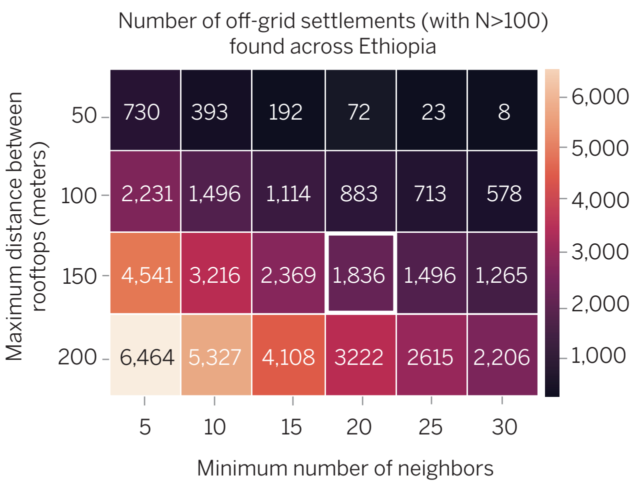
FIGURE 2.15 • Concept of the DBSCAN algorithm



Source: Hahsler, Piekenbrock, and Doran 2019.

(minClusterSize) related to the minimum number of buildings a cluster requires in order to be considered. This parameter filters out settlements below a certain building count and can be used in cases where this is needed (as shown in figure 2.16).

FIGURE 2.16 • Ethiopia's rural population settlements and mini grid deployment: Bounded DBSCAN clustering



Source: VIDA 2021.

Note: The y axis represents the eps parameter, maximum distance between rooftops (in meters); the x axis, the minPts, or minimum number of neighbors. The minimum minClusterSize is set to 100. Highlighted box indicates the reference pair of input parameters as derived from experience (eps: 150, minPts: 20, minClusterSize: 100).

Once the set of parameters are selected and the rooftops grouped into clusters, then the boundaries are drawn to identify the exact contours of the potential village. This is usually done by using an alpha shape generating algorithm, which estimates a village's size, area, and density (by comparison, a simple convex hull-based village boundary always overestimates the village area and underestimates density). Figure 2.17 offers a comparison of convex hull and alpha shapes.

ATTRIBUTING POPULATION CLUSTERS

Once the clusters have been identified, attributes are added. These are used to rank the most suitable locations for mini grid deployment. Common attributes in this ranking exercise are shown below:

- Cluster name (if available, or its ID)
- Cluster size
- Administrative division(s) (municipality, district, region, country)
- Building count
- Population
- Power situation and nighttime light intensity (electrified or not, existing mini grids or SHS)
- Distance to infrastructure (grid network, roads, substation/transformer, etc.)

BOX 2.2

FINDING THE OPTIMAL INPUT PARAMETERS FOR DBSCAN

The modeling exercise in Ethiopia has made it hard to identify a single set of input parameters that generate highly accurate results for the whole country. What works well for one area might be suboptimal in another owing to the differences in geography, topology, population densities, or even building structure and distribution.

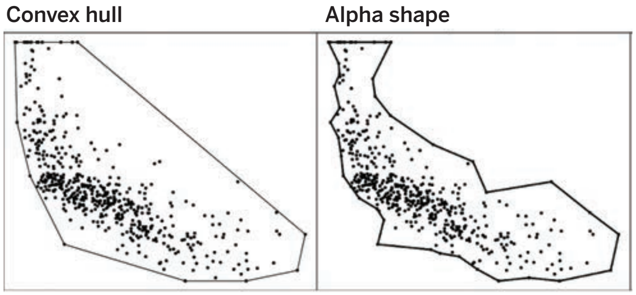
But a purely mathematical method might help identify robust clusters. One can, for example, use a density based cluster validation (DBCV) approach (or similar, for example, SC or AMI) and compare parameter values (Moulavi and others 2014). DBCV yields a validation index ranging between -1 and +1, with higher values indicating better clustering performance. But a mathematically good cluster will not necessarily capture a physical feature such as a village.

Yet another approach might validate results against real settlements via statistical validation. This would require a training data set and machine-learning-based and -supervised validation methods. The latter may contain boundaries and characteristics (such as population and building counts) of actual villages. The comparison could calibrate the input parameters under a framework that reflects the situation on the ground more accurately.

Finally, it should be noted that it is imperative to engage local counterparts in calibration and validation.

a. The implementation code of the density-based cluster validation (DBCV) methodology is available at https://github.com/christopherjenness/DBCV; another implementation is available at HDBSCAN's original GitHub repository at https://github.com/scikit-learn-contrib/hdbscan/blob/master/hdbscan/validity.py.

FIGURE 2.17 • Cluster contour delineation: Convex hull (left) and alpha shapes (right)



Source: VIDA 2021.

- Number of public institutions (for example, health facilities, education institutions, other services, and administrative offices)
- Commercial buildings, stores, and other anchor loads (mobile tower)
- Agriculture (crops, harvested area, production, yield, and so forth)
- Post-harvest activity (milling, drying, cooling, storage, and so forth)
- Resource availability (solar, wind, hydro, biomass etc.)
- Other socioeconomic characteristics (poverty rate, income level, household profile, and assets)

A growing pool of databases has recently been providing access to this information. Some examples worth mentioning:

- The open data platform Energydata.info[8] is a good place to start finding geospatial data for electricity and energy access planning.
- OpenStreetMap (OSM) and Humanitarian OpenStreetMap (HOTOSM)[9] are open-source projects with millions of geospatial features pertinent to population distribution, commercial and public buildings, infrastructure, and resources.
- FAO's GAEZ Data Portal[10] and the International Food Policy Research Institute's MapSPAM & Harvest Choice[11] series provide a suite of data sets related to agricultural activity and productivity (for example, land, water, soil, terrain and agro-climatic resources, protected areas, actual and potential production/yields as well as selected socioeconomic and demographic data).

On top of publicly available resources, one could also consult with local counterparts who might share additional, proprietary information that might be useful later in the ranking process. Often, geospatial data do exist in different governmental agencies, but their permission may be needed in order to use these datasets. Figure 2.19 illustrates a great example from Nigeria, where the Federal Ministry of Power and the Nigerian Energy Support Programme have compiled and collected data from the field on the extent of the medium voltage grid as well as other electricity infrastructure and made this information available on a web-based mapping platform.

Finally, some attributes will need to be calculated based on available data. For example, the area of each cluster can be estimated simply using spatial analysis. Or, as another example, determining the reach and extent of the main grid can help calculate its distance from a cluster. This kind of information is usually available in developed economies, but in developing countries may be hard to find; one may need to estimate or infer it from other data, like nighttime lighting satellite imagery. See Figure 2.18 for an example.

Where possible, knowledge of the grid distribution and grid-connection status of population clusters can be improved by better collaboration with distribution companies or by site visits. In case data on the existing grid network is not available for the country or area of interest, it can be simulated using other available GIS data sets as proxy (for example, night lights, road networks). In fact, gridfinder.org[12] has developed a methodology that predicts the routing of the transmission network using the above data and a minimum spanning tree approach. Results are available globally and the model is open source (Arderne and others 2020).

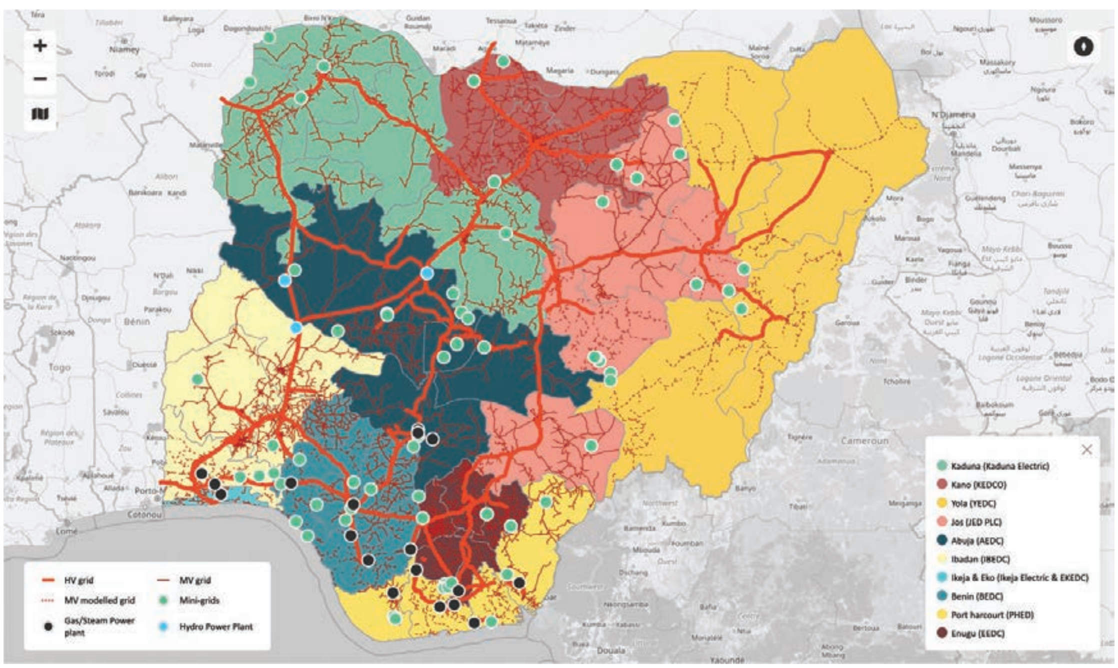
VIDA has further refined the code in the Gridfinder repository. As a result, the predictions have improved, making the code deployable across the globe for any given time period. A sample VIDA GridLight is shown in figure 2.20. The GridLight algorithm has been extensively tested and utilized in several countries. In Nigeria the algorithm was tested against 300 on-ground survey data points with an accuracy level of 82 percent. In Ethiopia, we identified an overlap of 80 percent with the latest utility data.

Apart from a proxy for the existing grid network, nighttime lighting[13] can be used, provisionally, to classify electrified population clusters in areas with high night light emissions. These regularly visible light emissions are usually based on the number of streetlamps or other permanent lights in villages or communities. Highly visible nighttime light activity suggests electricity sources. This logical assumption (of available electricity) should then be validated. In Nigeria, for example, data on education facilities from the Nigeria Millennium Development Goals Information System, which includes information on whether a facility is grid connected, have been used to verify the electrification status of the population cluster where the educational facility is located.

FIGURE 2.18 • Health facilities and education facilities within 500 meters of village boundary

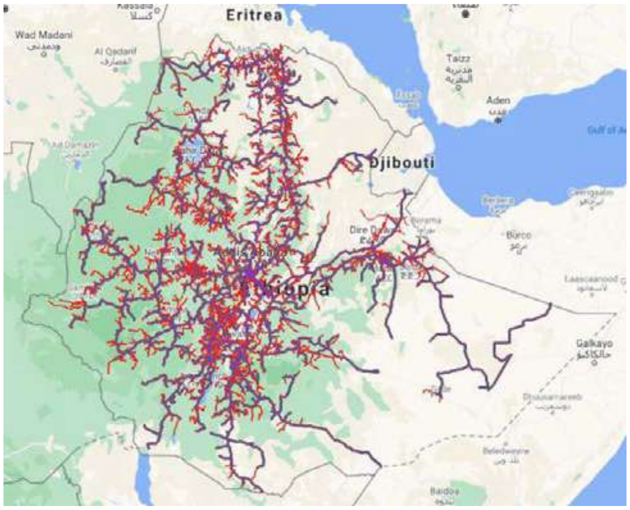
Source: VIDA 2021.

FIGURE 2.19 • Main grid coverage in Nigeria



Source: Screenshot from https://nigeriase4all.gov.ng/map.

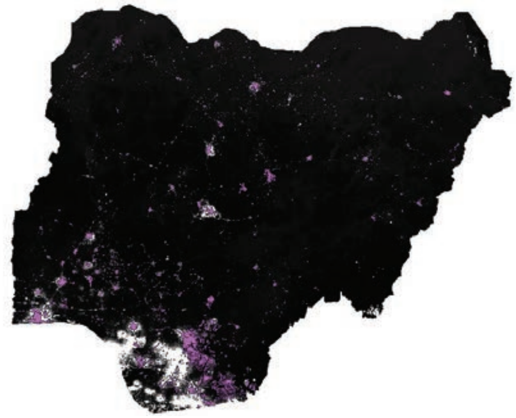
FIGURE 2.20 • VIDA GridLight prediction for Ethiopia (blue) compared to Ethiopian Electric Utility data (red)



Source: VIDA 2021.

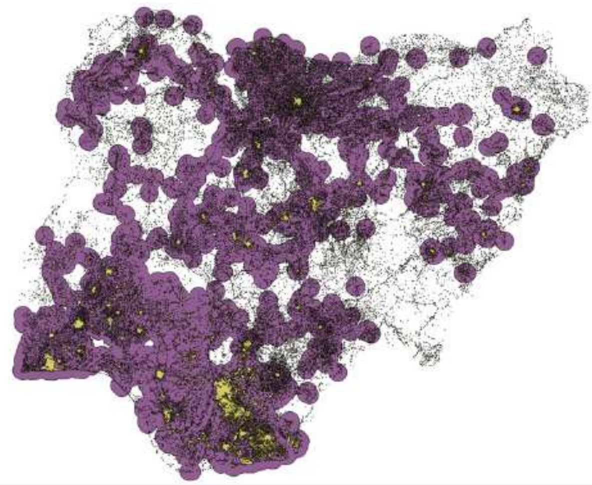
Figure 2.21 presents an example of the application of night lights' data, validated using data from other sources, to predict the electrification status of population clusters. Electrified clusters can then be interconnected with an automatic grid-extension algorithm, which takes several factors into account—including topography, roads, and water bodies—to derive the most realistic grid connections. The information on population or population density and electrification status and distance from the grid may be supplemented with additional socioeconomic data to allow for more criteria when prioritizing the population clusters for mini grid electrification.

FIGURE 2.21 • Nighttime lighting in Nigeria



Source: Integration and Reiner Lemoine Institut 2016.
Note: Nighttime lighting shown in white. Electrified consumer clusters appear in purple.

FIGURE 2.22 • Nigerian night lights and 20 km buffer zones



Source: Integration and Reiner Lemoine Institut 2016.
Note: Purple areas show 20 km buffer zones. Night lights are shown in yellow with population clusters in black.

LONG AND SHORT LISTS OF POTENTIAL MINI GRID SITES

After the identified clusters are attributed, they can be prioritized according to certain criteria to generate long lists and short lists stating the project's requirements and needs. The scope of this step is to eliminate clusters that don't meet certain criteria. Elimination saves computational time and effort in the workflow steps that follow. Below are some examples.

Once the locations of electrified clusters are known, a buffer zone can be applied around the clusters assumed to be electrified via grid connection. This represents a methodological shortcut to a least-cost electrification modeling approach: clusters within the buffer zone are considered likely to be subject to grid extension and therefore unlikely to attract investment from private mini grid developers. Meanwhile, clusters outside the buffer zone are unlikely to be served by the grid within the time horizon considered and may thus be good candidates for mini grid electrification. The decision on the size of a suitable buffer zone depends on the local context. In an analysis by the Nigerian Energy Support Programme, for example, a 20 km radius around electrified clusters was taken to be suitable for electrification via grid connection in the base scenario. Meanwhile, a 10 km buffer zone was thought appropriate in a low-grid electrification scenario (Integration and Reiner Lemoine Institut 2016). Figure 2.22 illustrates the 20 km buffer zones around electrified areas (based on night lights), where grid extension would likely be the preferred option.

Another approach would be to take the known grid coverage map, such as that in figure 2.22, and apply buffer zones directly around the network. This was done for the NEP, and given the poor financial health of the distribution companies in Nigeria, a more aggressive scenario for mini grids—where grid extensions are stalled—was considered, and the buffer zone was reduced to 5 km. Clusters outside these buffer zones were considered suitable for decentralized electrification, but further screening based on population was conducted. The economic viability of mini grids was deemed unlikely for population clusters of less than 1,000, which would be more effectively served via SHS.

After sites within a specified distance from the grid (5 km for Nigeria) and with a population below a certain threshold (1,000 people) are excluded from consideration, the remaining clusters can be ranked based on scored criteria. Recall the additional data collected on the clusters (presence and location of schools, clinics, and telecommunications towers). These can now be used to prioritize the clusters for mini grid electrification.

The prioritization categories for the NEP were population, density, distance to grid, and presence of telecommunications towers, schools, and health facilities. Normalized values for the prioritization categories were created and summed up with weighting factors, and the clusters were then evaluated according to the prioritization criteria and ranked by state. Figure 2.23 exhibits the top 100 clusters projected to be suitable for mini grid electrification for each federal state.

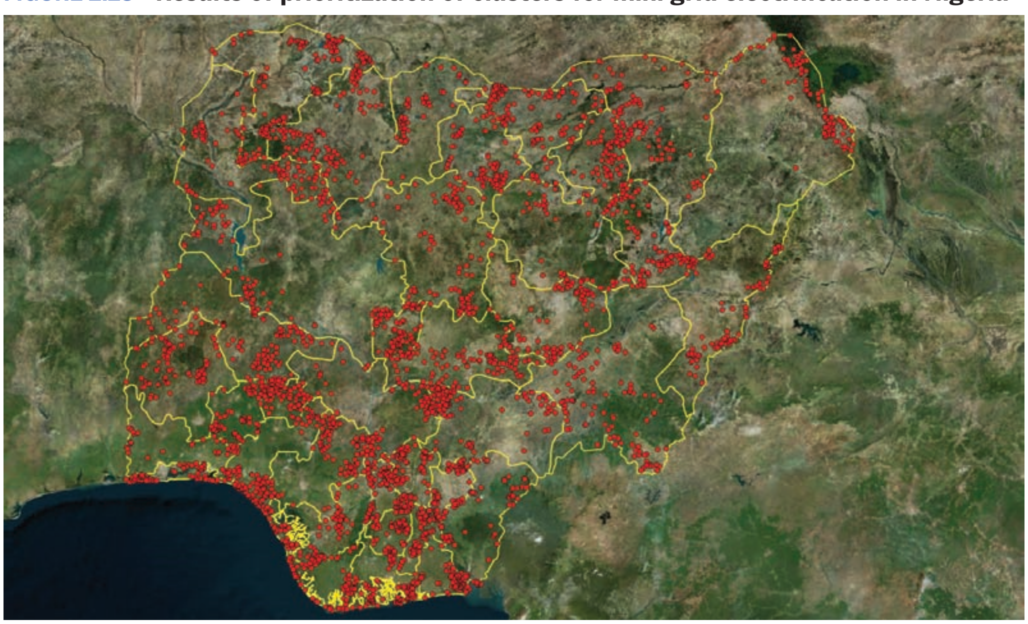
Environmental issues might also impose additional constraints in the prioritization process. For example, potential complications to implementing mini grid projects in environmentally sensitive areas, and the time and cost of obtaining necessary environmental permits and approvals, can be avoided by determining as early as possible whether a population cluster being considered lies in such an area, so that an informed decision can be made on whether to pursue a mini grid project at that site.

Key biodiversity areas (KBAs) are designated by the KBA Partnership,[14] a consortium of wildlife conservation groups including the World Wildlife Fund, while the International Union for Conservation of Nature (IUCN) maintains a comprehensive database of legally protected areas around the world. Protected areas are classified into different categories, such as IUCN I-VI, Ramsar, and World Heritage sites, which are all legally protected areas, while KBAs are not necessarily legally protected (though some protected areas coincide with KBAs).

The boundaries of population clusters can be compared with those of legally protected areas such as forest reserves and national parks, as well as KBAs, using the Integrated Biodiversity Assessment Tool.[15] This online geospatial tool hosts and maintains the three key global biodiversity data sets: the IUCN Red List of Threatened Species, the World Database on Protected Areas, and the World Database of Key Biodiversity Areas.

The NEP decided to avoid the additional scrutiny and compliance costs that come with implementing mini grid proj-

FIGURE 2.23 • Results of prioritization of clusters for mini grid electrification in Nigeria



Source: Integration and Reiner Lemoine Institut 2016.

ects in protected areas and KBAs (if they are permitted at all); therefore, any population clusters that intersected with them were excluded from further consideration. Figure 2.24 shows an instance of population clusters within protected areas or KBAs being flagged for exclusion.

FIELD VERIFICATION

While the site identification and screening methodology described in this section uses available geospatial data to propose communities where mini grid electrification may be suitable, in the absence of reliable data on the reach of the main grid, it does so partly by making assumptions about the electrification status of the population clusters. Before deploying multidisciplinary survey teams to collect data on these communities, wasting resources on false positives (communities thought to be off grid that are actually on grid) may be avoided with validation exercises. Such exercises include calling someone in the community, if possible, to verify whether the community is served by the grid, and deploying agents (for example, on motorbikes where this is a swift and safe option) to quickly check on the electrification status of all the population clusters shortlisted for potential mini grid projects.

> The site-screening phase of a geospatial plan for portfolio development includes identifying, characterizing, and ranking population clusters, as well as undertaking environmental screening and field verification. Throughout this phase, the criteria used for all these tasks need to be carefully considered.

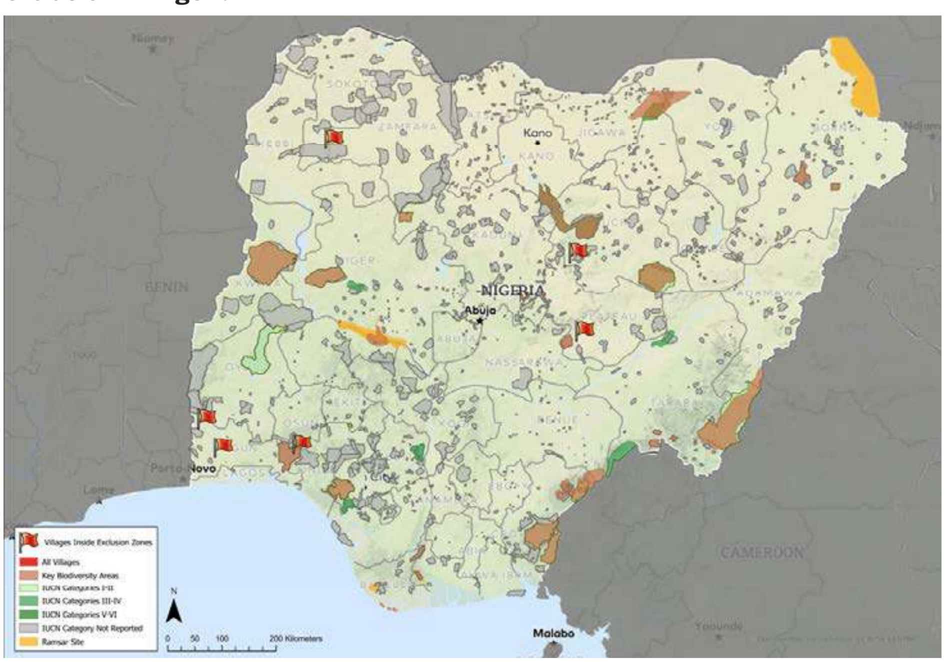
Part 2. Load profile characterization

The first part of the analysis identified, attributed, and validated—to the extent possible—the candidate sites for mini grid deployment. The following step focuses on estimating the load profile for each candidate site. Estimating the load profile is usually subject to requirements, as listed below and illustrated in figure 2.25:

- Identify the composition of potential customers
- Estimate the daily consumption of each customer segment
- Estimate the load profile in the cluster
- Incorporate seasonality of demand over the year
- Estimate growth rate (forecasting)

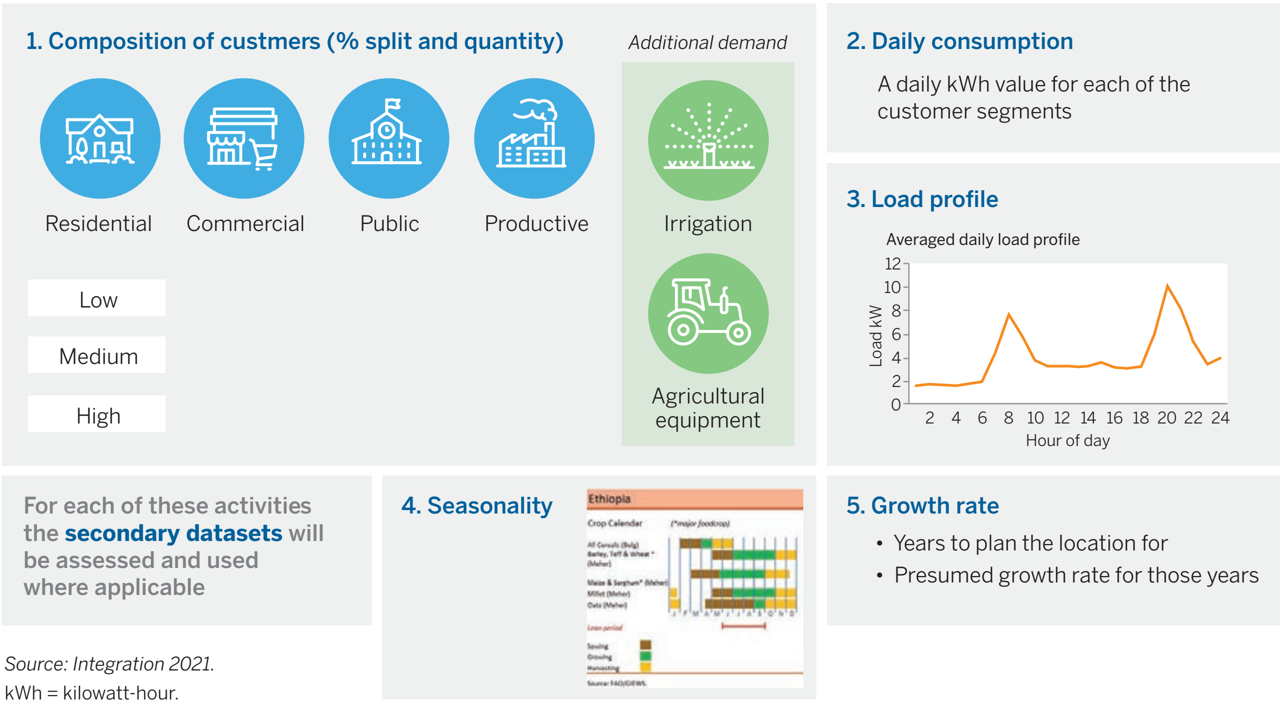
There are two paths. The first is to utilize all collected data and information, measure them against past experience, and estimate the load (or simulate it with machine learning). The second is to survey all the candidate sites—if they've been shortlisted—or, failing that, conduct a ground survey of sample sites on the load in those locations. The selection depends on the scope of the project as well as the available resources.

FIGURE 2.24 • Population clusters falling in protected areas or KBAs flagged for exclusion in Nigeria



Source: Screenshot from https://worldbank.africageoportal.com/.
IUCN = International Union for Conservation of Nature.

FIGURE 2.25 • Requirements for estimating load profile



Source: Integration 2021.
kWh = kilowatt-hour.

ROUGH ASSESSMENT BASED ON COLLECTED GIS DATA (EASILY SCALABLE)

The rough assessment is based on general assumptions. Some of them have been used (for example, in the case of Ethiopia) to provide a quick, high-level estimate of the total demand in the candidate sites. These assumptions are listed below:

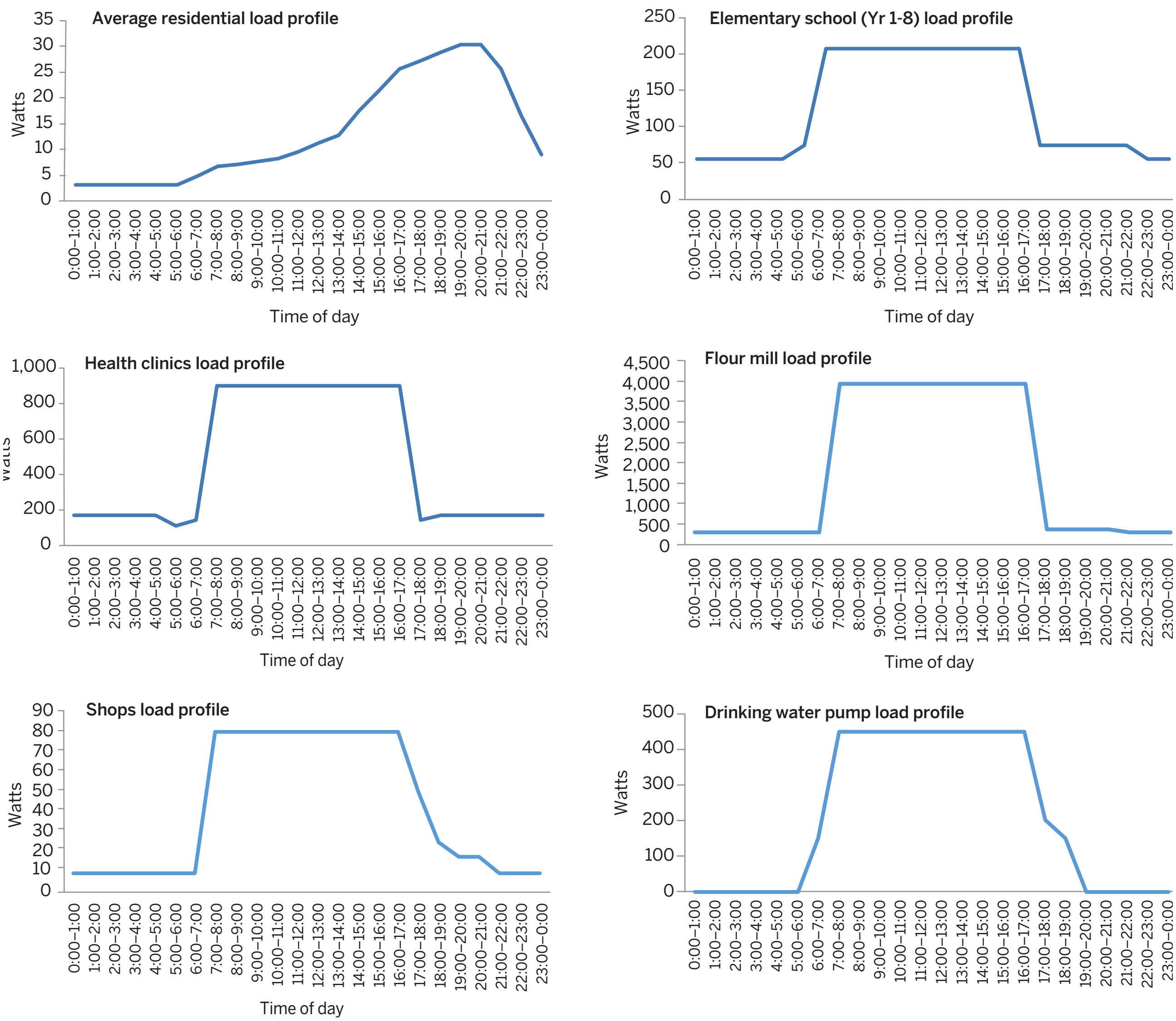
- Percentage of households connected to the mini grid (58 percent)
- Residential vs commercial customers
  - residential = (small rooftops and 50 percent medium-sized rooftops) x 0.58 (connection rate)
  - commercial = (large rooftops and 50 percent medium-sized houses) x 0.58 (connection rate)
- Residential customer demand, estimated at ~0.22–0.32 kWh/day
- Commercial customer demand, estimated at ~1.1 kWh/day
- Public institution demand (if existing) estimated at:
  - 2.97 kWh/day for primary schools
  - 11.23 kWh/day for health clinics
- Flour mill (if existing) demand estimated at about 43.77 kWh/day
- Water pump (if existing) demand estimated at 5,000 kWh/day
- Telecommunications tower (if existing) demand estimated at 84 kWh/day

MORE ACCURATE ASSESSMENT FOCUSED ON A FEW PILOT SITES (SURVEY DATA COLLECTION, MANUAL INTERVENTION)

In the second approach—and for the shortlisted sites—it is recommended that survey teams be deployed to collect data. Sending these teams only to those communities likely to host a viable mini grid project will save time and resources, and sending teams after the building mapping is completed will enable them to conduct their surveys more efficiently.

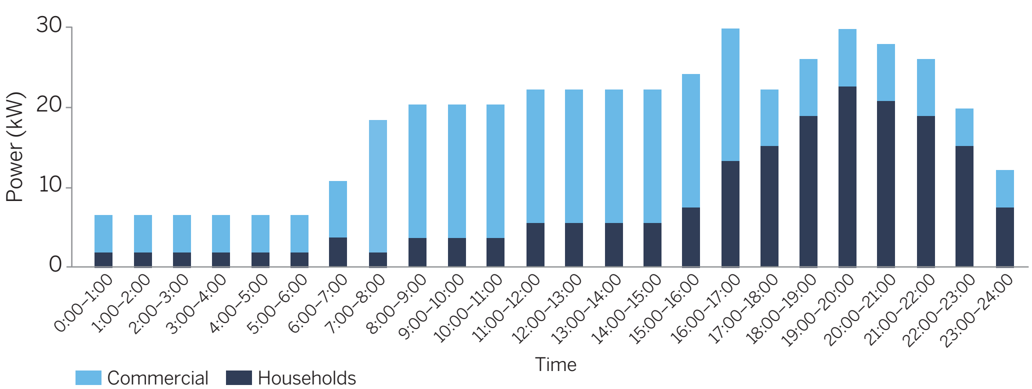
Under the NEP in Nigeria, survey teams were deployed to collect data on the community, households, public institutions, and commercial and productive users of energy in the prioritized unelectrified communities. Each survey covered community, commercial, household, and environmental-social data. The survey teams geotagged and surveyed nonresidential structures in each community to identify the key loads (large, daytime, productive and commercial) that might be critical to mini grid viability. They recorded the count and wattage of large appliances, light bulbs, and fans for each geotagged building. They also geotagged a subset of households, categorizing each as large, medium, or small.

FIGURE 2.26 • Indicative load profiles for various customer segments in potential mini grid locations



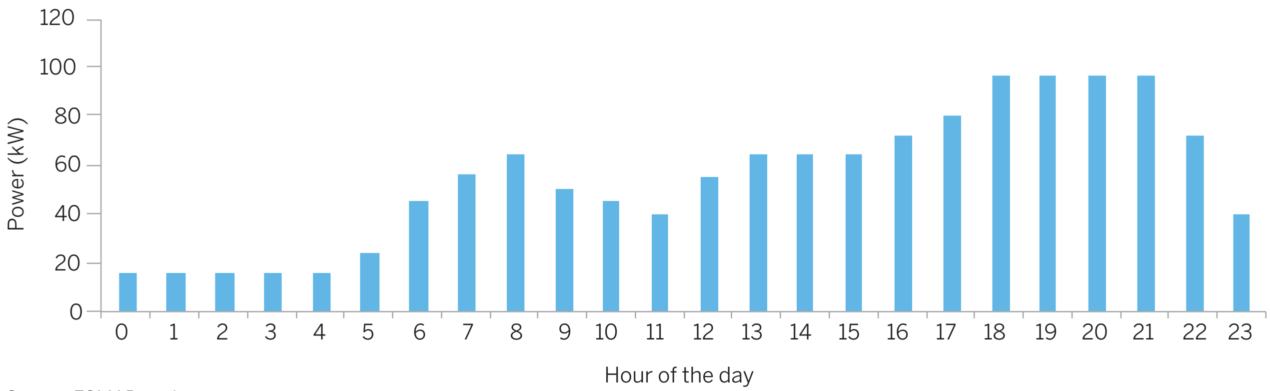
Source: VIA 2021.

FIGURE 2.27 • Demand curve for a randomly selected candidate site in Ethiopia



Source: VIDA 2021.

FIGURE 2.28 • Sample load profile for a village



Source: ESMAP analysis.
kW = kilowatt.

The surveys capture crucial information on electricity consumption, including:

- Community willingness and ability to pay
- Current expenditure on electricity generation using petrol or diesel generators
- Expenditures on candles, kerosene, and dry cell batteries
- Other data pertinent to demand estimates

We recommend that, with smartphones and tablets so ubiquitous, personal interviews be conducted with computer assistance. This practice ensures that data are collected with optimal efficiency and quality, minimizing the time and effort spent on data cleaning.

Survey data, along with data from the literature, should inform the development of load profiles for different customer segments. The load profile is a view of estimated electrical demand at a given hour or day. This information will be vital to designing the mini grid. Figure 2.28 presents a sample load profile.

Load profiles for the NEP were developed by aggregating the expected demand from households, commercial and productive loads, and public infrastructure, as described below.

Residential sector loads. Residential load profiles were developed with Rural Electrification Agency (REA) classifications for small, medium, and large households. These were also based on assumptions about the number of appliances per household type and the use profiles for each appliance (total watts and utilization factors for each hour of the day, considering seasonal variations).

Commercial and other productive loads. In the geotag survey, surveyors assigned commercial and productive loads to 13 different business categories. Then they recorded the count and wattage of the high-load equipment associated with each commercial and productive end user, recording the wattage and count of lightbulbs and fans at each location. The data were cleaned to adjust for outliers and to remedy survey errors. Equipment-use profiles emerged from applying utilization factors to each hour of the day (varying by "high" and "low" months), and each piece of large equipment was assigned a unique use profile by state and community size (small communities and large communities use commercial/productive equipment differently), and customer-type load profiles were generated by combining the equipment profiles with the survey data. It was assumed that all existing commercial lights would be replaced by 18W LED bulbs and residential lights by 6 W. All geotagged commercial and productive loads were included in each site's load profile.

> During the survey collection and load modeling phase, survey teams should be sent only to those sites that have been prioritized as having great potential for a viable mini grid, because of the costs of conducting on-site surveys. Survey teams typically collect data that can inform the estimation of potential demand from households, commercial and productive loads, and public and community institutions such as churches and hospitals.

Public sector loads. The locations of public institutions such as schools, health facilities, and religious centers in each community were determined from a geospatial database of such points of interest[16] and the REA geotag survey. Generic load profiles were written up for each type of public institution, based on consultations with a developer experienced with sizing and installing photovoltaic systems for public institutions,[17] and applied to the public loads at each site.

Part 3. System design and optimization

Once the power load is estimated, then follows the system design and/or optimization. There are multiple options for system optimization. Based on the load profiles developed for each community, modeling tools, each running on unique algorithms, calculate optimal solutions—least-cost mini grid system designs that meet predefined parameters—for each community.

For example, for mini grids to be included in the tender for the Nigerian NEP, a renewable fraction threshold of 60 percent was prescribed (that is, the mini grid design would need to produce at least 60 percent of its annual energy output from renewable sources). The NEP also has minimum technical requirements specific to several distinct system architectures. Depending on the system architecture selected for a particular community, the mini grid would need to meet the minimum technical requirements for that particular system architecture. These technical requirements cover both quality and sizing of components as well as quality of service, such as the number of hours the mini grid can be offline for scheduled or unscheduled maintenance. These design constraints are incorporated into the optimization exercise.

OPTIMIZATION MODELS

For the NEP in Nigeria, three optimization models (HOMER, REM, and REopt) were used to propose optimal mini grid designs for each community, given the load profile of that community and some design constraints, such as those described above. Each model takes a different approach to mini grid optimization. All three models provide generation system sizing, but REM also generates a customized distribution design for each mini grid. Each of these three optimization models is briefly described below. Additional details are available at the companion website to this book: www.esmap.org/mini_grids_for_half_a_billion_people.

Hybrid Optimization Model for Multiple Energy Resources (HOMER). Originally developed at the U.S. National Renewable Energy Laboratory (NREL), and enhanced and distributed by HOMER® Energy, HOMER software nests three powerful tools—simulation, optimization, and sensitivity analysis—in one software product, so that engineering and economics work side by side.[18] HOMER is the industry standard for optimizing mini grid design in all sectors, from village power and island utilities to grid-connected campuses and military bases.

The Reference Electrification Model (REM). Developed by the MIT-Comillas Universal Energy Access Laboratory, REM is a computational modeling tool designed to help plan detailed medium- and low-voltage distribution networks, with an implementation focus on developing countries.[19] REM uses cost minimization as the objective function to design the generation as well as network assets for rural electrification. REM can help project developers and investors with initial technical design and cost estimations, including both capital and operational expenditures. The modeling tool seeks to aid developers in making viable decisions regarding mini grid design by providing the analytics needed to conduct technical and financial evaluations. REM offers a single package capable of computing generation investment, operational performance, and detailed design of the network starting from the building level.

Renewable Energy Integration and Optimization (REopt). NREL has developed a tool called REopt™, which it uses to provide decision support, analyzing and optimizing mini grid designs for different systems.[20] REopt is a critical tool for understanding the technoeconomic trade-offs in the mini grid sector, which can lead to more sustainable business models and promote universal energy access. Formulated as a mixed-integer linear program, it solves a deterministic optimization problem to establish the optimal selection, sizing, and dispatch strategy of technologies chosen from a candidate pool, such that electrical, thermal, and or water loads are met at every step in the minimum life-cycle cost. REopt is a time series model that looks at a full-year energy balance to determine multiyear cash flows by applying appropriate discount and cost-escalation rates. As opposed to algorithmic dispatch strategies, REopt finds the global optimum by anticipating load and resource changes over the full analysis period. In the mini grid context, this allows REopt to dispatch batteries to maximize renewable energy utilization and minimize generator run time, maximizing economic efficiency.

OTHER APPROACHES

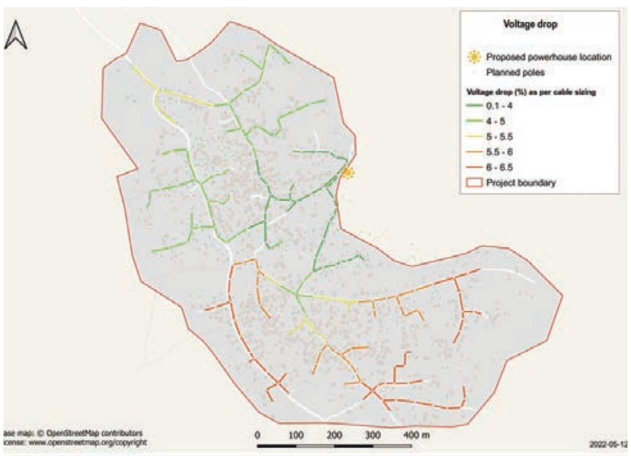
Other approaches, such as those described below, can also be implemented in the manner just presented.

Village Infrastructure Angels (VIA) employs another methodology to propose least-cost distribution network designs for mini grids, which excludes households that might be better candidates for SHSs. VIA has designed electrical power distribution networks for mini grids in the Philippines and Haiti (Craine, S) using a minimum spanning tree algorithm, which solves for the shortest network of lines to connect a given set of points. VIA conducts load-flow analyses, assuming an average load per building and a maximum 10 percent voltage drop between the power source and the end user, to determine what size wire (conductor) is necessary to distribute power to households, the distribution losses involved, and the cost. A Critical Distance analysis, based on the prevailing cost of SHSs, suggests the length of the mini grid or grid extension line that is viable before a SHS makes much more sense. This guides which lines of the distribution network should be kept or discarded in favor of SHSs. For the mini grids that remain, VIA lists wire sizes, poles, and any transformers (if required) and publishes them on a GIS platform. This gives aspiring developers, perhaps considering a project at the site, a useful bill of materials.

Integration combines manual designs and HOMER optimization. Based upon the analysis of building footprints and satellite imagery, a grid design is created remotely, and potential locations for the power asset suggested. The grid design can be made to assume that all or a portion of the buildings are connected within a certain distance from the central village cluster. From this data, a voltage drop model is generated to approximate the cable sizes required (figure 2.29). Specific load centers or anchor loads receive special consideration because they require higher peak power than a standard user. The power asset systems will then be sized according to HOMER demand analysis. The scope of the study employs a standardized simulation to scale up the modeling to more sites.

Village Data Analytics (VIDA) conducts a hyperlocal density analysis to identify village cores, outskirts, and outlying areas. Within the core area, VIDA's algorithm identifies high-value mini grid customers. using building category, the location of buildings with respect to roads, and the density of the built-up area (figure 2.30a). Special importance is given to anchor/institutional loads. Once demand is identified for the different customer segments, an algorithm then generates a distribution layout that connects the high-value mini grid customers. First, a minimum spanning tree is generated to get an upper limit for the connection density. Next, the trunk lines are generated (figure 2.30b). These are either single or three-phase and typically follow the main roads through the village. The poles are located

FIGURE 2.29 • Output of the voltage drop model

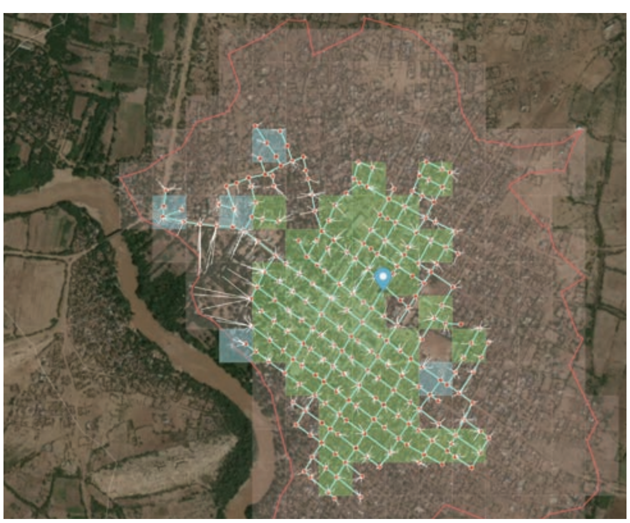


Source: Integration 2021.

There are multiple options for optimizing mini grid system design at each site. Based on the load profiles developed for each community, modeling tools, each running on unique algorithms, calculate the least-cost mini grid system designs that meet predefined community parameters. The most common system optimization tools are those from HOMER, MIT's REM, and NREL's REopt.

FIGURE 2.30 • Sample outputs of hyperlocal density analysis from Village Data Analytics

a. High-value mini grid customers (colored buildings)



b. Mini grid distribution layout with trunk line, poles, and dropdown lines connecting high-value mini grid customers

Source: VIDA 2021.

at equal distances and then dropdown lines are generated so they connect every high-value mini grid customer to the nearest poles. The bill of materials for distribution is then estimated, which leads to estimations of distribution cost, including the length of the predicted trunk line, the number of poles, and the length of the dropdown lines. The algorithm uses average cost per meter of wiring (of different sizes) and the average cost of poles to generate this information on a village-by-village basis.

Part 4. Sensitivity analysis and financial modeling

More scenarios are generated during the final part of the workflow, and these assess how sensitive the optimal solution is to input parameters and financial assessments. They might also assess sensitivity to demand levels, quality of service, level of renewable generation, to name a few. The sensitivity analysis goes hand in hand with the financial modeling, which can be developed for site-specific characteristics allowing for outputs of tariff, capital expenditure (CAPEX), viability-gap analysis, and other relevant outputs in view of project needs (figure 2.31). Besides the usual financial model parameters, some context-specific aspects include:

- *Scenarios with and without PUE.* The definition of project CAPEX could omit investments in productive activities and run the model under both scenarios. Such an analysis could, for example, identify viable sites (1) without depending on productive loads, (2) only if a minimum basic productive load is ensured, (3) only if extensive investment is undertaken to promote large-scale productive loads.
- *Tariff-based calculations.* In this mode the financial model can use predetermined CAPEX structure (equity, debt, and grant) and operating expenditure as inputs to drive the tariff needed to meet the required financial returns. Furthermore, time-of-use tariffs and tariffs based on customer type can also be modeled. This would provide a first indication of sites where affordable tariffs can be expected.
- *Viability-gap calculations.* Here, reverse logic can be applied whereby an agreed tariff is used as input to determine the viability gap of the projects and grant share needed in CAPEX to reach the required financial returns. This differentiates sites according to grant levels needed for sustainable mini grid operation.

Part 5. Result visualization and dissemination via an online platform

Geospatially planned portfolios of mini grids contain a wealth of information for developers. When produced as part of a mini grid program in partnership with a government or a developer, these portfolios should be shared with mini grid developers, presenting relevant information in an accurate and transparent way.

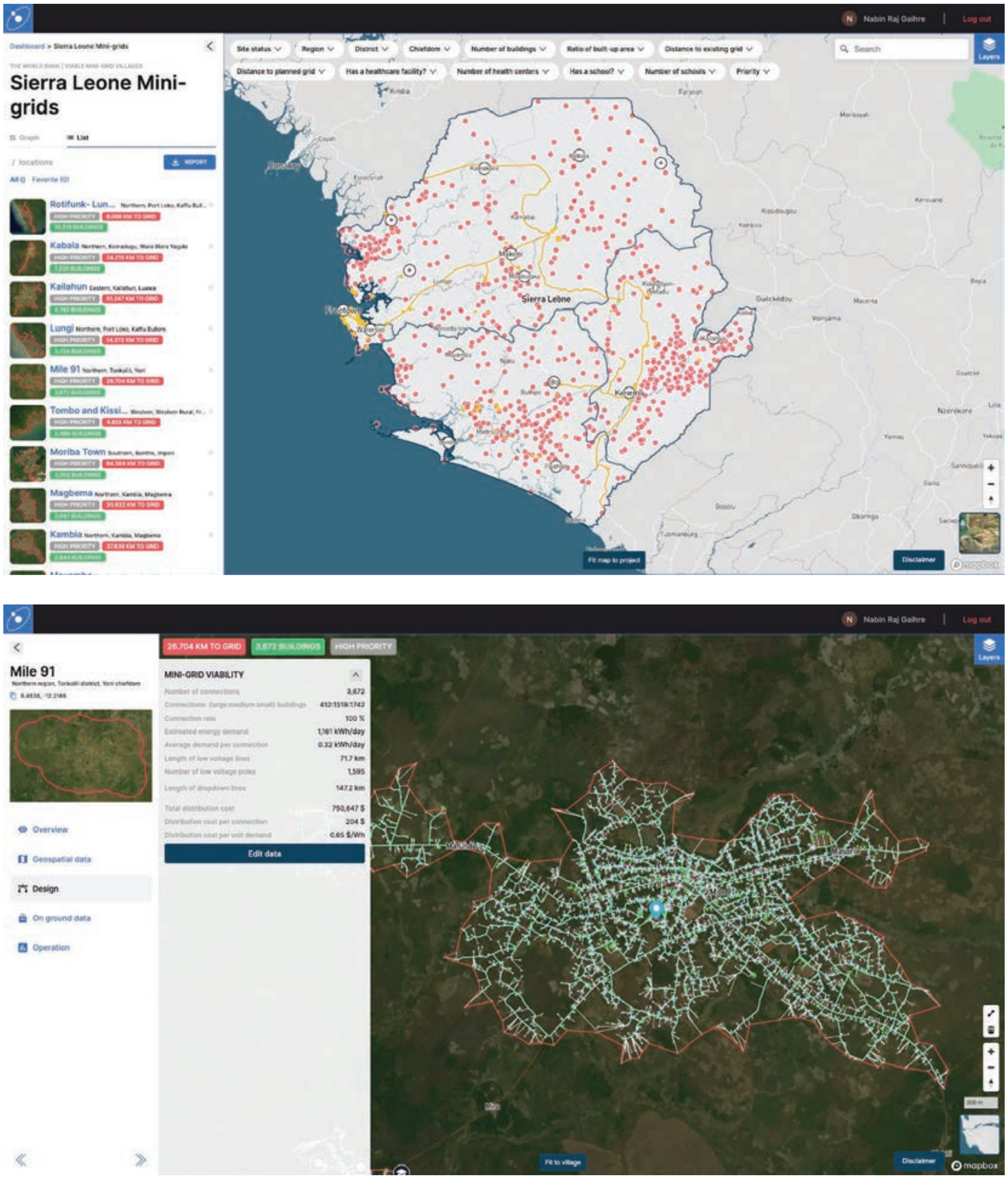
One example is the VIDA software, a tool for site identification, selection, prioritization, visualization, and collaboration (figure 2.32). The software visualizes the mini grid portfolio analysis on an interactive platform that offers both a high-level overview of the modeling exercise (national and regional levels) but also granular descriptions of all candidate sites. VIDA provides access to mini grid viability indicators and distribution layout characteristics. Users can download results, upload data, share information, and collaborate on the software platform.

Another example of such a dissemination tool is Odyssey Energy Solutions, which provides a web-based data platform that facilitates deployment of mini grids in emerging markets for developers, financiers, vendors, and governments and donors. It developed a customized version of its online platform for Nigeria's REA to manage data analysis and the bidding process for the sites included in the mini grid tender of the NEP.

FIGURE 2.31 • Indicative flow of financial modeling process of mini grids

Source: Integration 2021.

FIGURE 2.32 • VIDA interactive platform



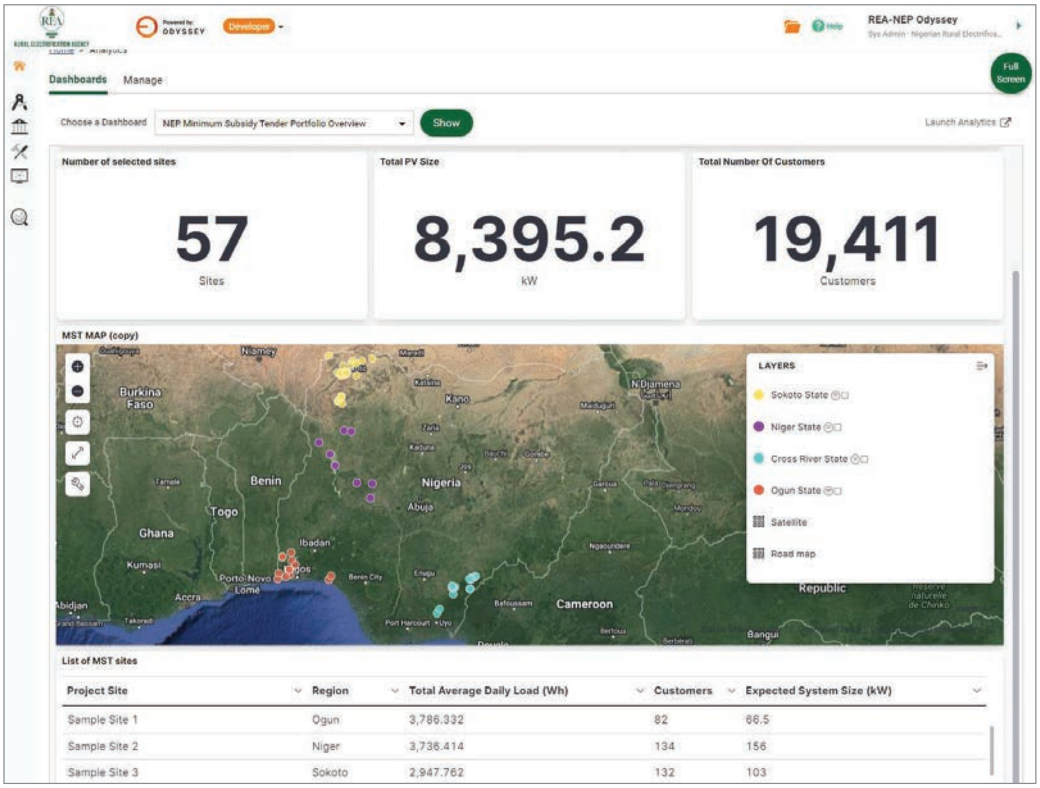
Source: VIDA 2021.

The user interface organizes data into modules that contain the technical and financial dimensions of each mini grid site: location, load forecast, generation system and distribution design, costing, tariffs, and financial model. The online platform has detailed, site-specific information on the customers and loads as well as suggested system sizing.

Once officially registered, program bidders gain access to information posted at the tender sites, where they can register to participate in the tender. Registered bidders may access key program information within the

Geospatially planned mini grid portfolios offer a wealth of information for developers. When produced as part of a government or development partner mini grid program, this information should present the relevant information to developers in an accurate and transparent fashion. The Village Data Analytics platform and Odyssey both offer excellent ways to visualize and disseminate the modeled results.

FIGURE 2.33 • Mini grid tender preparation in Odyssey



Source: Screenshot of Nigeria Electrification Project portal on https://www.odysseyenergysolutions.com/.
NEP = Nigeria Electrification Project.

platform, including all tender documents, deadlines, and instructions for submitting a bid. They may also view a list of all sites and run analytics within the software to view aggregate statistics about the sites (grouped by state, for example). Bidders can copy all site data into their own accounts in the platform, allowing them to use the software to assemble a technical and financial proposal for each lot using Odyssey's software tool suite and structured workflow (figure 2.33).

Once the technical analysis for each site is complete, sites are bundled into portfolios for each of the tender lots. Bidders must provide the business plan, financing approach, and required documents uploaded to the data room. Incomplete proposals cannot be submitted; a final checklist ensures all sections are complete and all required files uploaded to the data room. Only final portfolios for the tender lot are submitted to the evaluation committee.

The VIDA and Odyssey platforms are compatible and can form a strong toolkit for governments, REA, development financial institutions, or private organizations. VIDA's software can host village-level data, geospatial, and others in an interactive user interface that can then be accessed by Odyssey for tendering and deployment. A user in Odyssey could navigate to VIDA to view and access granular geospatial and on-ground data of the villages being tendered. Similarly, a user in VIDA software could push the village-level data to the Odyssey platform to tender and deploy mini grids.

> Geospatial analysis provides a broader picture of the locations and characteristics of communities that can be considered at a portfolio level, which enables mini grid developers to exploit economies of scale and prepare quicker, more cost-effective rollout plans and plans for service and maintenance. Governments can also use geospatial and other digital tools to catalyze deployment of mini grids led by the private sector to supply electricity to off-grid communities. For example, Nigeria's Rural Electrification Agency is holding minimum-subsidy tenders for portfolios of promising mini grid sites that it has identified and for which it has collected market intelligence.

LESSONS LEARNED AND NEXT STEPS

The introduction of geospatial and other digital technologies has lowered preparation and planning costs by an order of magnitude: from about $30,000 per site—because each site required high-level on-site analysis—to around $2,300 per site, based on the World Bank's recent experience in Nigeria. Furthermore, by 2024, high-resolution satellite imagery is expected to fall by nearly 60 percent from 2014 levels (Selding 2015). This too will drive down the cost of ever more accurate geospatially planned portfolios. Meanwhile, taking a portfolio approach to mini grid development, instead of building mini grids as one-off projects, can slash upfront capital costs by around $100/kW, according to analysis of the ESMAP's database of installed and planned mini grids presented in the overview to this handbook. In addition, geospatial analysis can help identify potential productive-use customers, thereby shaping developers' community engagement strategies to promote income-generating uses of mini grid electricity.

As developers achieve economies of scale by developing economically viable mini grid portfolios that support productive uses of electricity, and as mini grid component costs plummet over the next decade, as discussed in chapter 1, the cost of mini grid electricity is on pace to reach $0.20/kWh by 2030. As mini grid electricity approaches this cost threshold, mini grids become the least-cost option for more and more people. This means national least-cost electrification plans will need to weigh expected cost declines in mini grid electricity as they anticipate main grid expansions, more mini grids, and SHSs.

To catalyze deployment of private-sector-led mini grids to supply off-grid communities, Nigeria's REA, the implementing agency for this project, is holding minimum subsidy tenders[21] for portfolios of promising mini grid sites it has identified. The World Bank and the REA have developed an innovative protocol for mini grid site identification, screening, and analysis using geospatial tools, including a geospatial portfolio planning methodology to assess and select the communities to be included in the minimum subsidy tenders. The protocol enables governments, development partners, or other public institutions to prepare portfolios of mini grid projects and "crowd in" private sector cofinancing. We hope this may offer useful guidance to those seeking to develop mini grid projects at scale elsewhere. For example, governments could replicate these steps in other countries interested in competitive tenders to kickstart or scale up the market for mini grids.

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NOTES

1. The electricity distribution grid has not been mapped or the data are not available in many countries. Gridfinder, an open-source tool for predicting the location of electricity network lines, using nighttime lights satellite imagery and OpenStreetMap data, was used to determine the location of the grid for countries where the data weren't available. See https://gridfinder.org/ and https://github.com/carderne/gridfinder.
2. The GEP processes HRSL population data to transform them into population clusters (similar to GRID3) based on proximity and density. You may read more about this approach at https://www.nature.com/articles/s41597-021-00897-9
3. Firm power output of a mini grid is defined in chapter 1 as the generator capacity (kW) plus 25 percent of the solar array output rated peak (DC) power output (kWp).
4. Consortium members include KTH Royal Institute of Technology, Development Seed & Derilinx, World Resources Institute (WRI), and Cambridge University.
5. This material is organized and shared through the GEP's GitHub workspace.
6. The development of open access training material has been undertaken by the Climate Compatible Growth (CCG) program (https://climatecompatiblegrowth.com/).
7. In the case of Nigeria, this task was carried out by Integration and the Reiner Lemoine Institut. A similar approach has been employed at the Global Electrification Platform (GEP) following a methodology suggested by Khavari and others (2021) (https://www.nature.com/articles/s41597-021-00897-9).
8. Energydata.info is an open data platform providing access to data sets and data analytics that are relevant to the energy sector, available at https://energydata.info/.
9. HOTOSM is an international team dedicated to humanitarian action and community development through open mapping; the database is open and available at https://www.hotosm.org/tools-and-data.
10. The Food and Agriculture Organization of the United Nations (FAO) Agro-Ecological Zones (AEZ) database is available at http://www.fao.org/nr/gaez/en/#.
11. The International Food Policy Research Institute's HarvestChoice products are available at https://dataverse.harvard.edu/dataverse/harvestchoice.
12. The Gridfinder.org visualization can be found at https://gridfinder.org/; the modeled results for all countries are available at Zenodo (2020). https://zenodo.org/record/3628142#.YlgO85BKhPY.
13. In the case of Nigeria, the night lights' data set was retrieved from the NOAA Earth Observation Group (https://ngdc.noaa.gov/eog/). The World Bank's Light Every Night initiative provides open access to all nightly imagery and data from the Visible Infrared Imaging Radiometer Suite Day-Night Band (VIIRS DNB) from 2012 to 2020 and the Defense Meteorological Satellite Program Operational Linescan System (DMSP-OLS) from 1992 to 2013. You may find more information at https://registry.opendata.aws/wb-light-every-night/.
14. More information about the source is available at http://www.keybiodiversityareas.org/assets/8f1535aed3316ae2b720364019f8cb1c.
15. Tool available at https://ibat-alliance.org/.
16. The NGO ehealth Nigeria gave the authors access to this information from its database.
17. Em-One designed and installed solar solutions in public institutions such as schools and health centers in Lagos, Kaduna state, and northeastern Nigeria.
18. HOMER® Energy's software suite consists of two desktop products—HOMER Pro and HOMER Grid—and application programming interfaces for building web-based tools, such as HOMER QuickStart and QuickGrid.
19. More information about MIT's REM model and application is available at http://universalaccess.mit.edu/#/main.
20. More information about NREL's REopt model and application is available at https://reopt.nrel.gov/.
21. REA has grouped these potential mini grid sites into lots by state and will invite private developers to build, own, and operate these portfolios of mini grid projects. Through a competitive process, REA will award grants per connections to the private developers selected to implement these projects. Their bids will be evaluated based on the quality of their technical proposal and on their subsidy requirement.

CHAPTER 3

PRODUCTIVE LIVELIHOODS AND BUSINESS VIABILITY

CHAPTER OVERVIEW

This chapter highlights why productive uses of electricity can be a game changer for both mini grid developers and socioeconomic development. It presents an everyone-wins scenario for developers, local entrepreneurs, communities, and national utilities. Using real-world examples, the chapter outlines a six-step approach to implementing productive-use interventions and discusses who can organize such interventions.

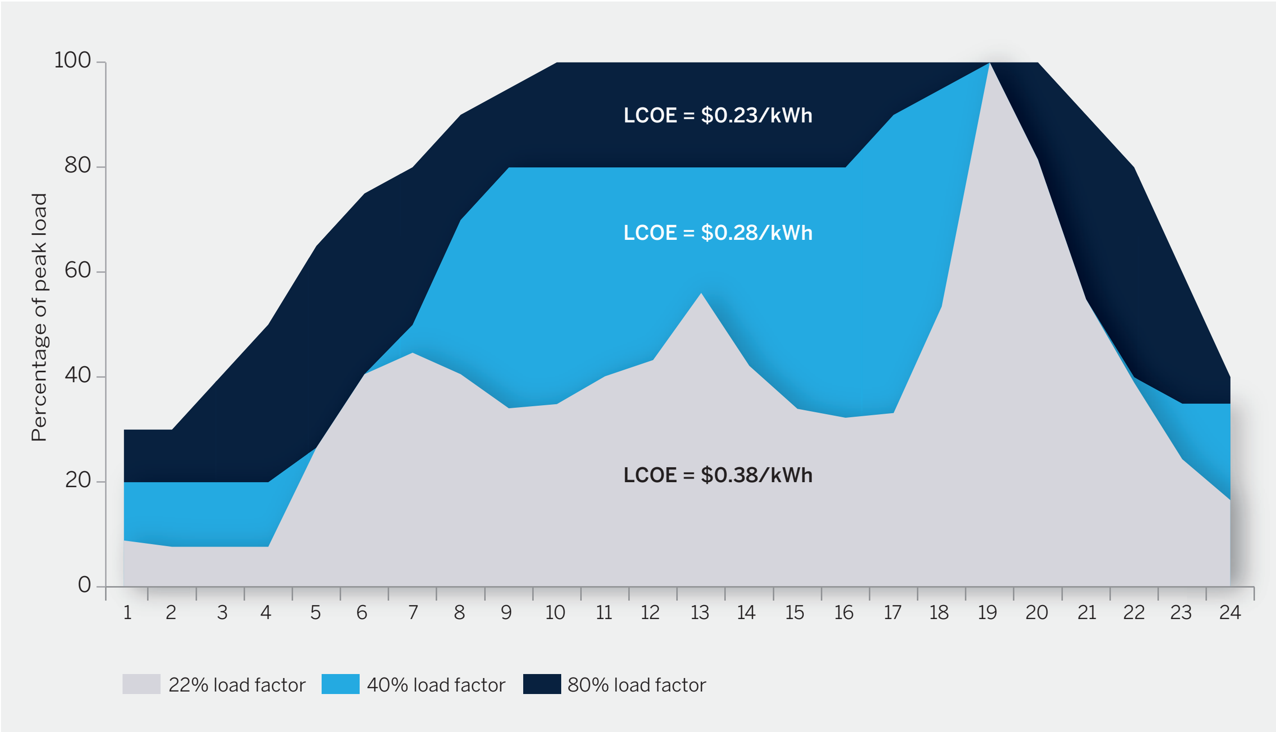
THE MULTIPLE BENEFITS OF CONNECTING INCOME-GENERATING MACHINES AND APPLIANCES TO MINI GRIDS

Increasing productive uses[1] of mini grid electricity creates an "everyone-wins" scenario for mini grid developers, rural entrepreneurs, communities, and national utilities over time. It reduces the levelized cost of energy, which increases the mini grid developer's margins and therefore financial viability. Entrepreneurs and small businesses benefit from switching from expensive diesel generators to affordable mini grid electricity. Communities benefit from the new jobs that mini grids create and the increased economic activity. The growth of rural economies also benefits national utilities once interconnection to the main grid is considered, because it increases customers' demand for high-quality electricity and their ability to pay for it.

Boosting productive uses benefits mini grids and their operational efficiency and financial viability (see also chapter 1). When income-generating machines and appliances boost demand for mini grid electricity, a mini grid's load factor gets a corresponding boost too. Meanwhile, a higher load factor (jumping from 22 percent to 40 percent) cuts the cost of electricity by 27 percent (see chapter 1). On a site analyzed by CrossBoundary Lab, a grain mill operator consumes 300 kilowatt-hours (kWh)/month, a hundred times more than the energy consumed by a nearby mini grid customer. Grain mills have power ratings in the 1,000–10,000 watt (W) range, about ten times more than commercial appliances like refrigerators and a hundred times more than household appliances (CrossBoundary 2020). Figure 3.1 shows the load profiles for mini grids operating with 22 percent and 40 percent load factors. Greater demand for electricity generates additional revenues for mini grid operators while improving the utilization capacity of their systems, which reduces the unit cost of electricity (per kilowatt-hour) and ensures efficient use of the mini grid's assets. Although increased demand requires more capital investment, it can optimize the use of systems, especially during daytime, when the residential load is small and systems are underused. Daytime use is critical for solar-based mini grids, which produce electricity at minimal marginal cost during the day.

Furthermore, an Energy Sector Management Assistance Program (ESMAP) analysis of 1,028 mini grids in Cambodia, Myanmar, and Nepal indicates that every additional 1 percent of nonhousehold customers (for example, microentrepreneurs and small businesses) served by a mini grid adds 20 percent to the mini grid's total average monthly consumption in terms of kilowatt-hours sold. So, if a mini grid serves 1,000 connections, going from 10 nonhousehold customers (1 percent of total customers) to 50 nonhousehold customers (5 percent of total customers) would increase the mini grid's average monthly consumption

FIGURE 3.1 • The impact of productive electricity uses on the daily load profile and levelized cost of energy



Source: ESMAP analysis.
kWh = kilowatt-hour; LCOE = levelized cost of energy; PUE = productive use of electricity.

by 80 percent (5 percent minus 1 percent, times 20). This additionality seems to be fairly consistent until 15 percent of a mini grid's customers are nonhouseholds, after which point, the effect begins to dissipate. It is worth noting here that most of the mini grids (about 60 percent) surveyed had a customer base that consisted of 1–5 percent nonhousehold customers, indicating substantial room to increase the share of nonhousehold customers in the mini grids' customer base.

The combination of savings and reliability brought by the mini grid makes business sense for local entrepreneurs. Reliable electricity will reduce costs for businesses as power outages and unreliable supply detract from revenues. In Sub-Saharan Africa, outages inflict sales losses of 30 percent on businesses. In some of the region's largest economies—Angola, Ghana, and Nigeria—more than 25 percent of businesses lose more than 10 percent in sales because of power outages, with individual firms reporting losing more than 70 percent. The firms with the greatest challenges average more than 200 hours a month without power, while even the companies getting highly reliable service still report more than 10 hours a month without electricity (Ramachandran, Shah, and Moss 2018).

In addition, more than 130 income-generating appliances have a payback period of less than 12 months, according to an analysis that ESMAP conducted in Ethiopia. The up-front investment costs, power consumption, payback periods, and revenue potential for some of these income-generating machines and other appliances are presented in table 3.4. Up-front investment costs typically ranged from $500 to $1,500, with an average of about $1,200. These appliances and machines generate between $50 and $500 of revenue per month after the conclusion of the payback period, with an average of $300 per month across the range of appliances identified.

Finally, mini grid electricity enables entrepreneurs to earn additional profits by extending the shelf life of goods, making productive processes more efficient, increasing output, and improving access to information and markets (IEG 2008). In Tanzania's Ludewa District, access to the 300 kilowatt (kW) hydro mini grid operated by Lumama cut milling costs in half (USAID 2018).

Stimulating demand for electricity from productive activities can, in particular, assist women-run enterprises to boost their earnings through the use of lighting, electrical equipment for cottage industries, baking, ceramics, and so on.

Productive uses of electricity can assist women in notable ways through their higher earnings achieved through better lighting and appliances for cottage industries, baking, ceramics, and so on.

Households and communities also benefit from productive uses of energy, which bring socioeconomic gains in addition to better opportunities to sell goods and services. If these opportunities existed prior to the mini grid, they were constrained by the need to rely on expensive diesel generation. Food and farm-related goods and services—for example, cooling, drying, processing, and so on—are two affected areas. Communications and connectivity are another (internet points), along with mechanical power (woodworking and metalworking machines), as well as lighting and entertainment. These goods and services lead to newly available and improved outputs, including:

- Household and community well-being;
- Longer life of, and added value to, agricultural products;
- Higher productivity;
- Better-quality manufactured goods, particularly in carpentry, upholstery and tailoring, and metalworking;
- Reduced costs; and
- Service availability after dark.

These outputs in turn lead to more jobs, higher incomes, time saved, and improved well-being (GIZ and others 2013).

The developer Mlinda has installed almost 100 mini grids in India. Load analysis and grid design have enabled Mlinda to power single- and three-phase electrical devices targeting productive and residential end users. The three-phase loads go to income generation. To support productive uses within communities and identify business opportunities, Mlinda set up a team to assist local business development. An impact assessment of the first 24 operating mini grids showed that microenterprise revenues rose 28 percent; 115 new local jobs have been created (Mlinda 2021).

An economic impact assessment offers more evidence. Tanzania's Mwenga hydro mini grid, with a capacity of 4 megawatts, was commissioned in 2012 and operated by Rift Valley Energy. Mufindi Tea Estates and Coffee Ltd. is the main client and anchor load, requiring electricity mainly to process tea leaves and power large motors, fans, and sieves. Over a 20-year project life cycle, economic benefits—from household energy cost savings, reduced reliance on diesel

TABLE 3.1 • The Mwenga hydro mini grid: Estimated costs and benefits

Type of benefit	Present value of cost or benefit (US$, millions)
Development subsidies received by project	–7.1
Household cost savings[a]	6.4
Tea company savings from reduced diesel backup[b]	1.4
Jobs created by electrifying villages[c]	8.6
Economic net present value	9.3

Source: Banerjee and others 2017.

a. Monthly savings of $14 for 5,600 households.

b. Diesel backup requirement of 10 percent of total power consumption.

c. Assuming that 65 percent of businesses create 1.5 jobs each, and that each job created is valued at the average expected annual salary of $1,500 a year.

Note: The estimated peak load averages about 700 kilowatts (kW) with a summer peak of 90 kW and a winter peak of 400 kW, and annual power consumption of 2,880 megawatt-hours.

backup, and job creation from new electrified businesses—are estimated at about $9 million (table 3.1) (Banerjee and others 2017).

Increasing the productive use of energy (PUE) also has important benefits for women in the communities served by mini grids. The physical and time burdens of some productive activities mainly run by women can be alleviated by ensuring that power goes to shared community facilities such as mills. Women's labor is dominated by the drudgery of preparing grain for household consumption (called "agro-processing" in the literature), particularly in Sub-Saharan Africa. For a family to eat over four to five days, a woman (and her daughters) will spend up to 13 hours to pound enough maize. Time-use estimates obtained for Nigeria show that two to three hours are spent each day just to prepare grains for pounding—that is, threshing and milling. Eighty-two woman-hours are spent processing one drum of oil palm fruits. It takes two hours to grate a basin of cassava; a grating machine can process a basin in one minute (Kes and Swaminathan 2006).

But it takes more than the introduction of electricity to boost enterprise generally and women-led businesses in particular. Outreach and capacity building are also needed. A SolarAid study of the solar lighting market in East Africa in 2012–15 found that 38 percent of households interviewed reinvested their energy savings into agricultural production or to seed other small enterprises (ODI and others 2016). The World Bank's work in Mali reveals some of the challenges in applying a gender lens to foster productive uses of rural electrification.

The benefits of increased productive uses of energy are especially profound for women, who spend a disproportionate amount of their time on farm labor (agro-processing chores), particularly in Sub-Saharan Africa. Transitioning from manual labor to machine-assisted processing can boost productivity and save many hours of drudgery each week. But evidence suggests that productivity and time savings do not automatically follow from the introduction of electric machines and appliances. Investments in outreach and capacity building are also needed.

Increasing the productive uses of a mini grid's electricity presents an opportunity for everyone to win. Mini grid developers can grow their revenues and lower their costs. Local businesses and entrepreneurs can transition from expensive on-site diesel generation to less costly mini grid electricity, or develop new businesses that use electricity services to generate revenue. Local communities benefit from the creation of new jobs and greater economic activity. National utilities benefit from the growth of rural economies and demand for electricity once interconnection to the main grid is considered.

Increased PUE in mini grids can also enhance the economic viability of expanding the main grid. In the absence of PUE, most mini grid customers in low-income areas use little electricity. So the main grid would sustain ongoing financial losses when it reached the mini grid's service area. Mini grids that stimulate demand for electricity through income-generating appliances and machines flip this narrative. They can provide economic growth in rural and peri-urban areas when they are designed to connect with the main grid and when PUE has been promoted through community engagement and training. By the time the grid arrives, a substantial load already exists and customers are better able to pay.

The most effective interventions to foster productive uses of energy acknowledge that men and women occupy different spheres in the productive economy. Men and women also benefit from electricity in different ways. Equitable interventions are designed to overcome the gender-based barriers around productive use. They need to deliver communitywide welfare improvements and grow the productive customer base—helping electricity suppliers become financially sustainable.

ROLLING OUT PROGRAMS TO PROMOTE PRODUCTIVE USES AND STIMULATE DEMAND

Electricity demand does not rise automatically with the arrival of a mini grid. The barriers to demand are numerous, among them limited markets, information, lack of skills, up-front costs, inefficient appliances, and scant access to financing. But efforts to promote PUE will pay off. In Indonesia, for example, local nongovernmental organizations (NGOs) promoted productive use at the outset of a rural electrification program, quadrupling annual electricity use from the main grid (World Bank 2000).

The adoption of electricity-powered productive equipment depends on demand, competition, and other sources of power—like diesel gensets and manual labor. What are the up-front costs of equipment? The "Diffusion of Innovations" theory (Rogers 2003) highlights the importance of peer-to-peer conversations and peer networks to stimulate productive use. These include end-user education and vocational training; manufacturers' road shows for potential entrepreneurs; more end-user engagement to raise awareness about what has worked, expected investment returns, and profitability; and the setting of tariffs conducive to productive-use appliances. Finally, financial guarantees and up-front financing can mitigate default risks (expanded from RMI [2018]).

In addition, interventions should acknowledge that men and women occupy different spheres in the productive economy. Yet measures to increase productive uses of energy tend to be gender blind and assume that men and women benefit from electricity in the same way. For instance, women are less likely to be employed than men, more likely to run informal enterprises from their homes, and are overrepresented in low-productivity businesses, while men tend to engage in mechanized, electricity-intensive sectors such as construction, welding, manufacturing, and repair. So, acknowledging the gender-based barriers to productive use must be part of equitable interventions that deliver communitywide welfare improvements and expand the productive customer base. Ultimately these will improve the electricity suppliers' financial sustainability. Community-based institutions such as self-help, savings, and farmers associations can become platforms for productive-use discussions.

TABLE 3.2 • Six steps to roll out a PUE program

	Description	Outputs
Step 1	Market/demand assessment with geospatial analysis overlying mini grids, appliances, and end-use finance	Online data platform List of key stakeholders List of high-impact opportunity areas
Step 2	Community engagement confirming and improving data from Step 1 through survey(s) and workshops	List of communities validated as areas of high-impact opportunity, combined with community-specific market data List of appliances that are relevant for these communities based on local contexts List of potential PUE customers in these communities List of local providers of microfinance in or near these communities List of local suppliers of appliances that serve these communities List of community leaders and district-level government officials who are supportive of the PUE program
Step 3	Demand analysis for mini grid design and market potential for appliances and associated end-user finance	Detailed characteristics of an initial set of community-relevant appliances List of prioritized appliances
Step 4	Preparation of road shows involving local government, community leaders, interested appliance providers and end-user financiers, mini grid companies	Road show logistics finalized: who, what, where, when, and how Information and marketing campaign launched ahead of the road shows
Step 5	Road shows to load centers explaining the value propositions to potential end users by mini grid developers, appliance suppliers, and end-user financiers based on current and aspiration lifestyles of the end users; document sign-ups by end users for mini grid connections, appliances, and end-user finance	Road shows Customer sign-up for mini grid connections, appliances, and end-user finance
Step 6	Rollout of mini grid connections, sales of appliances, and end-user finance	Customers connected Appliances sold and connected Financing secured

PUE = productive use of energy.

This next section presents six steps to roll out initiatives supporting the uptake of income-generating appliances in towns served by mini grids.

STEP 1
Assessing markets and demand: Geospatial analysis superimposed over mini grids, appliances, and finance for end users

A good rollout can accelerate uptake of productive uses of energy, especially when developers understand the sector's market potential and engage the stakeholders. In 2022, leveraging geospatial analysis is the state-of-the-art way to assess the productive-use market and its demand potential. This data informs collaborations among mini grid developers, appliance suppliers, and end-user financiers.

Machine-learning algorithms now analyze geospatial data sets and produce maps that highlight areas suitable for PUE programs. This technology-enabled, data-driven approach to market assessment first collects a range of geotagged data, including:

- Building footprints,
- Road and electricity networks,
- Nightlight imagery,
- Crop cover and yields,
- Socioeconomic and demographic data (like gender composition and household income),
- Cell-phone coverage,
- Topography, and
- Precipitation.

Then, to identify market opportunities, the machine-learning algorithms highlight possible high-impact collaborations for mini grid developers, appliance suppliers, and local finance providers. Exemplifying these high-impact opportunities are town clusters that lack electricity but are located in highly productive agricultural regions with good cell-phone coverage and good roads to major cities or trade hubs. But high-impact areas are everywhere: in arid regions, coastal settlements, agricultural towns, and in rural and peri-urban locales.

Once uploaded to an online platform, this geospatial data (and their maps) can be presented to governments and their PUE development partners, who can then share the information with mini grid developers, local microfinance providers, and appliance suppliers. Stakeholders can then overlay the opportunity areas with their own operations—for developers, their mini grid sites (existing and planned); for microfinance institutions (MFIs), their branch network; for appliance suppliers, their distribution networks and hubs. In addition, developers, suppliers, and MFIs can be matched when mutually beneficial opportunities are identified. For example, a high-impact opportunity might fall within the expansion plans of a mini grid developer, close to a local MFI branch and an appliance supplier. In this way, a market assessment that is data driven and geospatially enabled can become a platform for partnerships and collaborations likely to increase sales of PUE appliances and machines.

The outputs of Step 1 are: (1) an online platform that presents the data in a user-friendly interface; (2) a long list of key stakeholders, including mini grid developers, local providers of microfinance, and appliances suppliers; and (3) a long list of high-impact opportunity areas.

Working with TFE Energy's Village Data Analytics, ESMAP is deploying this approach in the Democratic Republic of Congo, Ethiopia, and Nigeria. Table 3.3 presents some of the PUE program stakeholders—appliance suppliers and local finance providers. These lists will grow alongside the ESMAP project.

TABLE 3.3 • Example of PUE program stakeholders identified in the Democratic Republic of Congo, Ethiopia, and Nigeria

Stakeholders	Congo, Dem. Rep.	Ethiopia	Nigeria	
Appliance suppliers	Agrimont Group Association of Cocoa and Coffee Exporters of the DRD (ASSECAF)" AVSI Foundation CONAPAC Fouani Lushebere Dairy and Cheese Factory Makita DRC Strategos Plantations The Breeders' Society of Bandundu (SEBO) The Society of Livestock Farms of Bas-Congo (GEL Bas-Congo)	"Tsehay Roschli Industrial and Agricultural Engineering (Selam Children Village)" Afesol Technology Plc Amio Engineering Plc Beza Industry Plc Bumzal DYD Trading Plc Ethio-Mercantile General Mercantile Plc Kaleb Service Farmer's House PLC Kalmeks Engineering Manufacturing Lacomelza Plc Marast Roda Business Group Plc Ten Tools Tsion Industrial Engineering	Adebash Manufacturing Company Alanco & Son Steel Fabricator Alaral Tech Engineering Design & Fabrication Alayan Metals Fabrication Nig Amadis Technical Company Apexskill Works Arcadem Basicon Engineering Company Bennie Agro ltd. Besuga Global Investment Bifem Technologies Nigeria Limited Blessed Silver Brothers Bomik Adeyeera Engineering Camco Chinige Technology Services LTD Coldbox Coldhubs Confidence Technical Work Enterprise Dangote Deban Faith Agro Allied Ventures DEE Technica Doing E. K. Fabricating Engineering Eamak Technical Services Ecotutu—Interview Emeka & Sons Construction Company ESE Engineering Service Fatoroy Steel Industry Gensaes Enterprises	Hanigha Nigeria Ibraham Onsachi Kenny Construction Company Kola Adekunku Koolboks Koolmill Lawod Metal Nig Magi Rches Limited MCAN Muharib Machine Muhat Nigeria N.C. Gilbert Ind Dev Co Nanyang Goodway Machinery & Equipment Co., Ltd Niji Lukas Nig Nova Technologies Nui-Lukas Oladimeji Success Olaleye Eliseri PAF Metal Fabrication and Youth Development Peak Products Pentawork Technical Work Process Concepts & Technologies S. Adiss Engineering Works Sakilan Engineering Company Segun Towoju Sominie Nigeria Limited Starron Sunday Omowaye Talitha Fabrication Company Teekay Tronics Tropical Development Engineering Ltd UNIC & Sons Weilai Machinery Zheng Zhou Sida

continued

TABLE 3.3 • *continued*

Stakeholders	Congo, Dem. Rep.	Ethiopia	Nigeria
Finance providers	Advans Bank Altech Business MFI Credit YA MPA Finca Hekima/Goma IFOD Kitumaini Light in Business SA/ Butembo Mam Tombuama MFI APE Micropop Paderu Paidek SA Procfin SMICO S.A./Goma Tout Pour le Genre Dans Le Developpement (TGD) Trust Investment Development TID SA / Butembo Tujenge Pamoja/Goma Tujenge S.A. Vision Fund Yoasi	Addis Credit & Saving Institution (ADCSI) Agar Microfinance Amhara Credit and Savings Institution (ACSI) Benshangul MFI Buusaa Gonofaa Dedebit Credit and Savings Institution (DECSI) Dire Microfinance Metemamen Microfinance Omo Microfinance Oromiya Credit and Savings Share Company (Ocssco) Poverty Eradication and Community Empowerment (PEACE) Sidama Somali Microfinance Specialized Financial and Promotional Institution (SFPI) Vision Fund Microfinance (VFMFI) Wasasa Microfinance	Justice Development and Peace Commission (JDPC) microfinance / Integrated Development Programme Addosser Microfinance Bank Afex Babban Gona Baobab Microfinance Bank Barnawa Microfinance Bank Chase Microfinance Bank Corebank / CORESTEP MICROFINANCE BANK Development Exchange Center (DEC) Microfinance GRASSROOTS DEVELOPMENT MICROFINANCE BANK Ibile Microfinance Bank Life Above Poverty Organization (LAPO) microfinance Nirsal Microfinance Bank Richway Microfinance Bank

Source: ESMAP and TFE-VIDA analysis.

STEP 2
Surveys and workshops build on Step 1 data through community engagement

Once the high-impact opportunity areas are identified, planners need to "ground truth" by engaging with communities. This engagement entails multiple rounds of site visits to identify the context-specific potential for PUE. Each successive round would home-in on top-priority locations, appliances, and stakeholders. In practice, this means sending teams of surveyors and community engagement specialists into the high-impact areas identified in Step 1. Equipped with smartphones and tablets, the team will collect data and take photos and videos, obtaining a deeper understanding of local socioeconomic dynamics, critical for effective interventions that promote productive uses and build a supportive ecosystem. If the mini grid developer leads this effort, it could gain support from the rural electrification agency, NGOs, and development partners in facilitated interaction with productive sectors and local businesses.

Two complementary methods—systematic and pragmatic—exist to identify opportunities for productive uses at the community level (de Gouvello and Durix 2008). Field investigation is, in both cases, a requirement to refine assessments of productive demand. The systematic approach maps all potential activities in a community that could benefit from access to electricity. Every stage of the existing and potential value chains—from inputs and processing to outputs and end uses—is screened to capture actors, market dynamics, cycles, and seasonality. This approach assesses the role electricity already plays and could play in the prioritized sectors.

The pragmatic approach, by way of contrast, does not look at the spectrum of productive uses. Instead, it takes advantage of existing opportunities to ease the interface between mini grid developers and productive sectors. The process of identifying PUE is speeding up, so moving on to implementation takes less time. Although less comprehensive, the pragmatic approach is faster and more affordable and builds on extant cross-sector ties.

After gathering information on appliance usage (current and potential), teams could tell productive users they may sign up for mini grid electricity at a later site visit. Furthermore, survey teams could also approach local suppliers of microfinance and appliances to gauge their interest in a PUE program. This might require visits to MFI branches and appliance or hardware shops in nearby towns to interview

Identifying context-specific potential for productive uses should begin as early as possible in the mini grid development project cycle. Two complementary methods—systematic and pragmatic—exist to identify opportunities for productive uses. The systematic approach maps activities that might benefit from access to electricity. The pragmatic approach appraises a sector (or location) first, and then identifies economic activities that are improvable through mini grid access.

staff. Finally, the community engagement teams will need to meet with community leaders and district-level government officials to introduce them to, and garner their support for, the PUE program.

Demand assessment should also assess the gender gaps that women and men face as they start up enterprises in an effort to identify the chief constraints on women-owned enterprises. For example, in the agriculture sector, men often mediate women's access to resources and community participation, and these men tend to be fathers or husbands. So the agricultural contributions that women make often go unrecognized.

Gender gaps are apparent everywhere, of course. But in Nigeria, the gender productivity gap for agriculture stands at 18.6 percent. Another notable gap is found in Dominica, a Caribbean island state, where women work mostly in the informal market in microenterprises and subsistence farming, which constrains their ability to advance (Mukasa and Salami 2016; ILO 2014). Gender gaps are also driven by the cultivation of smaller land parcels, discriminatory land laws, constrained access to financial products and services, snubbed by extension or business development services, and restricted to older technologies.

Step 2 outputs are lists of:

- Communities validated as areas of high-impact opportunity, combined with community-specific market data;
- Appliances relevant in terms of the communities' local context;
- Potential PUE customers in these communities;
- Local providers of microfinance in or near these communities;
- Local suppliers of appliances that serve these communities; and
- Community leaders and district-level government officials who are supportive of the PUE program.

At the community level, demand assessment should also look into the gender gaps in entrepreneurial activity. What is constraining the ability of women-owned enterprises to thrive?

STEP3
Demand analysis for mini grid design and market potential for appliances and associated end-user finance

During the early stages of the PUE program, a team's direct engagement with communities is important in identifying high-priority appliances and machines. Once these appliances have been identified, their economic and technical attributes should inform mini grid design, so it may more precisely ascertain the market potential for appliance suppliers and local providers of microfinance.

The range of energy-efficient appliances on the market today is continuing to expand. Table 3.4 presents indicative information on power requirements, costs, and payback periods for a sample set of widely distributed income-generating appliances and machines. Of the more than 160 appliances that ESMAP identified as being available on the market today, more than 130 have a payback period of less than 12 months. The typical up-front investment ranged from $50 to $1,500, with an average of about $1,200. At the conclusion of the payback period, the appliances generate between $50 and $500 in monthly revenues, with an average of $300.

Once the technical and economic information about productive-use appliances is better understood, potential customers will need to decide if acquiring the appliance is right for them. CrossBoundary's Mini Grid Innovation Lab has shared some of the questions that customers can ask to help them make this decision. These include:

- What level of electricity service—primarily in terms of capacity and reliability—is required to produce the final product desired, and is the mini grid capable of providing this level of service?
- How will converting from diesel or using an energy-efficient appliance affect the technical aspects of the machine?
- What tariff will make converting to electric power from diesel cost-effective?
- What time of consumption (across the day or night) will yield the greatest profits?
- Would it be more profitable for me to be located closer to the generation source?

TABLE 3.4 • Power requirements, costs, and indicative payback periods of selected income-generating appliances

Sector	Activities and appliances	Power required (kW unless specified otherwise)	Cost from supplier (US$)	Payback period (months)	Average monthly revenue after payback period (US$)
Primary industries (agriculture, fishing)	Crop dryer	6–1	1,000–5,000	12–18	236
	Egg incubator	80–16 watts (W)	50–100	1–3	58
	Hammer mills of various types for the respective grains	5–10	700–1,200	6–12	129
	Electric sawmill	1.5–3.0	500–800	12–24	44
	Threshing machine	7–9	500–1,000	3–6	208
	Grinder for pulses and beans	5.2	1,500–4,000	6–12	396
	Garlic/ginger paste machine	2–7	1,500–4,000	6–12	396
	Tomato ketchup/paste–making machine	5	800–2,500	3–6	483
	Water irrigation pump	3.7–22.4	200–1,000	3–6	183
	Oil expeller	6 (600 W for ordinary oil press)	800–2,000 for ordinary oil press	3–6	400
	Sterilizer (for dairy processing)	3–6	600–2,000	1–3	1,100
	Packager	250 W–3 kW	500–1,000	6–12	104
	Peanut roaster	1–10	1,000–5,000	6–12	458
	Electric crusher for peanut paster	3	1,000–3,000	3–6	583
	Automatic measurer/bagger	1	3,000–5,000	12–18	292
Light manufacturing	Electronic welding machines	3–7.5	200–300	6–12	33
	Angular grinder	2	100–200	6–12	21
	Circular saw for wood	1–2	150–200	6–12	23
	Electric smoothing plane	200–300 W	50–100	3–6	21
	Jigsaw	400 W	100	3–6	25
	Electric drilling machine	400 W	20–50	3–6	10
	Ice maker	4–6	500–1,500	6–12	146
	Socks knitter	4	2,000–5,000	6–12	500
	Biscuit maker	2	3,500–6,500	6–12	688
	C-brick maker	9	2,000–5,000	3–6	1,000
	PET bottle maker	24	3,000–10,000	3–6	1,917
	Popcorn maker	1.5–2.1	50	1–3	33
Commercial and retail activities	Phone charger	5–10 W	10	1–3	7
	Refrigerator for cold drinks in cafeterias or medicines in dispensaries	100 W	150–300	1–3	175
	Computer	15–100 W	250–800	3–6	154
	Printer/scanner for stationary	0.5–2	150–250	3–6	54
	Appliances for hairdressers' shops (hair clipper, hair dryer)	1.5–2.5 (hair dryer) 10–20 W (hair clipper)	40–60 (hair dryer) 15–30 (hair clipper)	1–3	19
	Sewing machine	200 W	30–100	3–6	17
	Television for local cinemas and bars (including decoder)	50–200 W	100–200	1–3	46
	Hi-fi stereo system	20–500 W	20–200	A hi-fi system in itself does not provide a payback period	n.a.
	Electric cookstove	3.5	50–100	Does not have a payback period due to high consumption	n.a.
	Deep fryer	2	100–500	6–12	46

Sources: de Gouvello and Durix 2008; Alibaba 2022; ESMAP and INENSUS analysis.

Note: Battery chargers come in a range of sizes. The one presented here would charge from 50 percent to 100 percent in about three hours. The ice maker can produce 1,000 kilograms of ice per day. kW = kilowatts; W = watts; n.a. = not applicable.

Of the 160 income-generating machines and appliances on the market today, more than 130 have a payback period of less than 12 months. The typical up-front investment cost ranged from $50 to $1,500, with an average of about $1,200. The monthly revenues generated by these appliances after the payback period typically ranged from $50 to $500, with an average of $300 across the identified appliances.

For mini grid developers, adding productive users to their customer base adds complexity to the project design, because they have to determine whether and how to connect these loads, which differ in terms of time of use, magnitude of power and energy demand, and seasonality. As such, mini grid developers will also need answers to a series of questions on how to include them in their business models as early as possible in the project cycle. CrossBoundary's work with developers has helped identify some of these questions, including:

- How much additional generating capacity is needed to support the load demand?
- What inverter size and distribution system will allow multiple productive-use machines to operate simultaneously?
- From how far away can the grid support a large productive load running on three-phase power?
- How low can the tariff be while still proving sustainable?
- What time of consumption will allow least-cost generation?
- How should the tariff structure be adjusted to account for seasonality?

Adding electric appliances to the systems is often not technically straightforward and requires demand-side management skills. Income-generating appliances typically require more power and energy to operate than consumer appliances (fans or televisions). Some types of income-generating appliances are already in use in the community but are powered by diesel engines and may not be the most efficient options to maximize limited load profiles. Others will be introduced into the community for the first time. As a result, mini grid developers often lack information on the power and energy requirements and load profiles of appliances and machines, which could lead to inaccurate demand forecasts and wrong-sizing the mini grid's generation and storage capacity. Accurate information on the technical characteristics of income-generating appliances is important to enable developers to effectively promote their uptake among customers, design their tariffs appropriately, provide financing options to end users, and design their mini grids.

The different productive-use appliances come with a range of load profiles, and developers can design their mini grids to prevent under- or oversizing the system to strengthen its economic viability. Undersizing could restrict revenues for the mini grid operator and push consumers toward alternative sources of energy. Excess capacity raises investment costs above revenues, lengthening the payback period, hiking operational costs, and reducing overall efficiency. Because prediction of demand tends to be unreliable, oversizing is common for mini grids in Africa.

The key elements of system design include:

- Peak power,
- Reactive power,
- Single- or three-phase distribution networks,
- Capacity utilization, and
- Incorporation of backup generators versus batteries.

Three-phase distribution systems are able to power large productive-use loads across a wider range of machinery, especially equipment above 10 kW or 10 kilovolts-ampere, or rural clusters of smaller appliances in a productive facility at an isolated site. Productive users usually require a minimum service at Tier 3, or peak available capacity of more than 200 W and eight-plus hours of energy supply, including at least two hours in the evening (Bhatia and Angelou 2015).

Mini grid developers generally have two ways to manage electricity demand from PUE appliances and machines: tariff incentives and contractual obligations.

Tariff incentives can stimulate demand and greatly boost the use of income-generating appliances and machines. In regulatory environments where developers are free to charge cost-recovery tariffs (see chapter 9 for a detailed discussion on mini grid tariffs), the guiding principle of setting an appropriate tariff should be to keep it easily manageable for the operator and easily understandable for end users. The tariff structure should also allow a reasonable return on investment while remaining attractive and affordable for productive end users. It should take into account the ability and willingness to pay of productive clients as well as the availability of alternative power sources or backups, the predictability of supply, and the possibility of combining different sources of electricity.

Tariff structures with a range of applications exist, including tariffs that are:

- Capacity-based,

- Inverted block,
- Per device,
- Time-of-use, and
- Seasonal.

When tariffs are tailored to end users, rates can be adjusted by load location and size and by type of connection and business. The mini grid operator can also decide to introduce lower, curtailable load tariffs for customers who agree to be curtailed.

In Tanzania, Jumeme and Energy 4 Impact designed a tariff schedule aligned with end users' needs after collecting data on businesses' energy consumption. They determined that, to be able to compete with diesel gensets, the mini grid tariff to power a maize mill should be about $0.32/kWh. This rate was much lower than what mini grid developers usually charged in Sub-Saharan Africa ($0.50–$1.20/kWh). Based on an incentivized use pattern, daytime tariffs were set at about a quarter of evening tariffs.

Payment terms should also be adjusted to reflect productive users' constraints. Some users may be reluctant to pay a connection charge (or a flat standing charge) when their activities are highly seasonal, with no electricity needs during certain periods of the year. Prepayment can also be problematic for productive users with limited cash flows, especially early in their development. As a result, two ways to accommodate PUE customers are, (1) waiving standing charges and (2) allowing productive-use customers to postpay for their electricity.

Operators can also use contracts to shift some productive consumption to daytime or other nonpeak periods. The Tanzanian villages of Lupande, Mawengi, and Madunda are connected to a 300 kW hydropower mini grid. Corn milling and welding are permitted only during business hours (9 a.m. to 6 p.m.) so households have enough electricity at night (USAID 2018).

Contracts can make demand-side management more efficient. They mitigate demand risk and anticipate the effects both on capital expenditures and the levelized cost of electricity. In doing so, contracts define the tariff structure, which determines what productive users should be connected when, and at what tariff. Beyond collaborations between mini grid operators and productive users—and in order to better secure the balance between demand and supply—developers can secure a guaranteed level of demand through contractual agreements with customers, which increase load predictability and therefore revenue streams. Signing up the load before the final system design improves the ability to right-size the system and gives the end user the option of securing the amount and quality of power it desires.

> Demand and load management are essential for productive users, who depend on Tier 3+ service. Two strategies are available to manage demand: tariff incentives and contractual obligations. Tariffs can incentivize productive uses. One common approach is to charge low daytime energy tariffs but, during peak morning and evening hours, to charge higher energy tariffs. Other approaches include allowing productive users to postpay for their electricity consumption, while waiving standing charges for productive users with seasonal business activities. Operators can also encourage or require a shift of some productive consumption to daytime or other nonpeak periods, through service agreement contracts.

Ultimately, one of the key outputs of Step 3 is to identify a set of high-priority appliances that appeal to both mini grid developers and customers. For developers, such appliances tend to be energy hungry at predictable daytime hours (or that run consistently over 24 hours). For customers, high-priority appliances have the shortest payback periods while generating income over time. Step 3 outputs also document community-relevant appliances—knowledge that informs the go-to market strategies of mini grid developers, local microfinance providers, and appliance suppliers.

STEP 4
Preparation of road shows involving local government, leadership communities, communities, interested appliance providers and end-user financiers, mini grid companies

Steps 1–3 focus on gathering data and information that will inform Steps 4–6, which are focused on implementing road shows and other community engagement activities and ultimately deploying income-generating appliances and machines in partnership with mini grid developers, local finance providers, and appliance suppliers.

Step 4 consists of preparing the logistics for road shows and other community engagement events. Ever since electricity systems were first installed outside major cities—for example, in the 1920s and 1930s in the United States—electricity providers, governments, and other community development organizations have organized road shows, competitions, and other events that introduce communities to electrical appliances and machines (Duke University 2022). Demonstrations were key. How do electrical appliances and machines work? Productive users of electricity share their experiences with prospective users, and explain the availability and terms of appliance financing, describing the mini grid developer's plans (timing, tariffs, and so on). Finally, potential customers sign up for mini grid electricity, appliance ownership, and consumer financing. Road shows, supported by information and marketing campaigns, have proved their effectiveness for more than a century, increasing uptake of income-generating machines and appliances. Analyzing these rural road shows in the United States between 1938 and 1945, Duke University found that they increased consumption by 64 kWh per customer per year (Plutshak, Free, and Fetter 2020).

But these events require careful planning and coordination across a diverse mix of stakeholders. In fact, six core stakeholder groups that will need to come together are:

- Current and potential users of income-generating appliances,
- Mini grid developers,
- Local providers of consumer finance,
- Appliance suppliers,
- Community leaders, and
- District government leaders.

All of these stakeholders should have been identified at Step 2—the task during Step 4 is to coordinate collective action to plan the road shows and other community engagement events. Additional stakeholders may also need to participate depending on the context, such as agriculture agencies and local training institutes.

The high-impact opportunity communities identified in Step 1 and validated in Step 2 are the geographic targets for road shows. Events should take place in areas accessible to several different high-impact opportunity communities. The geospatial data collected in Step 1 should guide road-show activities, taking into account access, community clusters, and other relevant information.

For road shows, good rules of thumb (de Gouvello and Durix 2008) are:

- Integrate initiatives from other sectors like agriculture to avoid duplication;
- Anticipate the effects of PUE on people, which is to say, be aware of how increased use changes household and social behaviors;
- Favor local initiatives and equipment;
- Tailor activities to targeted sectors and regions and adapt them to the literacy levels and habits of the targeted audiences;
- Design all activities to include women, and develop activities that specifically target women.

Information and marketing campaigns should preview the road shows, which are integral to Step 4. Notices on local radio, posters, leaflets, and other materials are vital for community presentations. Centralized resource centers or NGOs can handle this part, and they can gather information on productive equipment and techniques, advising on business capacity and productive processes. Campaigns should disseminate high-quality information materials, messages, and methods that focus on market surveys and targeting.

The outputs of Step 4 are finalized logistics (who, what, where, when, and how) for road-show marketing and information campaigns that target the high-impact opportunity communities identified in Steps 1 and 2. These steps demonstrate the first set of machines and appliances identified and analyzed in Steps 2 and 3.

STEP 5

Road shows to load centers where mini grid developers, appliance suppliers, and end user financiers explain the value propositions to potential end users based on their current and aspirational living standards

With the logistics in place and the marketing and information campaigns implemented, the road shows can be deployed to the high-impact opportunity communities. Road shows should be fun, informative, safe, and memorable events. Indeed, the road shows implemented by the Rural Electrification Administration of the United States were affectionately referred to by participants as the "Electric Circus" (Duke University 2022).

District-level government officials often serve as strong voices of support to open the event. A successful road show will offer:

- Highly interactive and participatory environments that engage the mini grid developer, local authorities, local community organizations, financing agencies, vendors of electrical equipment, and potential customers;
- Events or demonstrations that target women. Because women are less likely to be employed than men, and more likely than men to run informal businesses, they are less familiar with mechanized work. They need to see the benefits of the productive uses of appliances.

In addition to the road shows themselves, key outputs of Step 5 are concluding agreements with potential customers for the suite of products and services so they can acquire and use income-generating machines and appliances. Step 5 should therefore conclude with signing customers up for mini grid electricity; for an appliance; and for consumer finance (if necessary and desired by the customer).

TABLE 3.5 • Stakeholders that could be involved in road shows and their respective roles

Stakeholders	Roles
Local distributors of targeted equipment, local cottage industries	Demonstrate equipment Provide technical adaptation to local uses Train users Develop retail network to facilitate local purchase of appliances
Energy service providers and their associations	Build consumer awareness and support; help providers adhere to standards Educate and train customers Adapt energy infrastructure to local growth of energy demand
Microfinance and credit unions	Provide customized financing to potential users Conduct risk analysis Build sector awareness Educate customers about loans
Agriculture and other institutes, enterprises, and promotion centers	Provide sector knowledge, field presence, networking and outreach capacities, demonstration capacity, and vocational training Build user confidence Train users
Training and vocational centers	Develop vocational curriculum and train teachers

Source: De Gouvello and Durix 2008.

Road shows, combined with information and marketing campaigns, are effective ways to increase the uptake of income-generating appliances and machines. They require careful planning and collective action by six core stakeholder groups: current and potential users of income-generating appliances, mini grid developers, local providers of consumer finance, appliance suppliers, community leaders, and district government leaders. Road shows should be preceded by information and marketing campaigns, should be highly interactive and participatory, and should actively target women, who are less likely to be employed than men, more likely to run informal businesses than men, and less likely to engage in mechanized work than men.

STEP 6
Rollout of mini grid connections, sales of appliances, and end-user finance

Upon completion of a road show, the mini grid developers, appliance suppliers, and local finance organizations can begin to deploy their products and services to the customers they signed up at Step 5. It is rarely easy, however, for microentrepreneurs and local small businesses to make the leap from sign-up to acquisition. Two strategies are emerging to directly support local entrepreneurial uptake of income-generating machines and appliances as they arrive in the community: clustering, and advisory support.

Clustering productive users in an area close to the source of generation is one way to increase the connectivity of businesses. There are different ways to encourage clustering, including multifunction platforms, solar kiosks, productive-use centers have been experimented. Beyond the technical and financial advantages to the developer (higher-quality service, limited distribution investment), clustering facilitates day-to-day interactions, strengthens innovation and business development, and increases technology and knowledge sharing within the productive community. The role of public and central authorities, assisted by multilateral partners and donors, is key in clustering small business activities by enabling land tenure, facilitating permitting, and providing infrastructure (roads). (See chapter 8 for a discussion of the different institutions that are relevant for mini grids.)

In addition, to unlock the entrepreneurial potential of communities, local authorities, NGOs, or the developers themselves need to provide gender-specific business development services and mentoring activities for targeted local entrepreneurs. A study that covered Tanzania, Ghana, and Myanmar, highlighted differences found between enterprises run by men and women and the need for gender-specific support (IDS and GIZ 2019). Men own more businesses and spend more on electricity than women, who spend more on cooking fuels. Women operate in less electricity-intensive sectors that are mainly devoted to food preparation, hospitality, tailoring, hairdressing, and retail, while men are familiar with mechanized and electricity-intensive work. This gap between women and men and their respective patterns of productive energy use is eas-

Two strategies to improve small business uptake of mini grid electricity services are clustering productive users in an area close to the source of generation and providing gender-specific advisory support to entrepreneurs and small business managers.

Women often operate in jobs related to food preparation, hospitality, tailoring, hairdressing, and retail, which tend to be less electricity intensive. Meanwhile, men take jobs that tend to be more mechanized and electricity intensive. They also enjoy better starting conditions in terms of capital, resources, and skills. By way of contrast, women are constrained by household responsibilities and restrictive social norms. Nevertheless, access to electricity can generate income for both men and women who own and run enterprises, highlighting the need for gender-specific advisory support to boost the PUE.

ily explained: men start their working lives with more capital, resources, and skills, while women take on demanding household-care responsibilities, while social norms restrict their participation in certain occupations, such as fishing. Yet access to electricity led to increased profits for both men and women, thus highlighting the need for targeted, gender-specific advisory support to increase overall PUE.

Consumer financing will need to arrive alongside mini grid electricity and income-generating appliances and machines. The market potential is substantial. If mini grids are to reach their full potential—serving half a billion people by 2030 is a core solution for achieving universal access to electricity—then $3.6 billion in microfinance is needed for 3 million income-generating appliances, assuming an average of 15 productive-use appliances per mini grid for 200,000 new mini grids at an average cost of $1,200 per appliance (see table 3.4).

Expensive electrical appliances and high connection fees can impose a financial burden on entrepreneurs and small businesses, slowing or preventing the decision to invest in productive-use appliances and equipment, especially when no formal financing institution exists. A study from the Rocky Mountain Institute showed that when end users were offered 12-month loan terms to finance productive-use appliances, consumption almost doubled. After 11 months, mini grid revenues grew by 18 percent (RMI

Most productive-use appliances and equipment have relatively high up-front costs compared with the disposable-income levels of prospective entrepreneurs and small businesses, but they provide clear opportunities to generate or increase revenue. Financing the up-front costs of the appliance—whether from a mini grid operator or a third party—will be necessary to increase productive uses of mini grid electricity. ESMAP estimates that approximately $3.6 billion in microfinance for 3 million income-generating appliances is needed under the scenario in which Sustainable Development Goal 7 is achieved, in part through the development of 200,000 new mini grids.

2018). Appliance financing schemes are therefore needed for end users to overcome up-front costs of appliances through either the mini grid developer's "own-managed" financing facility or mechanisms managed by third parties, such as financing agencies, MFIs, or equipment sellers (NREL and E4I 2018).

Financing by third parties

Involving third parties as asset-financing companies lets developers remain focused on their primary activity—leveraging technology, competency, and capacity (Factor[e] Ventures 2020). Partnerships with pay-as-you-go companies for appliance financing services have been tested. Asset-financing companies such as Rent-to-Own in Zambia and EnerGrow in Uganda are emerging with a specific focus on financing appliances for on- and off-grid customers. Third parties, however, should tackle the issue of financial inclusion with end users, many of whom operate outside the formal financial system and often lack collateral. They often face high costs and short repayment periods for loans from the commercial banking sector in remote areas, especially when they want to develop new business activities. Women are particularly burdened by the lack of collateral and are less likely to have a bank account.[1] Many countries continue to have laws that restrict women's access to inheritance and land titling, which hinders their ability to access assets that can be used as collateral when securing a loan (World Bank 2020).

Third parties that finance productive uses include MFIs, community savings groups, rural electrification agencies, and ad hoc structures locally established by development partners, NGOs, and other local entities. As deposit-taking institutions targeting low-income people and microenterprises in developing countries, MFIs are well established and offer a variety of financing products. They also ben-

When trying to secure finance to purchase productive-use appliances and equipment, women are particularly burdened by the lack of collateral and are less likely to have a bank account. Many countries continue to have laws that restrict women's access to inheritance and land titling, which hinders their ability to access assets that can be used as collateral when securing a loan.

efit from existing customer bases and loan distribution networks. Not yet seen are equity investments by impact investors in productive-use technologies.

Development partners can support access to credit for equipment by increasing the awareness of financing agencies or equipment sellers regarding nontraditional proxies for creditworthiness and new approaches to assessing consumer risk (Cheney 2016). Lenders can use new sources of data—such as records of timeliness of phone bill payments, social network data, and mobile phone use—to determine the ability and willingness to repay of unbanked users (Baer, Tony, and Schiff 2013). Another option is to work through local governance structures.

Financing by the mini grid developers

In some cases, mini grid developers offer financing to their customers to support the acquisition of income-generating appliances and machines. One approach is to offer customers a fee-for-service model. In one example of this model, the mini grid company provides a productive hub and offers the use of income-generating appliances against the payment of a fee.

Another example comes from a deployment of 600 solar mills in Indonesia, Vanuatu, and Papua New Guinea funded by the United States Agency for International Development and implemented by Village Infrastructure Angels and Sumba Sustainable Solutions. Customers could trade goods and services (that is, share the production increase through sellable products made possible by time savings) for the use of income-generating appliances. This approach has demonstrated positive results, guiding end users through time savings gained from the mills and longer productive hours gained through nighttime lighting to make tradeable products. The approach proved particularly efficient and robust during the COVID-19 lockdown, when cash in the communities was tight and village agents who disbursed noncash payments fared better than those dealing only in cash (Village Infrastructure Angels 2019).

Offering financing directly to productive users enables the developer to better monitor its strategy toward productive clients, including whom to connect and what appliances they choose. Controlling the type of appliances connected to the mini grid and favoring high-quality equipment may facilitate system management and result in better operational efficiencies. As an example, a lease-to-own model (or on-bill financing) could enable end users to pay 30 percent of the purchase price up front, paying the rest to the mini grid operator month by month for a certain period through the electricity bill (NREL and E4I 2018). This mechanism helps end users, who pay less interest to the operator than they would to a commercial lender.

In Tanzania, Jumeme, a private operator, has run a 90 kW solar mini grid in Bwisya on Lake Victoria since 2016. Its presence has allowed for the automation and expansion of existing businesses (grain milling, carpentry, and bicycle repair) and supported the emergence of new businesses (egg incubation, ice block production, and metal welding). The company runs a shop selling appliances in the largest village. It has helped Jumeme avoid technical issues and control consumption by ensuring the use of effective and adapted equipment. Small and medium enterprises acquire appliances on credit (usually for about six months) provided by the mini grid operator. About 20 businesses have received appliances through in-house financing (USAID 2018).

This model may impose a financial burden on the mini grid developers' balance sheets, however, and divert the developer from its core business. It implies managing software systems for managing appliance loans and "pay-as-you-go" lockout systems in parallel with maintaining a billing system (Factor[e] Ventures 2020). Mini grid developers do not necessarily have the skills or expertise to handle in-house financing.

Once operational, mini grid developers should monitor users for one to two years after their connections. Monitoring will enrich their knowledge of the demand dynamics from productive-use appliances and help them address customer issues as—or even before—they arise. By monitoring demand, Vulcan Impact Investing (which owns about 10 mini grids in rural Kenya) found that the average revenue per user generated from the 10 percent of its clients that are small businesses was five times greater than the revenue generated from the other 90 percent. Even though most customers consumed less than 250 watt-hours a day, they were still critical to mitigating the risk of losing larger clients (Blodgett and others 2017).

Monitoring productive users for one to two years after their connection to the mini grid can enrich a developer's knowledge of the demand dynamics from productive-use appliances and enable the developer to quickly address customer issues as—or even before—they arise.

WHO ORGANIZES PUE PROGRAMS?

MINI GRID DEVELOPERS

As the providers of electricity to the end users of income-generating machines and appliances, mini grid developers are one of the main entities that can lead a PUE program. In particular, they can take a lead role in all six steps outlined above. In Step 1, they can inform the long list of high-impact opportunity communities by directing analysis toward communities that they are planning to serve. Similarly, they can use the data collected in Step 1 to inform their expansion plans. In Step 2, mini grid developers will be engaging with communities already, as part of their community outreach activities, so they can play a lead role in identifying prospective PUE customers, local community leaders, local finance providers, appliance suppliers, and even district-level government officials. Mini grid developers also have the technical knowledge to assess the technical and economic impacts of connecting different appliances and machines to their networks, and thus are in a good position to lead on Step 3. This can also help ensure that the PUE program targets appliances that are attractive to the mini grid developer. For Steps 4 and 5, the developer can also take a leading position in organizing and implementing the road shows, although logistical and marketing support from local, regional, or national governments can facilitate large-scale rollout of road shows. Lastly, the mini grid developer is one of the three main actors in Step 6, and can coordinate the on-the-ground activities of appliance suppliers and local finance entities after a road show.

Even if the mini grid developer takes the lead in organizing the PUE program, they will still need the support of the other stakeholders—indeed, it requires collective action toward a common goal. Orchestrating a PUE program, particularly on a large scale, is a resource-intensive activity, requiring not just money but also capabilities, networks, and legwork. As a result, the overarching recommendation is that mini grid developers can be the driving force behind a PUE program, but the program itself will need resources (time, money, and people) from a variety of stakeholder groups. And, in some cases, it might also make sense for other entities to take a coleading role in organizing the PUE program alongside the mini grid developers– notably, governments and local change agents. The following sections describe how these two stakeholder groups can organize, or help organize, PUE programs.

GOVERNMENT AGENCIES AND POLICY MAKERS

Government agencies such as rural electrification authorities or agricultural extension programs hold a strategic position in fostering productive use demand because of their national-level influence. They can serve as a coordinating agency to supervise and facilitate collaboration among stakeholders involved in promoting PUE (such as NGOs, developers, local communities, and equipment suppliers).

Operational support from rural electrification agencies can include designing and implementing comprehensive approaches that enhance the PUE in agricultural, industrial, and service sectors, for example, by enhancing the knowledge and skills of small and microbusinesses on how to use their newfound electrical and motive power for profitable enterprise. Additional enabling interventions could include, for example, strengthening the technical and financial management capacity of women's enterprises, expanding access to markets, creating linkages and access to financial products and services, enhancing extension or business development services, and possibly addressing discriminatory land laws. As an interface between mini grid developers and other stakeholders, rural electrification agencies can pursue these activities through the signature of individual memoranda of understanding with developers to formalize their collaboration and precisely define roles and responsibilities. A deep understanding of local socioeconomic dynamics is critical, however, to ensure these interventions succeed.

Partnering with other stakeholders enables rural electrification agencies to improve such understanding and build their capacity on the topic of productive uses. Partnerships could include engagement with in-country sectoral associations, microbusiness support entities, aid agencies and donors, governments, NGOs, private-sector firms, and researchers. For example, a rural agency could contract directly with competitively selected local NGOs to assess the market and identify and promote activities in close collaboration with developers. These contracts can be structured in two phases. The first phase includes conducting surveys to identify and assess productive potential and building the interface with other sectors or programs. During the second phase, the NGO designs and launches marketing and promotional campaigns to build capacity and awareness among entrepreneurs. The contract with the NGO would define targets, objectives, and implementation frameworks to measure the NGO's

Government agencies like rural electrification agencies and agricultural extension programs hold a strategic position with regard to the productive use of energy, able to design and implement comprehensive, multistakeholder productive use in agricultural, industrial, and service sectors. These government-supported initiatives can also impart knowledge and skills to micro and small business, including, for example, how to use newfound electrical and motive power for profitable enterprise, strengthen the management capacity of women's enterprises, improve access to markets, create linkages and access to financial products and services, and enhance services.

performance against indicators such as the amount of investment made in productive equipment, the amount of electricity supplied to productive users, and the number of additional businesses connected. The contract should provide enough room for NGOs to tailor their strategies and approaches to address local constraints and the specificities of each community.

Two examples of concerted, coordinated, government-supported programs are offered in box 3.1, on the Infrastructure Development Company Limited's program in Bangladesh, and box 3.2, on Ethiopia's efforts to introduce productive uses into its mini grid–based rural electrification program.

LOCAL CHANGE AGENTS

Local change agents such as village councils and committees, NGOs, and civil society organizations can also support productive uses and facilitate interactions among local businesses, mini grid operators, and equipment suppliers.

NGOs and civil society organizations have demonstrated that they can be successful partners for tasks that require substantial and continued support. Their diverse skills (technical, social, and financial) combined with their local presence allow them to work with entrepreneurs and coordinate with stakeholders in the field. Beyond identification of productive uses and promotional activities, NGOs could do business development, advising small enterprises on business challenges. Field-based teams give NGOs the ability to analyze market opportunities and assist entrepreneurs in preparing their business models and apply for credit, while coordinating with mini grid developers on how to provide adequate connections.

MFIs, small business development centers, chambers of commerce, and small business accelerators could also be mobilized. Implementation units of agriculture and rural

Coordinated, concerted efforts to promote productive uses of electricity have been quite successful, in one case (Bangladesh) increasing customer uptake by almost 500 percent.

development programs, microfinance organizations, appliance companies, energy service companies, municipalities, regional/district officials, and local associations are all important stakeholders. Coordinating all of them requires institutional support, which could be achieved through a platform that facilitates dialogue.

TIMING PRODUCTIVE USE PROGRAMS FOR MAXIMUM EFFECT

When should the programs launch? The answer is short and simple: Steps 1–5 should begin as soon as planning for mini grid deployments starts. Step 6 should coincide with the arrival of the mini grid.

Steps 1 through 6 can then be repeated throughout implementation not only to consider new data and learn from previous iterations but also to maintain momentum and customer anticipation for expanded electricity access and its benefits.

Indeed, the activities presented in this chapter should be sustained throughout the lifetime of a mini grid system, with new geospatial analyses to be conducted every year or every other year, and Steps 2 through 6 undertaken at least once per year.

WHAT'S NEXT?

Boosting productive use nearly ensures the chances of a mini grid's success by offering an everyone-wins scenario for developers, entrepreneurs, households and communities, and national utilities. More systematic and concerted efforts are required, however, to promote, finance, and ultimately boost the uptake of PUE. At the same time, developers and potential productive-use customers need to understand the economic and technical characteristics of income-generating machines and appliances to be able to make investment decisions accordingly. Successful examples of PUE programs, such as those described in boxes 3.1, 3.2, and 3.3 below, show what is already possible, but a dramatic scale-up of national mini grid markets will require greater efforts from government agencies across sectors, developers, MFIs, NGOs, and other stakeholders along the income-generating appliance value chains.

BOX 3.1

HOW IDCOL INCREASES PRODUCTIVE USES OF ENERGY IN SOLAR-HYBRID MINI GRIDS IN BANGLADESH

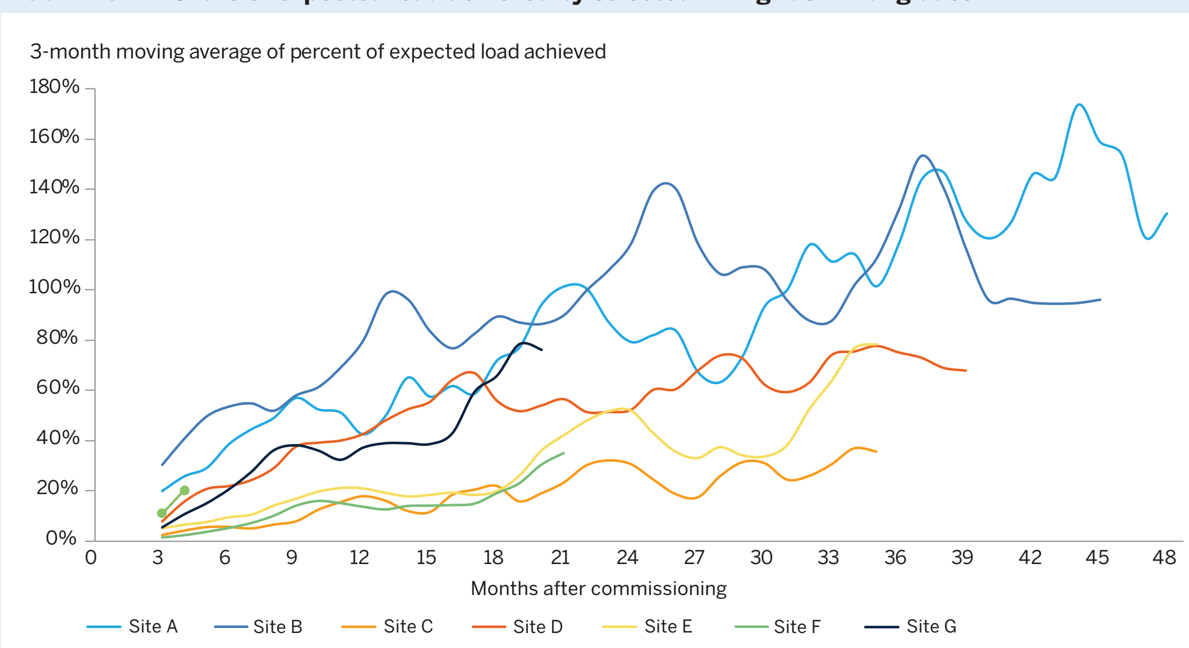
The Infrastructure Development Company Limited (IDCOL) is providing concessional project financing to enable mini grid developers to deliver improved energy services via solar and solar-hybrid mini grids in remote parts of Bangladesh. More than 20 mini grids are in operation, with a total capacity of almost 5 megawatts-peak, and many more mini grids are planned for development. Sites are located primarily on islands not reachable by grid extension because of rivers often several kilometers wide in the monsoon season.

Mini grid sites have their own microeconomies, which are usually a mix of seasonal activities (such as fisheries, agriculture, milling, husking, and oil pressing) and wood production and sawmills. They also host a range of supporting businesses: carpentry and metal working shops; diesel engine repair shops; and many small retailers of services, products, and foods in the local bazaars, which are open in the evenings. Almost all productive energy use is provided by dedicated diesel engines with belt drives. Most households and shops have had access to stand-alone home systems for several years, under IDCOL's home system program.

Mini grids have clear, long-term development impact potential, but uptake of productive uses varies widely and—despite careful and detailed consumer surveys and expected load analysis—customer uptake was lower than predicted (figure B3.1.1). After three years, the financials under the IDCOL package show that only two out of seven mini grids reached their expected level of demand. Eleven were only recently commissioned, while the remaining mini grids for which data are available, struggle to reach the expected level of demand.

Uptake lags were particularly striking among larger mini grids (>200 kilowatts-peak) at which productive energy use was expected to account for 40–65 percent of demand. Daytime productive energy users were not connecting as planned, and in some cases, larger nighttime customers were saturating plant capacity more quickly than expected. Higher investment in addition to low demand and underutilization of the plant exposed these mini grids to negative cash flows and risks.

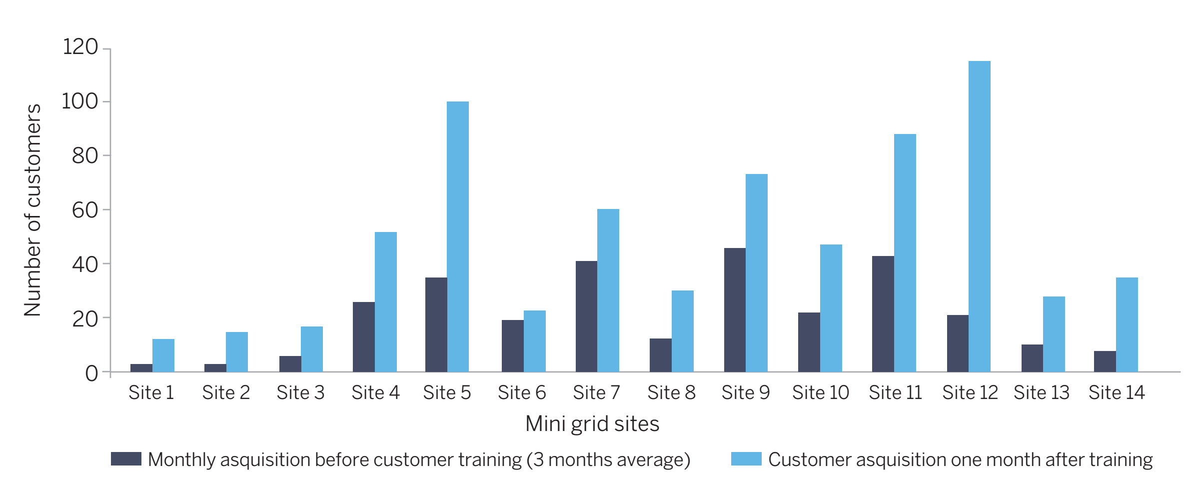
FIGURE B3.1.1 • Share of expected load achieved by selected mini grids in Bangladesh



Source: IDCOL analysis.
Note: Figures show three-month moving averages. Site names are not mentioned for confidentiality purposes.

BOX 3.1, *continued*

FIGURE B3.1.2 • Effect of extensive customer awareness campaigns on uptake



Source: IDCOL.
Note: For purposes of confidentiality, sites are not named.

To increase the uptake of productive uses of electricity, IDCOL launched intensive, three-day customer awareness campaigns starting in October 2017, conducted by international experts and trainers from major equipment manufacturers. These campaigns combined customer training with public shows featuring folk singing and street theater, increasing productive-use customers and total customer acquisition by nearly 500 percent (figure B3.1.2).

IDCOL also arranged for training in management skills and development to strengthen understanding among mini grid developers about business opportunities. It also required all funded mini grids to install remote, real-time monitoring capabilities for instantaneous troubleshooting and tracking of historical trends. Meanwhile, IDCOL provides assistance in mini grid–powered irrigation, which can greatly increase utilization rates. In-house agriculturists identified irrigation potential for the grid area, since almost all arable land is under cultivation and has three cropping seasons. Guidance was provided on irrigation services for farmers at lower cost than their diesel-powered pumps.

IDCOL continues to broaden its training program to sensitize developers and operators on leveraging the use of electricity to maximize socioeconomic benefit. Training content is under development for the gender dimension in mini grid interventions, highlighting the benefits of social facilities, streetlighting, schools and clinics, rickshaw charging stations, and so forth. This information will enable entrepreneurs to connect community benefits with their own sustainability as businesses. In addition, IDCOL plans to incentivize daytime loads via time-of-use packages and financing conversion packages ($120–$400, depending on industry and load). Most of the larger sites need softer loan finance terms (longer grace periods and terms) to be viable for the sponsor. A sponsor will need to play the lead microfinancing role.

Source: Analysis by IDCOL and the World Bank RERED II team.

BOX 3.2

RURAL, PRODUCTIVE USES OF ELECTRICITY: LESSONS FROM ETHIOPIA

In 2019, the government of Ethiopia issued the updated National Electrification Programme (NEP 2.0), which formalized its ambitious goal of universal electrification by 2030. The NEP 2.0 detailed a large-scale rollout of mini grids both through the national electrical utility (the Ethiopian Electric Utility, or EEU) and through engaging the local and international private sectors. Since then, the government, primarily through the Ministry of Water and Energy, has been developing and deploying programs and projects with the support of development partners like the World Bank, the African Development Bank and its Sustainable Energy Fund for Africa (AfDB SEFA), the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), the Rockefeller Foundation, the Foreign, Commonwealth and Development Office, the Ikea Foundation, the Rocky Mountain Institute, and many others.

One important example is the $500 million Access to Distributed Electricity and Lighting in Ethiopia (ADELE) project, financed by the World Bank. Approved in 2021, ADELE is a comprehensive, national-level rural electrification program powered through the grid, mini grids, and stand-alone solar solutions. So far, $270 million had been committed to the mini grid program alone. The mini grid component under ADELE is being implemented by the EEU and covers two key modalities for rolling out greenfield mini grids. As a substantial scale-up of the utility-led model, the EEU expects to deploy about 200 mini grids over the coming years through various engineering, procurement, and construction (EPC) and operation and maintenance modalities; it is also supported by the launch of a large-scale, private-sector-led, performance-based grant program.

Through ADELE and other programs, the Government of Ethiopia has chosen to center all its mini grid and off-grid rollout activities around income-generating uses of electricity: identifying, prioritizing and stimulating them. In practical terms, this means that it has been assembling a holistic and up-to-date map of every site across the country with the most agricultural and productive potential, to plan targeted mini grid developments. This comprehensive approach has emerged from partnering with the World Bank, the Ethiopian Agricultural Transformation Agency, the Rockefeller Foundation, AfDB SEFA, and others, putting together cutting-edge geospatial analyses and overlaying many layers of data and maps.

To foster productive uses, ADELE is conducting analytics to get a better understanding of the potential for a new appliance result-based financing scheme. This scheme would complement the ongoing project activities and maximize the transformational economic impact in the communities targeted with mini grid rollouts. Under the utility-led modality of ADELE, the EEU intends to build in a number of activities to improve appliance availability and appliance financing for the communities expected to be electrified by EEU with mini grids. Such activities are expected to range from community engagement and appliance demonstrations to connecting communities to microfinance institutions, nongovernmental organizations, appliance distributors, and so on.

The Ministry of Water and Energy, in partnership with the Agricultural Transformation Agency and with extensive support from the Rockefeller Foundation and AfDB SEFA, is currently piloting nine mini grid sites with major agricultural and irrigation potential, as part of the Rockefeller Foundation-supported Distributed Renewable Energy Agriculture Modalities (DREAM) project. The pilot is intended to test a grant-supported, private-sector-led modality, with results-based financing from Rockefeller and concessional financing expected from AfDB SEFA.

Finally, the Rockefeller Foundation is preparing a Productive Use Appliance Financing Facility (integrating grid, mini grid, and off-grid electrification), with support from the Collaborative Labeling and Appliance Standards Program (CLASP) and Nithio. The facility should make income-generating appliances more affordable and accessible.

Source: ESMAP and the World Bank ADELE team.

BOX 3.3

LESSONS FROM A UTILITY-NGO PARTNERSHIP IN INDONESIA

Indonesia's Rural Grid Electrification projects in the 1990s, funded by the World Bank, also promoted productive uses. The lessons learned then are relevant for mini grid development today (Finucane, Besnard, and Golumbeanu 2021). They show how partnerships between energy providers (in Indonesia the national utility PLN) and local nongovernmental organizations (NGOs) built an ecosystem that boosted rural electrification through jobs, income, and productivity. Fieldwork helped to tout the potential role of NGOs as channels to promote PLN service. NGOs in rural Indonesia had impressive operational capabilities, experience in the marketing of changes, and experience with rural cottage and small businesses and the poorest households. With the support of NGOs, project stakeholders held consultations in order to better understand the characteristics of current and potential customers and the reasons behind the slow take-up of grid services and design-marketing campaigns.

To run the campaigns, PLN contracted experienced NGOs, skilled in outreach to families and community groups in rural literacy, health, nutrition, and microenterprise development. The goal was to determine strategies, marketing mixes, and communication methods suitable for the different village contexts, and conduct a series of time-limited marketing campaigns. The complexities of each village would be different, for instance, in leadership, proximity to larger markets, landholding and crop patterns, and existing nonfarm income-generating activities, and the NGOs would need to craft their marketing to fit the specifics of the individual businesses and their contexts.

For the NGOs, the task was to market and sell an already designed, deployed, and priced service (rural business services) in ways that would motivate purchase decisions in the different rural and business contexts. The role of the utility, PLN, was to manage the program, including: (1) NGO contracting, supervision and payments; (2) village selections, which were expected to be recently electrified communities; (3) target setting (by village, NGO, and key metrics); (4) vetting of NGO marketing materials for accuracy; and (5) performance and impact monitoring and reporting. An effective outreach program, such as Rural Business Services, can improve load use and generate economic activity and employment.

Although the grid-based activity implies an extensive service area and varied clientele, the concept of customer-responsive service that makes good use of capacity is transferable to other supply situations. The success of this approach stemmed mostly from the holistic, opportunistic, context-specific design process, a process that outsourced marketing to a local NGO as a possible market entry point.

Source: ESMAP analysis of World Bank project documentation.

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NOTES

1. Global Findex database: https://globalfindex.worldbank.org/.

CHAPTER 4

ENGAGING COMMUNITIES AS VALUED CUSTOMERS

CHAPTER OVERVIEW

This chapter focuses on the role of community engagement in mini grid projects and the impact that inadequate or insufficient community engagement can have on their sustainability. It begins by underscoring the value of continuous community engagement through every phase of the mini grid project—starting at the early design and planning stages, through financing, procurement, operation, and maintenance. It next delves into concrete steps that a mini grid developer can take at each project phase to engage the community. The chapter concludes with examples of innovative ways to scale up community engagement across multiple projects at the national and international levels.

WHY IS COMMUNITY ENGAGEMENT IMPORTANT?

As shown in previous chapters, mini grids offer a least-cost option for providing reliable, affordable electricity to millions of people now living without access, people who would otherwise have to wait years for the main grid to arrive.

However, bottlenecks must be cleared before mini grids can take off on a large scale. Some, such as access to finance, workable regulations, and enabling business environments, are systemic and best addressed at the national and international levels. Others are highly localized, such as the specific socioeconomic, cultural, and environmental characteristics of each community to be electrified with a mini grid. A review of relevant literature and interviews with mini grid developers[1] demonstrates that, to identify the best technical solution for a given site and ensure its long-term sustainability, it is essential to continuously engage with the local community and determine the optimal fit between the community and the new mini grid.

Existing evidence points to several reasons why community engagement is essential for the successful implementation of mini grid projects—and rural electrification more broadly. Case studies reviewed by Crousillat, Hamilton, and Antmann (2010) reveal that rural electrification programs benefit greatly from local participation. Involving communities from the start can help improve the design (Peru, Vietnam), avoid disputes and gain local support (Bangladesh), mobilize contributions in cash or in kind (Nepal, Thailand), and increase local ownership, thus contributing to operational sustainability. In line with this, a study covering mini grid projects of the Energy and Environment Partnership (EEP) Trust Fund in 13 countries in Sub-Saharan Africa concluded that building strong relationships in the community is critical to the financial sustainability of mini grids (EEP 2018).

Community engagement is beneficial at all phases of a mini grid project, as discussed below.

DESIGN AND PLANNING:

- As the primary customer of the mini grid, the local community should be the first to be consulted and engaged if the mini grid developer is to obtain the "social license" (that is, buy-in and acceptance from the community) to operate the system.
- The local community has the best understanding of the surrounding conditions and resources (Mishra and Sarangi 2016), which can help the mini grid developer choose the optimal technology mix and operating model.

Existing evidence highlights reasons why community engagement is essential for the successful implementation of mini grid projects: improving the design (for example, in Peru, Vietnam); avoiding disputes and gaining local support (Bangladesh); mobilizing cash or in-kind contributions (Nepal, Thailand); increasing local ownership and operational sustainability; and ensuring financial sustainability (for example, in 13 Sub-Saharan African countries).

The central role of community engagement in ensuring the long-term sustainability of mini grids is further illustrated by mini grid failures linked to insufficient local community involvement. Overlaying the common causes of mini grid failure with the typical stages of mini grid development indicates that (1) more than half of the causes of failure involve inadequate community engagement, and (2) community engagement plays a particularly decisive role in the stages that precede the commencement of operations.

- During this early stage, community engagement will ease communication with local authorities, identification of reliable and capable local (technical and sales) staff, and identification of prospective customers (including anchor clients and businesses).
- Early community engagement will facilitate land acquisition or right of use for the project, assist in obtaining good socioeconomic and cultural information from prospective customers to underpin the business case of the project, and inform the community as well as the project developer about expectations, requirements, roles, and responsibilities.
- During this phase, a mini grid developer will use its contact with the community to accurately assess customer demand[2] (including willingness and ability to pay), compare the likely demand with prospective revenue streams (tariffs and subsidies), and reach conclusions about the project's viability.
- In addition, during this phase, community engagement will enable the developer to gauge residential and business energy needs and expectations, and to recognize the roles of men and women as energy consumers and stakeholders. Raising awareness and engaging in open dialogue will allow communities to make well-informed decisions about their mini grid options, improving the quality of "service fit" (in terms of situation, costs, payment modalities, business case) and protecting the project's viability by making customer satisfaction more likely. It will also assist in market segmentation.

FINANCING, PROCUREMENT, AND CONSTRUCTION:

- The information obtained during the design and planning phase will yield data useful in developing the project's tariff structure and improving its risk profile for investors.
- In the case of a project backed by a public-private partnership, transparency in the tender procedure will also raise the community's trust in the project.
- In some instances, mini grids may also recruit community members to install the systems.

OPERATIONS AND MAINTENANCE:

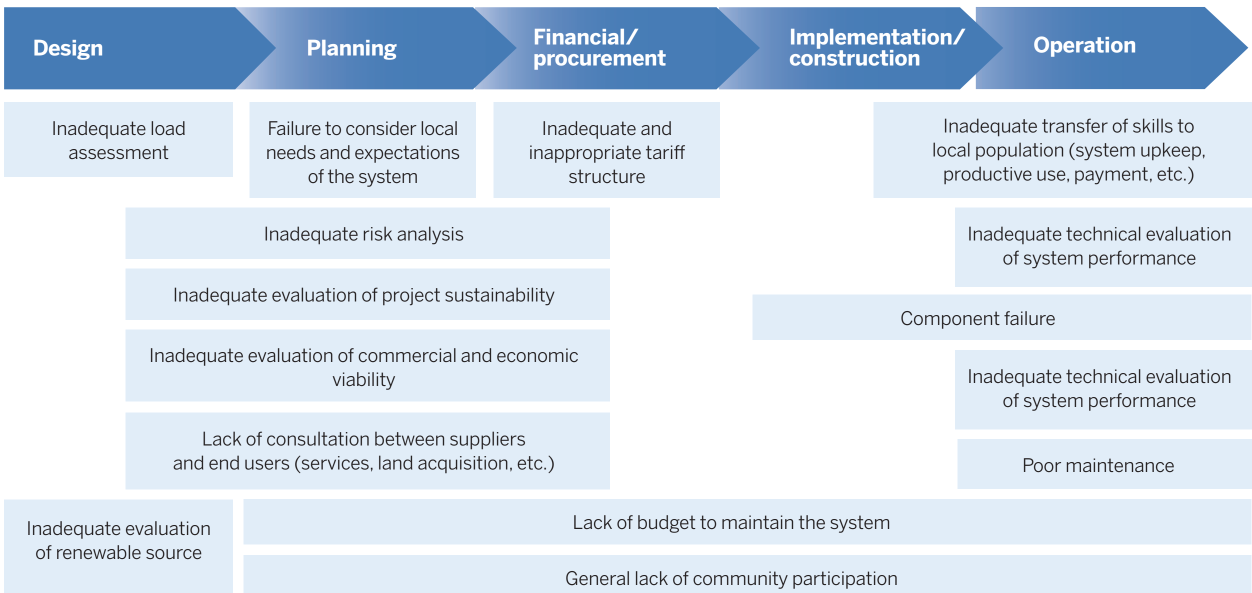
- Community engagement will improve the communication between operator and customer, creating trust and mutual understanding about system repairs and other matters.
- Assuming that sufficient capacity has been developed within the community, the participation of locals in the setup, maintenance, and repair of systems has been anecdotally shown to reduce the frequency of repairs (Fahey and others 2014) and increase the likelihood of more judicious use of systems by the community.[3]
- At this stage, the developer can also set up training sessions to stimulate demand and drive consumption among productive users.
- In addition, mini grid developers often recruit local village agents to assist in sales and ensure rapid responses to customer complaints and concerns.

The central role of community engagement in ensuring the long-term sustainability of mini grids is further illustrated by mini grid failures linked to insufficient local community involvement. An extensive study of mini grids in Fiji found many of them failing as a result of various technical and nontechnical issues (Dutt and Macgill 2013). Overlaying the causes of failure identified in the analysis with the typical stages of mini grid development (as shown in figure 4.1) indicates that (1) more than half of the identified causes of failure have a community engagement element (shown in the boxes outlined in red), and (2) community engagement plays a particularly decisive role before operation commences.

In another comprehensive analysis, the main risks of mini grid deployment were evaluated in terms of the potential impacts of the risk and the probability of the risk occurring (Manetsgruber and others 2015). Proper community engagement can significantly limit the exposure of mini grids to some of these risks (table 4.1).

Community engagement can thus be considered an essential component of the mini grid process during the design, implementation, operation, and maintenance phases. Based on existing evidence and interviews with mini grid developers, the next section will explore the principal steps that a mini grid developer can take during each phase to engage the local community.

FIGURE 4.1 • Typical issues hindering the mini grid development process



Source: ESMAP analysis of Dutt and MacGill (2013).

TABLE 4.1 • Potential for community engagement to limit mini grid risks

Risk	Community engagement aspect	Impact	Probability
Nonpayment of electricity bills as a result of either inability or unwillingness to pay	Inadequate assessment of customers during planning, limited social consensus regarding grid services, inadequate services	High	Medium
Unpredictable electricity demand, negatively affecting project sizing and cost structure	Poor feasibility assessment that fails to address "A-B-C" considerations[a]; insufficient promotion of services to productive users	Medium to high	Situational
Insufficient social acceptance leading to poor embedding of the project in the sociocultural context (for example, social services, agricultural activities)	Unfavorable public opinion, lack of transparency, insufficient involvement and development of local capacity	Moderate	Low to medium
Theft (of materials for which there is a secondary market) and vandalism (particularly in cases of conflict of interest among stakeholders)	Inability to create a "social compact"; insufficient understanding of local power structures	Moderate	Medium to low
Defective operation resulting from miscommunication between business and customer; conflicts of interest	Insufficient understanding of "A-B-C" expectations, needs, and limitations; insufficient understanding of local power structures	Low to medium	Medium
Unfavorable mini grid regulations do not permit attractive tariffs (for either supplier or consumer) or competition	Insufficient understanding of "A-B-C" expectations, needs, and limitations; insufficient consumer organization	High	High
Policy and planning fail to sufficiently stimulate productive and income-generating activities, undermining the viability of the investment	Insufficient market segmentation, limited productive-use awareness, and insufficient access to appliances for productive uses	High	High

Source: ESMAP analysis of Manetsgruber and others (2015).

a. In mini grid market segmentation, A-B-C refers to anchor, business, and community customers.

COMMUNITY ENGAGEMENT THROUGHOUT THE MINI GRID PROJECT CYCLE

Examples from the field indicate that successful community engagement begins with raising awareness in the potentially connected community. It continues during adoption and productive operation, as satisfied customers promote the technology to their neighbors and friends. Each community requires a flexible approach, with a clear understanding of the local socioeconomic and cultural characteristics, and a potential tailoring of the promotional tools, materials, and channels.[4] The typical mini grid project cycle, outlined in figure 4.2, maps these steps.

> Successful community engagement begins with raising awareness in the potentially connected community. It continues during adoption and productive operation, as satisfied customers promote the technology to their neighbors and friends. Each community requires a flexible approach, with a clear understanding of the local socioeconomic and cultural characteristics, and a potential tailoring of the promotional tools, materials, and channels.

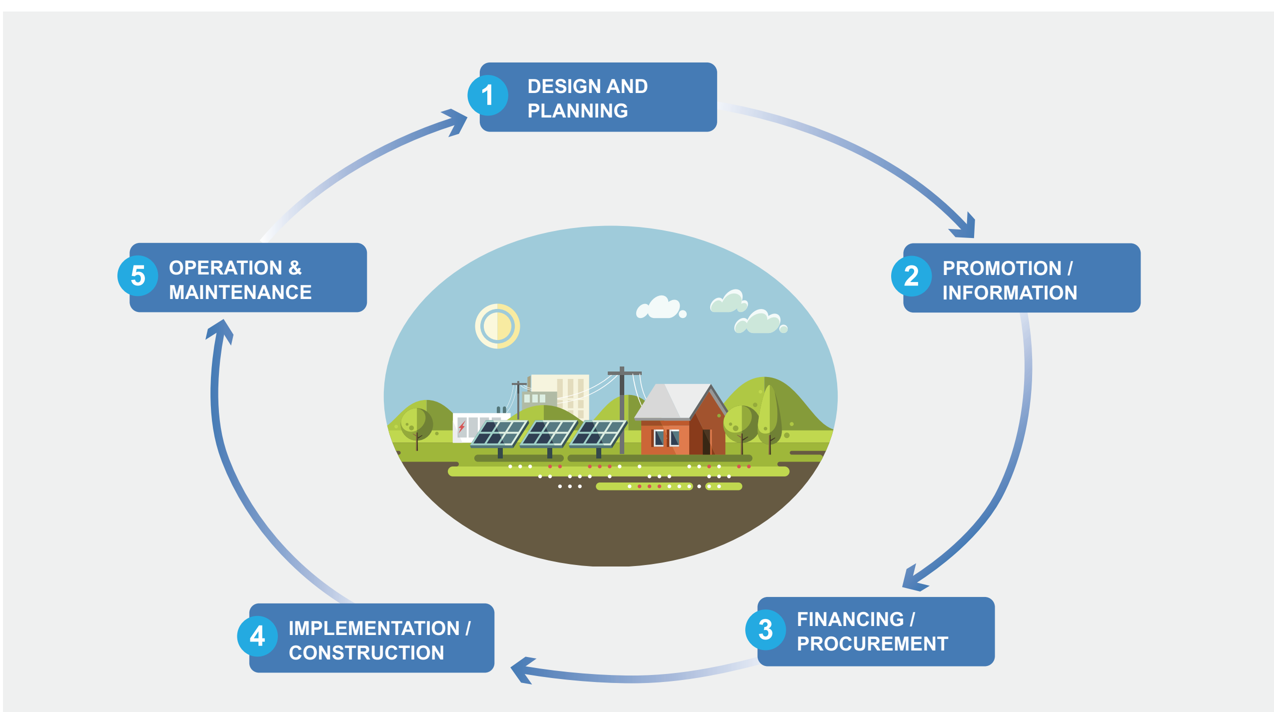
DESIGN AND PLANNING PHASE

During the design and planning phase, community engagement can

- Establish a relationship between local authorities and the project developer
- Identify partners, local stakeholders and authorities, and local staff
- Improve community confidence in the project developer or service provider
- Provide insight into local expectations of the technology and services
- Improve the assessment of demand and load
- Create awareness of the technology and the potential uses of electricity, and develop a portfolio of prospective customers
- Assist with segmentation of the market into A-B-C customers
- Profile (and segment) potential customers or archetypes and forecast their ability to pay (ATP) and willingness to pay (WTP).

In this initial phase, community engagement is preceded by a preliminary market assessment, and public data are analyzed by the developer to identify potential mini grid sites. If the developer is new to the country, this exercise is also likely to include an evaluation of national regulatory, policy, political, economic, financial, and environmental considerations.

FIGURE 4.2 • Typical mini grid project cycle



When a site or a group of potential sites has been identified, the developer will typically conduct a site visit to assess conditions on the ground, accompanied by a brief survey of residents and contacts with the local government. This step—outreach to the local authorities and, in particular, village chiefs—is emphasized by developers as key to demonstrating respect and securing the favorable attention of the village residents.[5] Once communication with the local village representatives is underway, the developer can go on to sign a memorandum of understanding with the local authorities, discuss land acquisition or rights of use, and pursue any subnational government approvals that may be required.

Following this, the developer will typically dispatch a full customer survey team to carry out household-size surveys using tablets and standardized survey instruments. For larger developers that operate in several markets, these surveys are often adapted to the local context.[6] The objective is to gain a deep understanding of how to satisfy customers' needs. Good surveys will help developers gain an understanding of six areas that ultimately affect the satisfaction of their customers.

Customer satisfaction is directly influenced by four considerations, all of which can be addressed in the survey questions:

- *Livelihood:* The potential role of mini grid electricity in domestic or commercial activities and the effect the services may have on employment, entrepreneurship, and quality of life
- *Influences* on the mini grid's activities, including seasonal labor migration; national and regional media; market effects of nearby major towns (particularly if those towns are connected to the national grid); and existing marketing campaigns, including those developed by the government
- *Aspirations* of prospective consumers, including education, careers, and communication
- *Consumption:* Need-based or additional consumption, return on investment, purchasing behavior.

These considerations are in turn influenced by

- *Community:* The role of the family, gender, and community institutions
- *Infrastructure:* Energy and appliance markets; available technology, the existing infrastructure for power and information and communications technology, and the availability of finance and services (health care, education).

Customer profile

Where possible, the information gathered during an initial survey of potential customers is supplemented with the findings of a domestic energy baseline study and, in a later stage, user surveys. The surveys inform a detailed customer profile that ensures prospective customers are effectively served. In practice, these profiles are further differentiated—by type of farming, type of enterprise, and so on.

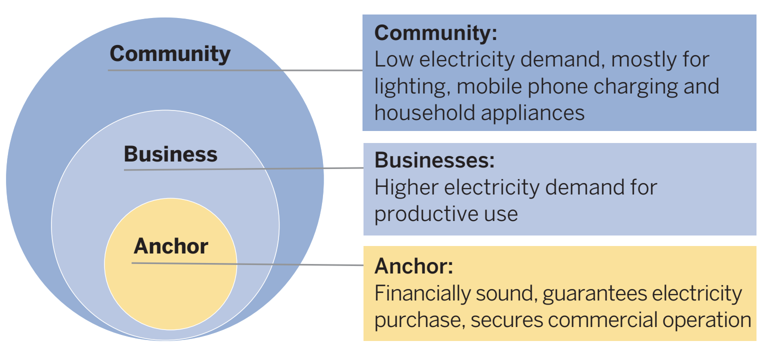
The customer profile prepared by the developer based on the initial data gathering can be used to inform a gender-specific approach to connecting customers. In such an approach, the cultural and socioeconomic nuances and potential barriers to women's participation are taken into account.

Segmenting the market into A-B-C customers

An additional approach to segmenting the market further—into A-B-C customers—may enhance the robustness and viability of a mini grid. The A-B-C approach is a business approach rather than a community engagement methodology, but it can offer added value in helping the mini grid developer identify A, B, and C client segments through proper community engagement.

The A-B-C business model (figure 4.3) was first developed by companies such as OMC Power in India, which built mini grid companies around anchor clients (GIZ 2014). Under the model, the supply of electricity from the mini grid is prioritized for an anchor load customer, typically a commercial or industrial user, followed by businesses (shops, small enterprises, and so forth), and then households. The A-B-C model stipulates that the size of the generation unit is typically determined primarily by the demand needs of the anchor load (Bhati and Singh 2018), with the aim of securing stable and predictable revenues. OMC and other mini grid operators in India have used telecommunications towers close to population centers to scale up mini grid systems and expand into surround-

FIGURE 4.3 • The A-B-C model



Source: GIZ 2014.

ing businesses and households. Agroprocessing and mining activities have also frequently been used in Africa to provide reliable loads.

A study of mini grid projects in 13 countries in Sub-Saharan Africa (EEP 2018) finds that "the most financially sustainable mini grids use an A-B-C strategy: first, identify and negotiate an agreement with an anchor load client (often in agroprocessing); then identify, or help develop, small local businesses; and only last target domestic consumers." Or, as Kennas and Barnett (2000) put it in their microhydro assessment: "It is easier to make a profitable micro-hydro plant socially beneficial than to make a socially beneficial plant profitable."

Growing evidence (discussed in detail in chapter 3) suggests the need to increase the prioritization of small and medium-size enterprises—the B of the A-B-C model—as income streams for the mini grid. This is largely because securing anchor clients can be a challenge, particularly in rural economies based on subsistence agriculture and small-scale artisan networks. In addition, anchor clients may have unrealistic expectations about tariffs, and operators may become overreliant or even dependent on them, threatening their financial position.

Some developers have been combining multiple business clients to act as the anchor. In this approach, the mini grid's generation assets are sited near a cluster of small businesses that may be housed in the same building. This approach allows for mitigation of commercial risks and diversification of the mini grid customer base. A good example is the community engagement, load acquisition and micro-enterprise development approach (CELAMeD), which has been promoted by Smart Power India and implemented by several energy service companies in India—notably TARA Urja. CELAMeD is discussed in further detail in the next section.

Including both anchor and business clients will enable the project developer to connect households at affordable rates, because these clients (1) may cross-subsidize connection and consumption fees for households and (2) will consume the lion's share of the energy generated during the day, whereas household consumption tends to intensify during the hours before and after work.

> Segmenting the customer base into anchor, business, and community customers can enhance the robustness and viability of a mini grid. The A-B-C approach is a business technique rather than a community engagement methodology, but it can offer added value in helping the mini grid developer identify client segments through proper community engagement.

PROMOTION AND INFORMATION-SHARING PHASE

During the promotion and information-sharing phase, community engagement can

- Improve the information on mini grid services shared with the community
- Fine-tune customer segmentation
- Leverage women's social and trust networks to spread information
- Increase consumers' "energy education" on matters such as understanding energy bills, performing maintenance, handling grievances, and maximizing safety and health
- Select, record, and share early successful adoption stories.

The objective of this phase is to increase awareness of the technology, its services, and the facilities offered by the developer. Community engagement activities in this phase traditionally target fairs, radio, word of mouth, local extension services, construction activities, and—increasingly—social media. Marketing hubs are an additional engagement "tool," as described below. In addition, through billboards, social media, radio, and television, projects can target family members who migrated to urban centers, as they are often interested in helping parents gain access to electricity.

To build up their presence in the community after the initial site visits and meetings, mini grid developers often cohost workshops for community members with members of relevant cooperatives, nongovernmental organizations (NGOs), microfinance institutions, and financial institution workshops for community members. These workshops can be used to build awareness of (1) opportunities to connect income-generating and household appliances and machines to the mini grid; (2) agricultural applications of mini grid electricity; (3) financing available for the purchase of household, agricultural, and commercial appliances and machines; and (4) entrepreneurship and business training.

Establishing marketing hubs

For the community engagement process to be successful, the underlying communication platform must have sufficient reach and trust within the community. Some established mini grid companies have developed community engagement practices as a core capability. However, new entrants to the market are likely to have insufficient resources and skills to properly develop a robust community engagement process.

Marketing hubs are one solution that can help mini grid startups engage with their communities. These local platforms strengthen consumer confidence and allow for combined community engagement efforts between the mini grid developer and organizations over the entire project cycle. Strong candidates for marketing hubs are entities that perform local or regional network functions, exhibit entrepreneurial drive, and have a natural affinity with mini grid or off-grid electricity services.

Examples include savings and credit cooperatives, dairy or agricultural cooperatives, agricultural input dealers, and rural development NGOs. The project developer may support the marketing hubs with capacity building, a dedicated liaison or extension officer, and incentives for sales and extension activities.

The advantages of such hubs include lower operating costs (promotion, training, extension), access to a more targeted market, and knowledge sharing. In addition, hubs often perform initial client eligibility screenings and may serve as a physical location where microfinance institutions and other local financiers can meet their potential (or current) customers. The hub-hosting entity, on the other hand, benefits from being able to offer an additional service to its members.

Experience with marketing hubs from other sectors shows that a hub's activities must fit into its regular agenda, and the hub should not be converted into a "sales machine" for mini grid developers, as this erodes trust within the local community. When set up properly, marketing hubs can instead develop into "marketing beachheads" (Moore 1999), preparing the market for uptake by early adopters.

Sharing information with prospective customers

After prospective customers have a basic awareness of the technology, they will require more detailed information to properly assess its usefulness to them. It is important to ensure that the information provided is correct, unbiased, and comprehensive (addressing the merits, costs, and limitations of the technology).

The information will have to be provided by well-qualified project staff. At this stage, information can be shared either individually or in smaller functional groups (for example, hosted by local authorities, microfinance institutions, NGOs, or other community stakeholders). In addition, exchange visits to existing installations, where peers can share their experience, can be powerful sources of information.

Information should also be provided to local leaders, staff of value chain organizations, and financial institutions, as they are often consulted about innovative technologies and practices.

Engaging women as leaders of promotional and information-sharing activities

Energy service companies are increasingly engaging women in promoting their service. Women are well aware of the challenges that other women face, such as unique time constraints, household responsibilities, and energy needs. Their access to other potential female customers may be significantly less constrained by social or cultural norms than male sales agents in certain cultural contexts. However, despite women's potential to build robust distribution networks for energy solutions, especially in rural areas, they are still underrepresented in the sector.

One successful example of engaging women in promoting energy access is Solar Sister, an African initiative that recruits, trains, and supports female entrepreneurs to serve as last-mile distributors of clean energy products, such as solar lights, mobile phone chargers, and clean cookstoves. By 2012, Solar Sister had empowered 2,000 female entrepreneurs in Uganda, Nigeria, and Tanzania, who in turn provided solar and clean cooking solutions to more than 370,000 beneficiaries (Arc Finance 2012).

FINANCING AND PROCUREMENT PHASE

During the financing phase, community engagement can, on the demand side:

- Assist in ATP/WTP assessments and the development of a viable demand forecast
- Organize in-kind contributions (for example, construction, at both individual and community levels)
- Improve consumer access to energy and credit for productive-use appliances.

> Energy service companies are relying increasingly on women to promote their service. Women are close to their female customers, can more easily tap into social networks, and are well aware of the challenges that other women face, such as unique time constraints, household responsibilities, and energy needs. Their access to other potential female customers may be significantly less constrained by social or cultural norms than male sales agents in certain cultural contexts.

On the supply side:

- Improve the risk perspective of the project (detailed portfolio, WTP/ATP assessment, A-B-C segmentation, reliable load assessment).

Adequate financing is key to the sustainability of a mini grid. Customer financing plays an important role in this area for households and enterprises alike. It allows households to spread the costs of the connection over time and to finance their domestic and productive appliances. Innovative credit arrangements, such as pay-as-you-go and lease-to-own, are showing their potential in the scale-up of mini grid uptake and in enabling customers to gain access to appliances and equipment.

Mini grid developers may offer such financing options to customers directly, often through the support of bilateral or multilateral development partners. Support from the Rockefeller Foundation, for example, allows Nigeria's Havenhill Synergy to offer household and productive-use appliance financing to customers with 20 percent down and a 12-month payback period.[7]

In addition, the developer's staff and partners may help farmers and businesses during the loan application process and facilitate the relationship between the appliance supplier, the lender, and the customer.

IMPLEMENTATION AND CONSTRUCTION PHASE

During the implementation and construction phase, community engagement can

- Involve future stakeholders and recruit local human resources for construction and installation jobs
- Use the construction and installation processes as opportunities to promote the new technology to the surrounding community
- The construction phase provides an excellent opportunity for the developer to connect with prospective customers. The developer, who may already be joined by the local sales team, local leaders (including from marketing hubs), and possibly representatives from the national or local government, can invite local households and businesses to the construction site for the commissioning of the mini grid, thus allowing local residents to observe the system, ask questions, and sign up for service. If local community members were involved in building the system, they can be trained to engage with the audience on the expected benefits and purposes of the electricity produced by the system.

OPERATIONS AND MAINTENANCE PHASE

During the operations and maintenance phase, community engagement can

- Facilitate the registration and connection process
- Build consumers' capacity to contribute to O&M and safety
- Stimulate community dialogue on additional or improved services
- Encourage productive uses of energy
- Mediate disagreements among consumers, project personnel, and local authorities
- When local community members are engaged as part of the O&M team for the mini grid, activities will focus first on ensuring that local staff have a proper understanding of how to operate and maintain the mini grid system safely and in a way that ensures good customer service. Training sessions are usually held before and immediately after the installation of the system.

Many households and businesses will also require ongoing support to make the most of the electricity provided by the mini grid. From a commercial perspective, activities during the O&M phase focus on signing up new customers and ensuring growth in energy consumption to achieve the targets set to ensure financial solvency.

One example of such demand stimulation is the intensive customer awareness campaign launched in 2017 by the Bangladesh Infrastructure Development Company Limited (IDCOL) to support customer uptake and demand growth for 20 solar mini grids. The campaigns combined customer training with public events, such as folk songs, shows, and street theater. The comprehensive efforts have resulted in a five-fold increase in customers. Based on the success of the campaign, IDCOL is now developing training content focused on women, specifically highlighting the benefits of social facilities, street lighting, schools and clinics, rickshaw charging stations, and so forth, to enable local entrepreneurs to see the broader picture and make linkages between community benefits and the sustainability of their own businesses. A more detailed example of a government-supported community engagement initiative is described on the companion website to this handbook: www.esmap.org/mini_grids_for_half_a_billion_people.

Another community engagement tool that developers can leverage during the O&M phase is customer service centers (CSCs) (SNV 2008). These centers can be both virtual—with customers accessing the CSC by phone or online—and in person. The primary tasks of the CSC are to track mini grid functionality, address customer issues, and both track and increase overall customer satisfaction. CSCs will flag issues and relay them to the developers—for example, a string of customer complaints about the tariff may result in the developer holding a workshop to explain tariff options. CSCs can also relay customer questions and issues to other relevant entities. For example, the CSC can connect customers with local suppliers of household and productive-use appliances and can route customer concerns about lack of financing for income-generating appliances to a local microfinance institution.

CSCs may be established in-house by the developer or operated by a community organization or business. In addition, and increasingly, CSCs play a role in capturing the potential demand for mini grid electricity that exists in the community. The CSC will follow up with prospective customers identified in earlier phases of the mini grid's development.

SUMMARY OF COMMUNITY ENGAGEMENT OVER THE PROJECT CYCLE

Table 4.2 tracks the community engagement objectives, channels, targets, actors, and activities over the mini grid's entire project cycle.

IMPORTANT GENDER ASPECTS OF THE COMMUNITY ENGAGEMENT PROCESS

Women are increasingly important customers for mini grids, both at the household and enterprise levels, particularly in Sub-Saharan Africa, where female entrepreneurship rates are estimated to be the highest in the world (GEM 2017). Inclusive community engagement during A-B-C client scoping can identify these key clients.

To gain insight into women's roles and energy needs in a given community, it is important to understand the underlying gender norms and the financial, educational, and social patterns that may hinder their access to and full participation in the mini grid project cycle.

Men and women often have different experiences and perceptions of community assets, such as mini grids, and

TABLE 4.2 • Key community engagement activities over the project cycle

	Design and planning	Promotion and information	Financing and procurement	Implementation and construction	Registration and connection	Operations and maintenance
OBJECTIVES	Obtain prospective user and situational information Customer expectations Current energy use Geographic conditions Prepare a mini grid design that is: Socially inclusive (in its tariff structure and in meeting expectations) Technically sound (load distribution and likely future demand) Financially viable (tariff covers cost)	Increase community-level awareness of energy access issues Provide relevant information (for example, potential productive uses) and raise active interest to promote early buy-in and sign-up Assist prospective customers in their registration decision with specific, detailed information (signup, tariff, payment methods, etc.)	Establish a clear financial model to determine ideal public/private-sector investment needs Prepare a project document showing financial structuring, risk assessment and mitigation, financing partners, and adherence to regulations Carry out procurement based on proper tender documents and a transparent process	Construct a robust, appropriately sized, and scalable mini grid Include provisions for potential future expansion (for example, modular construction) Install simple control systems to manage demand levels	Secure a viable customer base with (fairly) secured power load Identify anchor customers in advance and secure connections	Ensure reliability of services, maximizing benefits of investment Ensure functionality and domestic and productive benefits (potentially offering household and productive-use appliances for sale or lease) Strengthen and incentivize local service capacity Establish a cost-effective maintenance program, with local service providers engaged
TARGET GROUPS	Community Local leaders and authorities Financial institutions Local and national government agencies	Community members Productive users	Financial institutions, investors, local and national government agencies	Experienced service providers Local businesses and laborers	Households Local businesses and startups Operating companies	Households Local businesses and startups Operating companies
CHANNELS	Meetings with local institutions, stakeholders, and community	Campaign Local radio, newspaper, social media, brochures Community meetings Marketing hubs	Meetings with local and national finance institutions and local government	Community meetings	ICT for connections Social media, user video CSC	ICT for connections ESCO office CSC
ACTORS	Project developer, ESCO staff, CE manager and team Local authorities, lead community members	Project developer, ESCO manager, CE team Local media	Project developer, ESCO manager, local banks	Project developer, ESCO manager, local technicians and laborers	ESCO manager and staff, CE manager and team	ESCO manager and technical staff CE manager

continued

TABLE 4.2, *continued*

	Design and planning	Promotion and information	Financing and procurement	Implementation and construction	Registration and connection	Operations and maintenance
COMMUNITY ENGAGEMENT	Carry out a community scan to assess WTP/ATP and expectations of potential customers, particularly if the A-B-C approach is followed Ensure women's participation in all design and planning activities Engage on local permits and approvals Develop a client portfolio (A-B-C segmentation) Inventory local human resources Engage on land acquisition or right of use	Carry out a promotion and information campaign regarding mini grid services Increase consumers' "energy education" in understanding their bill, maintenance, grievance handling, safety aspects, and health benefits Finalize customer segmentation Prepare and present impact videos Attract, organize, and include women in promotional and sales activities Mobilize women's networks to disseminate mini grid information	Finalize WTP/ATP assessments Finalize market segmentation (A-B-C customers) Finalize tariff structure Mobilize women's finance networks to make available investment financing for female-run households and businesses	Recruit local human resources Engage with future stakeholders (A-B-C clients, local authorities) Offer gender-differentiated user training on O&M and productive-use opportunities	Continue community dialogue to stimulate inclusion Carry out a PUE inventory Carry out a community service inventory	Continue community dialogue to monitor customer satisfaction Promote PUE extension Prepare impact documentation (including video) Carry out O&M training Mediate conflicts as needed

Note: The term ESCO (energy service company) is analogous to the term "developer" in the chapter text.

A-B-C = anchor-business-community; CE = community engagement; CSC = customer service center; ICT = information and communications technology; O&M = operations and maintenance; PUE = productive uses of energy; WTP/ATP = willingness to pay/ability to pay.

their benefits are not equally distributed. In many contexts, women are excluded from community consultations because of cultural norms whereby men assume leadership, women are uncomfortable speaking in front of men, or household and care responsibilities constrain women's time and ability to attend. Working to address these barriers is key to ensuring a more equitable division of benefits and viable loads for developers. In the case of community-owned mini grids in India, enabling women's participation has improved governance processes and equity (Katre, Tozzi, and Bhattacharyya 2019). Mini grid operators in India keenly distinguish gender aspects in customer behavior and provide loans to support productive uses of mini grid electricity for women's income-generating activities (Katre, Tozzi, and Bhattacharyya 2019).

Accounting for the gender aspects of the community engagement process is important because mini grids can transform female clients' lives, as discussed below.

Drudgery and time savings. Mini grids can significantly reduce women's drudgery and save them time, particularly in female-dominated labor-intensive agricultural and food processing activities, through the use of electrical appliances such as water pumps, grinders, mills, blenders, refrigeration, and, in a few cases, electric stoves.

Employment. Studies in South Africa, Nicaragua, and Guatemala show that women are 9–23 percentage points

> Men and women often have different experiences and perceptions of community assets, such as mini grids, and their benefits are not equally distributed. In many contexts, women are excluded from community consultations because of cultural norms whereby men assume leadership, women are uncomfortable speaking in front of men, or household and care responsibilities constrain women's time and ability to attend. Working to address these barriers is key to ensuring a more equitable division of benefits and viable loads for mini grid developers.

more likely to gain employment outside the home following electrification (Smith 2000). The time savings delivered by electric power and the ability to perform domestic chores in the evening frees women to accept paid work. Findings from electrification programs in Bangladesh, however, suggest that the increase in time devoted to wage labor may not result in a decrease in unpaid work in the home, causing women to work longer hours overall (Magis 2010).

Health and well-being. Electrification can reduce fertility levels. Greater exposure to television often improves access to information and may depict new norms, such as

Incorporating gender in community engagement is important because mini grids can transform women's lives by reducing drudgery, saving time, opening opportunities for employment, bettering health and well-being, and improving intergenerational outcomes for families.

family planning and smaller family size (Buckley 2012). In Indonesia, exposure to television increased the use of modern contraception by approximately 12 percent (Wiemann, Rolland, and Glania 2014). Anecdotal evidence from West Africa suggests that electrifying clinics for lighting and refrigeration of medications has an especially beneficial impact on maternal health.

Gender norms and women's agency. Evidence from several states in India highlights the role television plays in decreasing domestic violence and preference for sons. Women also report increased autonomy, measured by such factors as the ability to go out without permission and participation in household decision making (Wiemann, Rolland, and Glania 2014). Mini grid projects can also shape new community decision-making and leadership models. If local electrification committees give women equal opportunities to run for key positions, for example, their voice in decision-making may be enhanced. Another example is provided by the Nigerian Rural Electrification Agency, which requires that women be included in local decision-making bodies set up for the implementation of mini grids. The agency also hosts women-only consultations.

Intergenerational effects on education and health. Some evidence indicates that the improved lighting provided by electrification can promote more hours of study among children. In Bangladesh, years of schooling for both boys and girls rose after electrification (Magis 2010). Reports from West Africa also suggest that lighting and refrigeration in clinics improve child health. Both effects shape intergenerational outcomes for families.

REMOVING BARRIERS TO SCALE THROUGH INNOVATIONS IN COMMUNITY ENGAGEMENT

One of the primary challenges of community engagement is that it requires boots on the ground—a significant, human presence in the community served by the mini grid. But developers are increasingly building large portfolios of mini grids to achieve economies of scale. Is this compatible with conducting high-quality community engagement activities? The following two examples are innovations from the frontier of community engagement efforts—the first at the national level in India; the second at the developer's level, also in India.

COUNTRY-LEVEL PROGRAM: SMART POWER INDIA

Smart Power India was launched by the Rockefeller Foundation in 2015 as part of its $75 million Smart Power for Rural Development initiative, focusing on the states of Uttar Pradesh, Bihar, and Jharkhand. With a goal of bringing electricity to a thousand villages and a million Indians (Muther 2016), the program has supported the installation of more than 100 mini grids, affecting more than 40,000 people (Rockefeller Foundation 2017).

The program's approach was to establish Smart Power India as an India-based, Indian-led organization that would play an intermediary role among key stakeholder partners—the private sector, national and local governments, community organizations, and developers such as OMC, Husk Power, TARA Urja, and DESI Power—thereby developing a harmonious ecosystem to drive sustainable mini grid installations at scale through comprehensive community engagement (Rockefeller Foundation 2017).

As part of its larger design, Smart Power India has used the CELAMeD approach, which involves close engagement with local communities and partners to not only secure strong buy-in and sustained demand for electricity, but also to stimulate economic development in the villages. Through work with partners such as the Society for Technology and Action for Rural Development (TARA) and People's Action for National Integration, developers have developed communication and marketing strategies to inform consumers about the benefits of renewable energy and enable rural businesses to emerge and expand (Smart Power India 2017).

The aim of the CELAMeD approach is to mobilize communities around the mini grid, helping developers exploit latent demand and induce new businesses to use its electricity (Smart Power India 2016).

Some community engagement activities begin as soon as villages are identified by the developer. These include focus group discussions, door-to-door contacts, street plays, fairs, and community meetings. In the first four to six weeks following installation of the system, the developer's sales team works with the CELAMeD team to sign up customers (Smart Power India 2017). Initially, the vast majority of the connections are for households and small shops, primarily for small load needs, such as lighting and cell phone charging. A subsequent effort is made to engage existing businesses to persuade them to switch from self-generation using diesel with the prospect of gaining expanded services at lower cost.

One of the key principles advocated by the Smart Power India program is that village residents are treated not as "consumers," but rather as "producers," with needs beyond simple lighting solutions (Smart Power India 2016). With this approach, the program works to create a thriving ecosystem by catalyzing entrepreneurship through promotional events, training, and capacity building. During the first month, the developer's team typically focuses on preplanning activities, such as site scoping, identification of focus areas, and preparation of tailored enterprise packages. It spends the next three months identifying businesses and entrepreneurs—both existing and potential—for contacts and promotional activities. One example of the latter is the Expansion Mela, an event carried out locally to ramp up adoption of appliances (Smart Power India 2016). The event promotes on-the-spot registration for electricity services for interested participants by offering discounted tariff packages and lottery tickets for additional subsidies.

To support new entrepreneurs, TARA Urja uses Start and Improve Your Business training programs, which have been certified by the International Labour Organization. The programs are focused on identifying entrepreneurs with high chances of success; they also have a specific focus on women. The programs include Generate Your Business training for novice entrepreneurs looking to flesh out a business idea and Improve Your Business training for existing businesses looking to scale up.

By 2016, TARA Urja had trained more than 140 potential and existing entrepreneurs, of whom 30 percent were female; 40 percent had set up new businesses, and 20 percent had expanded their existing businesses (Smart Power India 2016). As part of the program, TARA Urja offers support for the purchase of productive equipment, often customizing tariff packages to bundle in equipment costs. By 2016, the program had enabled 30 existing entrepreneurs (including small computer shops, printing businesses, grocery shops, mobile repair shops, and photo studios) to expand their businesses, reporting overall increases in incomes of approximately 15–20 percent (Smart Power India 2016). With this program, the developer saw returns on its investment within approximately five to six months (Smart Power India 2016).

ICT FOR COMMUNITY ENGAGEMENT AT THE DEVELOPER LEVEL: A PILOT VIDEO HUB DELIVERING MINI GRID STORIES

As part of its efforts to mainstream new solutions and best practices into programs to scale up mini grids, the Energy Sector Management Assistance Program's Global Facility on Mini Grids has piloted a novel approach to community engagement. Called Mini Grid Stories, this pilot supported the creation of a digital community for mini grid stakeholders. Piloted in India with support from Quicksand Design Studio, the program used a YouTube-like online video platform and accompanying smartphone application to easily create, upload, download, and share videos. Together, they were intended to enable developers, households, businesses, microfinance institutions, NGOs, and other groups to share customers' experiences as a means of community engagement across the development phases of a mini grid project.

In this pilot program, mini grid developers, their small business and household customers, and other community members used the smartphone application to record short videos. The application guided users as they created their mini grid story—reporting, for example, the impact the electricity from the mini grid has had on their lives. Once uploaded to the online platform, the video could be viewed online or downloaded for viewing offline and could be used by mini grid developers, marketing hubs, and CSCs to showcase the transformative potential of mini grids to prospective clients.

The approach was inspired by the success of a similar program focused on peer-to-peer learning for farmers set up by Digital Green, a global development organization. Digital Green's agricultural web platform amplifies the existing informal networks of farmers, extension providers, and markets with digital tools that transform development from the bottom up by raising local voices. An ongoing two-year randomized control trial conducted by the International Food Policy Research Institute in Ethiopia has yielded some promising preliminary results:

- Digital Green's video-enabled approach reaches 24 percent more farmers than the Ministry of Agriculture's conventional approach and results in 35 percent higher uptake of promoted practices.
- The inclusive approach increases women's access to extension information by 20–25 percent.
- Public extension agents who use the video approach make a greater effort to visit farms, inspect technology use, and provide follow-up advice to farmers than those who use the conventional extension approach.

A separate controlled evaluation found the approach to be 10 times more cost-efficient than traditional community engagement services on a cost-per-adoption basis. Key success factors of this approach include highly localized content, human mediation to reinforce key messages, and capacity building that strengthens service provision.

Translating this innovative approach into the mini grid sector, such as ESMAP's Mini Grid Stories pilot, is likely to have similarly transformative impacts if implemented at scale.

A detailed description of the Digital Green initiative is provided on the companion website of this handbook: www.esmap.org/mini_grids_for_half_a_billion_people.

CONCLUSION

Insufficient community engagement has been identified as one of the major limitations of many energy access projects (in particular mini grid projects), as the work requires a substantial commitment to educate, train, and build the trust of communities (Valencia and Caspary 2008). Even when communities are involved in day-to-day operations and management of mini grid systems, insufficient capacity building and training may inhibit a project's sustainability and impact.

This chapter explored the importance of involving local stakeholders in all phases of setting up and operating a mini grid. The chapter highlighted how local stakeholders and authorities can help assess electricity needs, support project monitoring, help organize the community, develop local productive enterprises or value-added activities, stimulate demand, and enable women to reap equal benefits from the new source of electricity. Based on examples from the field, the chapter showed that when communities feel a sense of ownership and all local stakeholders are sufficiently involved in setting up, maintaining, and repairing the new systems, more customers tend to become connected, the level of consumption tends to increase, and the mini grid's O&M costs tend to be lower.

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NOTES

1. For this chapter, ESMAP consulted with the teams of Havenhill Synergy Ltd., Powerhive, PowerGen International, and ENGIE PowerCorner.
2. In one of the interviews carried out for this chapter, a mini grid developer—Powerhive—noted the importance of not relying too heavily on community-sourced data on expected demand for the preparation of an adequate demand assessment for appropriate sizing of a mini grid system. The Powerhive team highlighted the challenges of customers who have not previously used electricity in accurately translating their needs and expectations into monthly expenditure and realistic consumption plans. Overreliance on such data can subsequently lead to substantial under- and oversizing of systems. At the same time, the Powerhive team emphasized the value of other demographic and socioeconomic data that should be gathered across the community from early stages to serve as prediction markers for electricity use (for example, number of residents in a household, number of homes in a compound, sources of income, number of acres of farmed land, types of crops, number of children in a school). Such data can be further validated through comparison with other sites that may be operated by the same mini grid developer in or near the area.
3. One example from the mini grid run by Gram Oorja in the village of Darewadi in the Indian state of Maharashtra shows that, with the local community having an active stake in the mini grid, its members self-moderate their electricity use during the monsoon season to ensure its continued functioning (Fahey and others 2014).
4. The importance of tailoring the community engagement approach to each local context was particularly emphasized in an interview by Havenhill Synergy Ltd., a Nigerian mini grid developer operating several solar-hybrid mini grids in the Kwali and Kuje local government areas of Nigeria.
5. The importance of securing the approval of the local chiefs at the initial design and planning stage of the mini grid project was highlighted in an interview by ENGIE PowerCorner.
6. Based on an interview discussion with ENGIE PowerCorner.
7. Based on an interview discussion with Havenhill Synergy Ltd.

CHAPTER 5

DELIVERING SERVICES THROUGH LOCAL AND INTERNATIONAL ENTERPRISES AND UTILITIES

CHAPTER OVERVIEW

This chapter first provides context for the rise of private-sector participation in the mini grid market, the motivation behind that participation, and a high-level overview of the various types of companies involved. It then presents a preliminary assessment of the profit at stake for private-sector players along the value chain, as well as for select mini grid operators. Third, the chapter outlines the private-sector players that are active in various stages of the mini grid industry's value chain, and how they generate revenue and manage costs. Finally, the chapter highlights the ways companies across the value chain can collaborate. Throughout this chapter, results from the World Bank's recent surveys of mini grid operators in Cambodia, Myanmar, and Nepal are provided to further illustrate concepts and provide concrete data from operating mini grids.

Small and medium enterprises (SMEs) play a major role in most economies, particularly in developing countries.[1] They represent about 90 percent of businesses and more than 50 percent of employment worldwide. Formal SMEs contribute up to 40 percent of national income (measured as gross domestic product, GDP) in emerging economies. These numbers are much higher when informal SMEs are included. Mini grid companies are a small yet important group of SMEs. As we describe later in this chapter, the Energy Sector Management Assistance Program (ESMAP) has identified 168 private-sector mini grid developers (registered companies) currently active in countries with low rates of electricity access. All of them are SMEs (World Bank 2022).

According to World Bank estimates, 600 million jobs will be needed by 2030 to absorb the growing global workforce, which makes SME development a high priority for many governments around the world. In emerging markets, most formal jobs are generated by SMEs, which create 7 out of 10 jobs.

However, access to finance is a key constraint to SME growth, including for mini grid companies. It is the second-most frequently cited obstacle to growing their businesses in emerging markets and developing countries. SMEs are less likely to be able to obtain bank loans than large firms; instead, they rely on internal funds, or cash from friends and family, to launch and initially run their enterprises. About half of formal SMEs do not have access to formal credit. The financing gap is even larger when micro and informal enterprises are taken into account (World Bank 2022).

A key priority is to improve SMEs' access to finance and find innovative solutions to unlock sources of capital, for example, through SME lines of credit, partial credit guarantee schemes, and early stage innovation finance. Good practices also show the necessity of financial sector assessments to determine where regulation and policy might be improved; identify an enabling environment, design, and setup for credit guarantee schemes; improve credit infrastructure; and deploy innovative SME finance such as e-lending platforms, use of alternative data for credit decisioning, and supply chain financing (World Bank 2022).

In the past, small, local companies—often relying on internal or philanthropic funding—would design, build, and operate mini grids. Increasingly, however, private companies and private capital are participating across the mini grid value chain. Their participation brings the benefits of more advanced technology, access to lower-cost capital, and a focus on innovation, replicability, and scale. Today, the mini grid space is seeing participation not just from local enterprises, but also from international companies providing tens of thousands of families with an income.

Scaling up the mini grid sector to achieve the Sustainable Development Goal 7 (SDG 7) targets will require merging the advantages of large international companies that have the scale to manufacture standardized mini grid components and systems, with those of "on-the-ground" companies that can engage the local communities being provided electricity from mini grids.

Although some of the largest developers of mini grids today are national utility companies, it is the private sector that will drive exponential growth in the industry, particularly as many utility companies in electricity-access-deficit countries are struggling financially.[2] Indeed, private-sector developers have the top five largest portfolios of mini grids planned for construction in the next five to seven years, totaling more than 23,000 mini grids. This represents 76 percent of all currently planned mini grids, according to ESMAP's database of more than 50,000 installed and planned mini grids around the world. Are we doing enough to support all 160+ private-sector developers? Do we consider women-specific needs? Do we offer service providers the right tools to increase their productivity and build back stronger? These need to be top-priority questions for government officials, financiers, and development partners as they launch or scale up national and regional mini grid programs.

AN EVOLVING TECHNOLOGY FROM FIRST-GENERATION TO THIRD-GENERATION MINI GRIDS

Mini grids are not a new concept; indeed, they have played a critical part in the electrification of many countries.

FIRST- AND SECOND-GENERATION MINI GRIDS

More than 100 years ago, mini grids served as a starting point for electrification in countries as diverse as China, Sweden, and the United States. The first modern electric power plant, Thomas Edison's Pearl Street Station in Manhattan, New York, began operating in 1882 and served only 80 customers using thermal power. Generally, these first-generation mini grids were located either in dense urban environments or in areas where the cost of supply was low. As the technology improved and demand increased through the Industrial Revolution, larger generators and distribution systems could be built. Eventually, these larger systems connected to what became the main grid known today. The smaller mini grids that had been the starting point for this evolution were either integrated into the expanding main grid or simply abandoned.

SECOND-GENERATION MINI GRIDS

As focus shifted from the developed markets to lower-income countries, the original notion of using mini grids as starting points for electrification re-emerged. But as the technology supporting larger generation and distribution had matured by the time these countries began to electrify, many urban areas in these lower-income countries could simply begin rolling out large-scale electric grids. However, for reasons spanning both social and economic factors, many rural areas were left unconnected to these growing grids.

This gave rise to the second generation of mini grids: small-scale power systems often deployed in remote or rural areas with little industrial activity or low population densities. To date, these mini grids have been built and operated by local communities and local entrepreneurs. If and when the main grid is extended to these rural areas, these mini grid installations are generally abandoned, such as in the case of Sri Lanka and Indonesia. But not all second-generation mini grids become stranded assets when the main grid arrives; in Cambodia, many mini grids converted to small distribution companies, using the existing mini grid footprint (Tenenbaum and others 2018).

The World Bank recently undertook large-scale, nationally representative surveys of mini grid operators in three countries—Cambodia, Myanmar, and Nepal—to understand the market landscape of their second-generation mini grid operations.

For more than three decades, mini grids have provided electricity service in these three countries to those without access to grid-based electricity, particularly in remote rural areas. Mini grid operators, on average, started operating 12 years ago in Myanmar, 14 years ago in Cambodia, and 10 years in Nepal. Almost half of all mini grids surveyed had been in operation for more than 10 years. The earliest mini grid operation, in Myanmar, dates to the late 1950s. The number of mini grid operations in these three countries soared in the mid-2000s. Nearly a decade later, the pace of growth has slowed, but the number of mini grids continues to grow.

THIRD-GENERATION MINI GRIDS

Over the past few years, a new, third, generation of mini grid technologies and business models has emerged. As noted in the overview of this report, these mini grids differ from the second generation in several important ways. For example, third-generation mini grids use more modular technologies, such as solar photovoltaic (PV)-based hybrid plants, which are combined with mobile-based pay-as-you-go billing and internet-based remote monitoring.

The characteristics of third-generation mini grids—in particular, their use of new technologies and market mechanisms alongside improved regulations specific to mini grids—are creating environments that attract local and international industry players to invest in portfolios of mini grids in countries with low levels of electricity access.

Third-generation mini grids are increasingly being supported, developed, and deployed by a variety of private-sector companies, including large local companies and multi-national operators. These companies use new market mechanisms, such as public-private partnerships, as seen in Kenya and Sierra Leone. Such new operating paradigms are coupled with a more targeted regulatory environment, particularly when mini grids must contend with the need to connect to the main grid or operate in parallel with the main grid (Shakti Foundation 2017).

When taken together, these factors provide conditions that lead to greater participation of the private sector in the development and operation of mini grids. International technology providers use global supply networks to offer standardized, economical mini grid systems. Large local and international operators, by using advanced mini grid designs and relying on clear regulatory systems, are having discussions with private investors to support the deployment of portfolios of mini grids. Public-private partnerships and targeted regulations are providing greater certainty to investors, thereby creating an environment that allows operators to raise equity and debt to supplement grant capital.

THE BUSINESS CASE FOR PRIVATE-SECTOR PARTICIPATION IN THIRD-GENERATION MINI GRIDS

More than 800 million people today lack access to electricity, while nearly 3 billion lack access to clean cooking. By some estimates, this segment of the population spends as much as $37 billion per year on kerosene and biomass for lighting and cooking fuel; converting this use to sustainable alternatives in line with the universal electrification ambition of SDG 7 could require more than $50 billion to be invested annually through 2030 (Asmus 2013; IEA 2017).

For lower-income countries that must invest in expanding electricity infrastructure to unelectrified areas, third-generation mini grids will play a critical role in providing a more economical alternative to grid extension. With grid extension costs running as much as $2,500 per connection, it would take more than $600 billion to provide a grid connection to every person without electricity (Attia and Shirley 2018). For private companies that develop or operate mini grid technologies, such a prohibitive cost provides a unique opportunity to offer a more cost-effective alternative solution to grid-level service. Indeed, as noted in the overview, average connection costs for mini grids are currently less than $2,000 per customer and are expected to continue to fall through 2030. With an addressable market of 167,000 load centers for mini grids in energy-access-deficit countries, representing about 86 million connections by 2030, this amounts to an estimated investment opportunity of approximately $105 billion by 2030. Mini grid electricity sales could grow from an estimated $500 million per year in 2021 to $16 billion per year by 2030, assuming 9 million connections in 2021 and 86 million connections in 2030.[3] Meanwhile, ESMAP estimates that the addressable market for productive use appliances and machines is approximately 3 million units by 2030 (assuming 15 appliances per mini grid and 200,000 new mini grids). With an average cost of $1,200 per appliance, this represents a $3.6 billion per year market, and a $3 billion end-use finance opportunity by 2030.

The impact of mini grids on the private sector is not limited to companies directly involved in their development or operation. By some estimates, not having an adequate supply of electricity can result in enterprises losing more than 30 percent of potential sales (Ramachandran, Shah, and Moss 2018). Often, an enterprise must rely on its own electricity sources; globally, the expenditure on backup diesel generation for individual homes and businesses likely exceeds $40 billion annually (Velamala 2016; Orlandi 2017). Offsetting such expenditures by delivering reliable electricity to commercial customers through a mini grid can further bolster the mini grid's economic viability.

The mini grid sector complements the vertically integrated utilities and distribution companies as well as the solar companies that sell stand-alone solar systems.

For electric utilities, mini grids can reduce the financial burden of costly utility connections for rural customers and provide such customers with reliable electricity. The unfortunate rural reality is that (1) utility connection rates remain low; (2) utilities have struggled to recover costs when they rapidly increase electrification rates; and (3) even when customers are connected, reliability is often a problem.

Data on electrification rates by electric utilities in Africa are surprisingly sparse. The most up-to-date publicly available data on utility connections in Africa are from the African Development Bank's *Africa Infrastructure Knowledge Program Portal* and only cover the period from 2004 to 2014 (African Development Bank 2016). Initial analyses of these data are shown in table 5.1.

Table 5.1 reveals several important points about utility electrification rates in Africa. First, we lack consistent, recent data. The most recent publicly available comprehensive data cover only up to 2012, with one country covered through 2014. Because data are scarce and outdated, it is not possible to draw conclusions about utility connection rates over the past several years. What we can say, however, is that in the decade leading up to 2014, the pace of utility electrification was just barely keeping up with population growth, connecting an additional 1.2 percent of the population per year on average. In some countries, we can see that population growth was actually outpacing utility connections (Comoros, Guinea, Madagascar, and Togo). In terms of annual connection rates, the fastest-growing utilities are in Africa:

TABLE 5.1 • Utility connection rates, 2004–14

Utility connections as percentage of total number of households

Country	Utility	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Avg. annual change
Benin	SBEE	19.0	19.9										0.8
Burkina Faso	Sonabel	10.7	11.3			12.4	13.2	13.7	14.7	15.6			0.6
Burundi	REGIDESO		2.3	2.3	2.3	2.6	2.6	3.2	3.2	3.1			0.2
Cameroon	AES SONEL	14.7	14.8		15.2	15.9	16.6	17.4	18.1	18.2			0.5
Cabo Verde	Electra	71.3	76.0										4.7
Central African Republic	ENERCA							3.1	3.1	3.1			0.0
Chad	STEE	1.1	1.2										0.1
Comoros	Ma Mwe		20.6	20.1	19.6	19.2	18.7						-0.5
Congo, Rep.	SNEL	44.1			42.9	41.9	40.4	40.2	42.8	50.0			0.3
Côte d'Ivoire	CIE	23.3	24.3		25.3	25.9	26.4	26.8	26.8	26.2			0.4
Djibouti	EDD		21.4	22.4	23.1	23.6	24.2						0.7
Ethiopia	EEU				5.5	6.8	7.0	6.9	7.3	7.1			0.3
Gambia, The	NAWEC		29.3	34.3	37.7								4.2
Ghana	ECG				23.5	25.5	28.4	29.9	32.4				2.2
Guinea	EDG							9.0	7.0	7.6	8	8	-0.2
Kenya	KPLC				8.7	9.7	11.3	12.7	14.8				1.5
Lesotho	LEC									29.0			
Madagascar	JIRAMA	10.9	10.8		10.2	10.0	10.0	9.9					-0.2
Malawi	Escom				4.5	4.7	5.0	5.5	5.2	5.4			0.2
Mali	EDM	6.8	7.2	7.6	8.0	8.2	8.5	9.0	9.7	10.5			0.4
Morocco	ONE		50.8	55.7	59.9	62.6	66.1						3.8
Mozambique	EDM	5.8	6.7		10.3	12.0	14.0	15.9					1.7
Namibia	NORED	6.0	7.0										1.0
Niger	NIGELEC	5.2	5.4		5.7	5.9	6.7	6.7	6.8				0.2
Rwanda	RECO				2.8	4.0	5.4	7.0	9.0				1.5
Senegal	Senelec	44.1	46.7		52.6	55.2	58.0	60.0	59.8	61.0			2.2
Seychelles	Public Utilities Company							17.0		17.3			0.1
South Africa	Capetown and ESKOM		41.7						97.3				9.3
Tanzania	TANESCO				7.9	8.4	8.8	9.3	9.8	10.5			0.5
Togo	CEET		14.2	13.8	13.4	13.1	12.7						-0.4
Uganda	UMEME						4.6	5.4	5.9	5.7			0.4
Zambia	ZESCO							10.9	12.1	11.7			0.4

Source: African Development Bank 2016 and ESMAP analysis.

High … Low

- ESKOM and Capetown were each year, together, connecting 9.3 percent of South Africa's population.
- Electra in Cabo Verde: 4.7 percent.
- NAWEC in The Gambia: 4.2 percent.
- ONE, in Morocco: 3.8 percent.

Still, in nearly every country large portions of the population remained unelectrified by the main utility companies. In 2012, the most recent year for which data were available for many countries, only three countries in Sub-Saharan Africa saw more than half their households served by utilities: SNEL in the Republic of Congo, Senelec in Senegal, and the combined utilities in South Africa.

According to a World Bank study (Balabanyan and others 2021), while generation capacity grew from 63 gigawatts (GW) in 2000 to 106 GW in 2017, electricity access in Sub-Saharan Africa remains mixed: 12 countries representing 14 utilities[4] have low access rates (less than 33 percent of the population), 22 countries representing 46 utilities have mid-level access (33 to 67 percent), and 11 countries representing 16 utilities have high access (above 67 percent). These World Bank figures are roughly corroborated by findings from an International Energy Agency global database (IEA 2022) on electricity access rates. The IEA indicates an overall electrification rate for Sub-Saharan Africa of 49 percent, but in rural areas this falls to 28 percent of the population. Many countries are substantially lower than this. For example, in Central Africa, Chad has an 8 percent overall electricity rate, while less than 1 percent of the rural population has electricity access; the Democratic Republic of Congo has similar access rates (9 percent overall, less than 1 percent rural). In East Africa, Djibouti's access rates are 42 percent overall and less than 1 percent in rural areas, while in Burundi the overall rate is 10 percent and the rural is also less than 1 percent. In West Africa, Mauritania has 47 percent overall, and less than 1 percent rural; Sierra Leone has 22 percent overall and less than 1 percent rural.

As low as these figures are, they overestimate electricity access from utility connections because they include off-grid sources such as solar home systems (SHSs), diesel generators, and mini grids (IEA 2020).

In Sub-Saharan Africa the median time to connect customers steadily improved in recent years, dropping from 117 days in 2012 to 90 days in 2018. But with high costs of connecting new rural customers ($2,500 per connection, as already mentioned), utilities have found it difficult to cover costs, particularly those that have attempted rapid expansion of service. In countries where on-grid electricity access improved by more than 5 percent from 2015 to 2018, 69 percent of utilities failed to recover their costs. Conversely, utilities recover their costs in 53 percent of the countries where the increase in on-grid electricity access is less than 5 percent over this period (Balabanyan and others 2021).

Across Sub-Saharan Africa, households and small businesses have outages lasting for hours. In some countries—including Burundi, Ghana, Guinea, Liberia, Nigeria, and Zimbabwe—more than half of households connected to the main grid reported receiving electricity less than half of the time (Blimpo and Cosgrove-Davies 2019). Disaggregated data from diagnostic survey reports carried out by ESMAP in a range of countries, based on the Multi-Tier Framework, provide additional evidence of this lack of reliability, both in the Sub-Saharan region and beyond. The report from Rwanda indicates 97 percent of grid-connected households experience more than four electricity disruptions a week (Koo and others 2018). The Ethiopia report shows that 57.6 percent of grid-connected households face 4–14 outages a week, and 2.8 percent face more than 14 outages a week (Padam and others 2018). The report from Cambodia indicates that 69.3 percent of grid-connected households face frequent, unpredictable power outages, and 9.9 percent of all grid-connected customers receive less than four hours of service per day (Dave and others 2018).

Utility information, while limited, corroborates this survey information. In Sub-Saharan Africa only about a third of the vertically integrated utilities reported the System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI) in 2018, and only 5 out of 21 distribution companies reported SAIDI and SAIFI. Of those that did, the median reported SAIDI and SAIFI in 2018 were 51.6 hours and 24.7 interruptions per year, respectively. These are high by international standards. In order to receive any points under the scoring methodology used by the World Bank's Doing Business indicators, the maximum SAIDI and SAIFI is 12—equivalent to a one-hour-long outage each month (Balabanyan and others 2021). These SAIDI and SAIFI are corroborated by survey data: in some countries—including Burundi, Ghana, Guinea, Liberia, Nigeria, and Zimbabwe—more than half of connected households reported receiving electricity less than 50 percent of the time in 2014 (Blimpo and Cosgrove-Davies 2019). Information on load factors for these utilities was not available.

Mini grids also complement the expansion of basic electricity services like solar lanterns and SHSs by providing next-step options as rural communities grow and needs increase, and by providing electric service to towns that complement household-scale systems in surrounding areas.

As of June 2022, over 100 companies were members of the Global Association for the Off-grid Solar Energy Industry (GOGLA). Globally, there were 261 quality-verified solar lanterns and SHSs from 67 brands listed by VeraSol (the sector's quality assurance program) in 2021, up from 201 products from 51 brands in 2019. SHSs are increasingly sold with appliances, for which there is also a sizable market of quality-tested products, including 152 TVs from 88 brands, 131 fans from 86 brands, and 94 refrigerators from 52 brands. Solar off-grid systems range from 0.5 watt to power a light bulb, up to several hundred watts to power efficient DC (direct current) appliances such as TVs, fans, refrigerators, and productive-use equipment. Global market turnover is now $2.1 billion annually.

Based on conservative life span assumptions, GOGLA estimates that in Sub-Saharan Africa, 64.5 million people are using an off-grid solar product. Using the multitier framework, 33 million people are in Tier 1 and 9.7 million in Tier 2. Globally, there are 34.6 megawatts of newly installed capacity through off-grid solar products. When customers have the opportunity to shift to mini grids, these household solar products could continue to provide supplemental energy services or be passed on through family networks to areas with no electrical services (Galan 2022). In 2012, equity and debt investment in the sector totaled $17 million; in the past decade, that grew over 25-fold to $447 million (GOGLA 2022).

PRIVATE-SECTOR SEGMENTATION

Operators and facilitators

The private sector's role in the mini grid space spans from the development of mini grid technologies to their installation, operation, and servicing. Broadly, two types of private-sector entities participate in the mini grid space: operators and facilitators. Operators include energy service companies (ESCOs), utilities, and independent power producers (IPPs). Facilitators include original equipment manufacturers (OEMs), engineering, procurement, and construction companies (EPCs), system integrators (SIs), and financiers. Operators assume primary responsibility for the life cycle of a mini grid or a portfolio of mini grids, such as identifying a mini grid location, engaging with the community, and operating the mini grid. Facilitator organizations help operators design, build, and manage mini grids and include original equipment providers and financiers.

> Broadly, two types of private-sector entities participate in the mini grid space: operators and facilitators. Operators assume primary responsibility for the life cycle of a mini grid or a portfolio of mini grids, such as identifying the mini grid location(s), engaging with the community, and operating the mini grid(s). Facilitator organizations help operators design, build, and manage mini grids; such companies include original equipment providers and financiers.

Operators can be local or international, while facilitators generally are international entities. Local companies are generally SMEs whose operations are geographically restricted to an area that could be a district, a state, or even an entire country. These entities are generally staffed with local resources from the same region where the company operates. Their products and services are developed locally, tailored to the needs of the region they serve. International operators, or companies that operate mini grids in more than one country, tend to set up in-country operations similar to local companies in each region they operate, relying on local resources to engage with the communities they seek to serve, while maintaining a headquarters function that engages in activities common across geographies, such as raising capital to deploy mini grid equipment.

Facilitating organizations generally do not engage with the community receiving electricity directly; rather, they engage with the local and international companies that will operate the mini grids. International companies are suited to serving such a role. Their operations across geographies allow them to develop wide-scale supply chains, source technology components more cost efficiently, and place manufacturing facilities in low-cost regions. These companies generally have established processes for quality assurance and after-sales service. Local and international companies have their respective advantages; therefore, success in scaling the mini grid space will require engagement across different types of organizations. Box 5.1 offers an example of such a partnership.

BOX 5.1

GREEN VILLAGE ELECTRIC PARTNERS WITH SCHNEIDER ELECTRIC

Green Village Electric (GVE), a local Nigerian enterprise focused on mini grid development, has partnered with Schneider Electric, a large multinational power electronics manufacturer, to develop several mini grids. For example, GVE and Schneider partnered on a mini grid for the villages of Bisanti, Kolwa, and Onono-anam, developing a 24-kilowatt solar mini grid with prepay meters. GVE engaged with the community and developed the project, while Schneider provided the solar hybrid system based upon each site's unique needs. The net result was power for 250 homes, four classrooms, small businesses, and a health center (Schneider Electric 2018).

During the early development of the electricity sector, when first-generation mini grids were prevalent, their design, manufacturing, and operation were often handled by a single company. When Thomas Edison first began operating Pearl Street Station, the world's first mini grid, the Edison Illuminating Company took responsibility for designing and operating the power plant, signing up customers, and selling electricity. When second-generation mini grids began deployment to remote areas, the power plant components were manufactured by different companies, while another local company or the community itself would operate and maintain the system. This is the case for the mini grids surveyed in Cambodia, Myanmar, and Nepal. Mini grids are mostly owned by private entities or individuals in Myanmar (82 percent, with the remaining mini grids owned by communities or the government) and Cambodia (99 percent), while virtually all mini grids in Nepal (95 percent) are owned by the local community.

With third-generation mini grids, more private-sector companies are participating across the value chain. Whereas second-generation mini grids have been primarily hydro or diesel based, with third-generation mini grids, other manufacturers, such as solar or battery companies, are becoming involved. Whereas a good portion of second-generation mini grids have been operated by communities or nongovernmental organizations, third-generation grids are increasingly run by profit-seeking companies. Indeed, across the value chain described earlier, private-sector companies are performing one or more of the steps to design, develop, deploy, and operate mini grids.

Table 5.2 highlights the different categories of local and international private-sector players, the stage of the value chain in which they participate, and what levers each type of player can use to accelerate how mini grids achieve scale.

In addition to operators and facilitators, a few technology companies provide services to the mini grid industry. This niche category consists of pure software developers that provide software to operate, monitor, and manage mini grids remotely, or facilitate the project development process of mini grids. For example, AMMP Technologies and Infinite Fingers conduct remote monitoring; Odyssey and Village Data Analytics facilitate project development and preparation.

Mini grid developers / operators / ESCOs

This first category of private-sector participants is categorized as operators, or entities that operate mini grids to sell electricity directly to end customers. These SMEs focus primarily on developing and operating mini grids, and also may provide additional goods and services. Many ESCOs received their start during the rollout of second-generation mini grids, when local companies were required to operate mini grids that were targeted for rural areas. ESCOs are often staffed using local resources; therefore, they often are in a better position to engage with communities that can benefit from mini grid deployment.

Once a site has been identified, ESCOs may either directly or through another provider survey the village to develop a demand profile, work with facilitator organizations to design and install the mini grid, and then oversee its oper-

TABLE 5.2 • Categories of local and international private-sector players

Type	Category	Value chain segment	Primary strategies to: Generate revenues	Primary strategies to: Manage costs
Operators	Mini grid developers	Market assessment, permitting and financing, grid design and procurement, O&M, after-sales	Sell electricity, other products, or services	Local staffing, bulk procurement, digital automation, mobile payment, prepaid meters, replicable processes
	Utilities	Grid design and procurement, O&M	Sell electricity	
Facilitators	Original equipment manufacturers (OEMs)	Component manufacturing, O&M	Sell equipment for mini grids	Low-cost manufacturing, mass customized packages, digital automation
	Engineering, procurement, and construction companies (EPCs)	Grid design and procurement, integration and installation	Procure, design, and install mini grids	Local staffing, mass customized processes, replicable processes
	System integrators (SIs)	Grid design and procurement, integration and installation		
	Financiers	Permitting and financing	Finance operators, projects, additional goods, or services	Data analytics, standardized offerings

Source: ESMAP analysis.
O&M = operation and maintenance.

ation. Given the close relationship that ESCOs form with their customers, they are also in an ideal position to pursue the "after sales" portion of the value chain, using their electricity delivery service to support selling other products.

Mini grid ESCOs generally can be categorized as local entities, or international entities with local operating units. Local entities may be small companies, such as those that have been operating second-generation mini grids, or larger, more established companies that operate several mini grids, among other business lines, such as Muhanya Solar in Zambia and Nayo Tropical Technologies in Nigeria. International companies may have their headquarters in a location outside the countries where they operate; each local unit assumes the same structure as a local entity. Sample mini grid developers are listed in table 5.3.

Status of mini grid operators globally and in Sub-Saharan Africa

In addition to a global database of 50,000 installed and planned mini grids around the world, discussed in the overview, ESMAP has compiled a database of more than 180 investment deals in mini grid companies active in energy-access-deficit countries, using publicly available sources. Combined, these databases give us an unprecedented view of mini grid developers targeting energy access.

The mini grid industry is starting from a solid foundation of already active private-sector developers. We have identified 168 active mini grid developer companies targeting the energy access market. These are registered companies that have built mini grids, are planning mini grids, are members of a mini grid industry association, and/or have secured investment for mini grids. These developers operate at least 2,100 mini grids in energy-access-deficit countries, serving approximately 5 million people. Of these developers, 115 are active in Africa, operating at least 900 mini grids and serving approximately 2 million people. As of early 2022, 41 of these developers were members of the Africa Minigrid Developers Association (AMDA). A further 50 developers are active in Asia, operating approximately 1,200 mini grids that serve around 2 million people.

The majority of active mini grid developers are taking a portfolio approach to building mini grids. Of the 167 active developers that we identified, 93 had built 3 or more mini grids. The average portfolio size is 23 mini grids per developer. The top three largest portfolios of installed mini grids are in Asia (BRAC in Afghanistan, Husk Power in India, and Tata Power Renewable Microgrids in India), followed by MeshPower in Rwanda and NS Resif in Senegal.

There are also clear signs that the private-sector mini grid industry is growing. As mentioned in the overview of this handbook, the largest portfolios of planned mini grids are all being developed by private-sector developers, and these portfolios are an order of magnitude larger than existing portfolios. The five companies with the largest portfolios of planned mini grids—OMC Power, Tata Power Renewable Microgrids, Husk Power, Engie Energy Access,

TABLE 5.3 • Sample mini grid developers

Company	Countries	Number of mini grids	Description
OMC Power	India	> 200	OMC Power is a rural utility company in India that builds, owns, and operates solar hybrid mini grids. They target areas with a telecommunications tower or other anchor client and build the mini grid to serve the surrounding community. Website: https://www.omcpower.com/page/whatwedo.
Tata Power Renewable Microgrid	India	> 100	Tata Power Renewable Microgrid builds, owns, and operates solar hybrid mini grids in India. It is a wholly owned subsidiary of Tata Power, a multibillion dollar utility company in India. Website: https://www.tata.com/newsroom/business/rural-india-solar-microgrids-tata-power.
Redavia	Tanzania	> 10	Redavia uses a lease structure to deploy solar systems that can be integrated with diesel generators. The containerized units reduce investor risk, as they can be redeployed. The company has secured more than $20 million in investment. Website: https://www.redaviasolar.com/.
Jumeme	Tanzania	> 20	Jumeme builds, owns, and operates solar hybrid mini grids in Tanzania, with a strong focus on tailored solutions for productive uses of electricity. Website: http://www.jumeme.com/.
Havenhill Synergy Ltd.	Nigeria	> 20	Havenhill Synergy builds, owns, and operates solar hybrid mini grids in Nigeria. The company provides other renewable energy services as well, including solar water pumping and energy audits. Website: https://havenhillsynergy.com/.
Earthspark	Haiti	< 10	Earthspark has focused entirely on Haiti through its local company, Eneji Pwop. The company builds, owns, and operates solar mini grids under a concession framework. https://www.earthsparkinternational.org/.

Source: ESMAP analysis.

and Renewvia—have collectively made public commitments to build more than 22,000 mini grids. In addition, the industry is professionalizing as it matures: AMDA, for example, grew its membership from just 17 members in 2019 to 41 in early 2022.

Investors have taken note of this strong base of active mini grid developers, and the pace of investment has accelerated over the past decade. Between 2010 and 2022, 188 investment deals were made between investors and mini grid companies, totaling more than $560 million. The top five developers in terms of investment capital raised are Husk Power ($80 million), OMC Power ($65 million), Engie Energy Access ($60 million), PowerHive ($52 million), and PowerGen ($46 million). Of the $302 million of investment capital raised by these five developers since 2010, $206 million was raised since 2019 alone. And looking across the full data set of investment deals, the 2018–22 period saw an average of 28 deals per year, compared with just 3 deals per year between 2010 and 2014.

Profitability of mini grid developers

The profit potential for operators is significant, with the right enabling environment and if universal access to electricity is achieved by 2030. The primary mechanism operators use to generate a profit is charging a tariff for each unit of electricity higher than the fixed and variable costs of generating that electricity. We note that in many cases there is a "viability gap" between what the developer must charge to be profitable, and what the customers are able to pay in terms of disposable household income. Performance grants would be needed to bridge this viability gap, as we discuss in more detail in chapter 6.

The profit potential of mini grid operators, given assumed tariffs and costs of service, is summarized in table 5.4.[5] It is important to note that financial support packages, including performance grants from governments and development partners, will be needed to unlock this profit potential, particularly over the next few years, to set the market on the trajectory of rapid scale-up. Public funds enabled high-income countries to achieve universal electricity access; the same will be true for electricity-access-deficit countries today.

As table 5.4 shows, the profit potential for mini grid operators is expected to increase over the next decade, even as tariffs decline. This analysis indicates a profit potential that could exceed $3.3 billion annually across all third-generation mini grids deployed globally through 2030, under the scenario in which mini grids serve 490 million people by 2030. These tariffs are reflective of the low end of mini grid tariffs today, resulting in a conservative estimate for margins. More than 70 percent of operators' expected profit potential is concentrated in Africa, also the region where the largest number of new mini grids are required in order to achieve universal access by 2030.

TABLE 5.4 • Profit potential of mini grid operators given certain tariffs and costs of service

Profit component	2022	2030
Average tariff (US$/kWh)	0.41	0.23
Cost of service (US$/kWh)	0.38	0.20
Profit on mini grids deployed in that year (US$, millions)	66	754
Profit across all mini grids deployed through that year (US$, millions)	290	3,324

Source: ESMAP analysis.
kWh = kilowatt-hour.

While operators' potential profit, under the assumption that universal access will be achieved, is quite large, the financial results of mini grid operators indicate that profitability remains difficult to achieve. Table 5.5 highlights the audited financial results of select mini grid energy service companies (ESCOs 15) from 2018; for comparison, the audited financial results of three multinational IPPs are also shown.

Analyzing the current financial health of the ESCOs, particularly in relation to the more established IPPs, leads to several interesting conclusions.

Profits are constrained. Many of the selected ESCOs exhibit large negative profit margins, due in part to the high capital expenditure and other early investments needed to establish operations, while not yet having sufficient time or capability to drive greater revenue from those investments. As indicated by the comparison companies, ESCOs should target a 1–10 percent net profit range as operations become more established. To this end, ESCOs might adopt digital solutions and focus on economies of scale to allow for the costs of overheads and assets to be spread among many units sold.

Greater focus on cost containment is needed. Several of the ESCOs have higher administrative costs, as a percentage of revenue, when compared with the IPPs. To address this, ESCOs should focus on economies of scale, standardized hardware, greater use of local resources, and digital tools to lower personnel costs and improve productivity.

Consider expanding into energy services. The ESCOs considered have low asset turnover, which encapsulates how efficiently a company can monetize its asset base; they also exhibit low or negative returns on assets. Part of this finding is driven by the deployment of relatively expensive mini grid infrastructure into areas where the customer mix may be primarily residential, thus leading to lower tariff revenue. To offset that, ESCOs should use the installed asset

TABLE 5.5 • Mini grid developers and large-scale IPPs: A comparison of audited financial results, 2018

Financial category	ESCO 1	ESCO 2	ESCO 3	ESCO 4	ESCO 5	IPP 1	IPP 2	IPP 3
Revenue (US$, thousands)	46	85,050	1,564	40	145	73,900,000	43,736,000	10,530,000
COGS (US$, thousands)	297	21,882	578	36	181	41,700,000	33,845,000	8,043,000
Gross profit (US$, thousands)	−251	63,168	985	4	−36	32,100,000	9,892,000	2,487,000
Operating expense (US$, thousands)	1,505	83,270	Unknown	958	Unknown	10,963,000	2,551,000	8,043,000
Personnel (US$, thousands)	1,273	13,141	248	147	127	11,600,000	3,420,000	216,000
EBIT (US$, thousands)	−3,029	−33,243	1,195	−1,100	−126	5,365,000	1,862,000	2,372,000
Interest expense (US$, thousands)	N/A	205	219	19	23	988,000	1,429,000	1,170,000
Tax (US$, thousands)	344	N/A	304	N/A	N/A	483,545	500,000	990,000
Net income (US$, thousands)	−2,600	−33,448	672	−11,100	−$148	2,216,000	4,750,000	−148,000
Net profit (% of revenue)	−5,454	-39	43	−2,744	−102	2	10	−11
SG&A as % of revenue	2,700	15	16	370	88	16	8	2
Asset turnover ratio	0.01	0.15	0.12	0.01	1.88	0.43	0.69	0.32
Return on assets (%)	−65	−6	5	−32	−191	1	7	−4
Current ratio	7.14	0.81	1.82	0.32	0.04	1.06	1.12	1.06

Source: ESMAP analysis.

Note: All values are in thousands of US dollars. Revenue is from business operations only; it excludes revenue identified as "other" and other extraordinary items. Comparable companies are large multinational energy service providers, and are used only for the purpose of providing a benchmark for the financial ratios. COGS refer to cost of goods sold, the variable cost to sell electricity. SG&A refers to all selling, general, and administrative overhead costs; it excludes personnel costs, which are shown in the table separately.

ESCO = energy service company; IPP = independent power producer.

base and established customer relationships to provide other services that would generate additional revenue. ESCOs also can consider identifying sites with a greater mix of commercial activity, thus allowing for a wider range of tariff values and structures.

Capital constraints vary. The current ratio encapsulates a company's ability to address short-term liabilities based on its current asset base; a number higher than 1 indicates a company's ability to successfully address short-term liabilities. Select ESCOs have large current ratios, while others are more constrained. This situation implies that certain ESCOs are in a position to scale quickly, while others may need to focus first on their existing installations, and find additional ways to generate more revenue before accruing additional liabilities to fuel expansion plans.

Financial support packages are needed to achieve scale. Profitability for existing mini grid companies remains difficult to achieve. As a result, financial support packages, including subsidies from governments and development partners, will be needed to unlock the profit potential and subsequent scalability for mini grid companies, particularly over the next few years. Public funds enabled high-income countries to achieve universal electricity access; the same will be true for electricity-access-deficit countries today.

Cumulative profit potential for mini grid developers could exceed $3 billion by 2030 if the SDG 7 target is achieved. However, an analysis of the financial results of existing mini grid developers suggests that profitability is difficult to achieve. As a result, financial support packages, including subsidies from governments and development partners, will be needed to unlock the profit potential and subsequent scalability for mini grid companies, particularly over the next few years.

Another way to facilitate growth and economies of scale is through partnerships between local and international industry players. Organizations can act as conveners, publishing information or organizing events that enable knowledge sharing and networking among various private-sector entities. Groups such as the Africa Minigrid Developers Association (box 5.2), the Alliance for Rural Electrification,

BOX 5.2

AFRICA MINIGRID DEVELOPERS ASSOCIATION

The Africa Minigrid Developers Association (AMDA) was founded in 2017 to act as a trade association for mini grid developers across Africa. AMDA currently has more than 40 members, with chapters in Kenya, Nigeria, and Tanzania. a

AMDA has established the following governing principles:

- *Advocacy:* Collaborate with industry, policy makers, government authorities, donors, and other stakeholders to advocate for optimal policies and efficient capital deployment that will benefit the mini grid sector and the people it serves.
- *Coordination:* Serve as the voice of the mini grid development industry in Africa to promote the growth and sustainable development of the mini grid sector and act as a unified focal point for stakeholders to engage the sector.
- *Industry intelligence:* Provide a platform that enables transparency in industry performance through comprehensive market data and analytics to establish, evaluate, and promote key financial, business, and policy solutions to overcome the sector's major barriers to growth.

To become a member of AMDA, a company must be a for-profit entity, have developed or be developing at least one alternating-current mini grid, and have some type of nonconcessional investment. In addition, member companies must be willing to share data on 40 key performance indicators, such as cost, quality, and reliability.

Source: ESMAP analysis.

a. More information about AMDA is available at http://africamda.org/.

as well as companies such as Odyssey, can provide a valuable platform for the exchange of information about potential mini grid projects and equipment specifications or requirements; they can also serve as a forum for the private sector to engage with regulators and other public officials.

National and regional utilities

These traditional energy service providers are tasked with distributing and selling electricity; they may also own generation assets. In certain instances, these utilities may be directed to provide electricity to remote areas under a universal access mandate. In other instances, they may view providing electricity service through mini grids as a growth opportunity, to access a new customer base. Either way, they may decide to invest in mini grids directly, or may enter into an agreement with ESCOs, such as through a distribution franchisee arrangement. Sample national utility projects servicing mini grids are listed in table 5.6.

Generating revenues for mini grid developers and utilities

One of the primary means developers and utilities use to generate revenue is by selling electricity to existing and new customers. Mini grid tariffs are often, but not always, regulated. As discussed in chapter 9, allowing developers to set a tariff using a "willing-buyer, willing-seller" approach can be a powerful enabler for scaling up private sector investment. Regardless of how tariffs are set, they generally fall into three categories: flat tariffs, volumetric charges or a combination of these.

- *Flat tariffs* are standardized fees that a customer pays monthly to the mini grid operator. When Husk Power Systems first started, one of its initial tariffs was a flat 50 rupees a month (approximately $1/month), which was used to support a mini grid that could power two 15-watt lights at a customer's house or business. In this case, customers were assured that by paying a fixed amount each month, a certain amount of electricity would be available. However, with a flat-tariff design, customers cannot dynamically adjust how much electricity they use.
- *Volumetric charges* are paid according to the quantity of electricity used, whether on a per kilowatt-hour (kWh) basis (for energy), a per-kW basis (for power), or both. One way to make volumetric rates more accessible is to tie them to appliance use; for example, a solar PV mini grid operator in the Indian state of Odisha charges for each hour of television watched. Volumetric rates can also be designed to vary based upon time of day or availability of supply. If a renewable energy source is abundant during certain hours of the day, tariff levels can be kept low, to incentivize customers to use low-cost energy. In the evening, when a more expensive diesel backup generator must be run, customers can be charged a higher tariff to reflect the higher cost of service.

TABLE 5.6 • Sample utility mini grid projects

Company	Country	Number of mini grids	Description of sample project
Horizon Power	Australia	> 30	Horizon Power currently services one of the largest remote microgrid portfolios in the world. The Onslow microgrid will be set up as a solar hybrid, which will make it one of Australia's largest distributed microgrids.
Northwest Territories Power Corporation	Canada	< 20	Northwest Territories Power Corporation installed a 104 kW solar array to supplement existing diesel generation, which is enough to power approximately 17 households. The installation is expected to reduce CO2 emissions by 76 tonnes per year.
TANESCO	Tanzania	> 20	Of TANESCO's 26 operational mini grids, 19 are powered by fossil fuel and 7 are hydro.

Source: Horizon Power n.d.; Northwest Territories Power Corporation 2018, n.d.; Odamo and others 2017.
CO_2 = carbon dioxide; kW = kilowatt.

BOX 5.3

UTILITY-LED ROLLOUT OF MINI GRIDS ON THE NATIONAL SCALE: CASE STUDY FROM ETHIOPIA

With a population of nearly 120 million and an electrification rate hovering close to 50 percent, Ethiopia has the second-highest electricity access deficit on the Sub-Saharan continent, in terms of total population without access to electricity, outpaced only by Nigeria. Faced with this significant challenge, and focused on an ambitious goal of reaching universal electrification by 2030, in 2017 the government of Ethiopia issued a National Electrification Program (NEP), followed by an even more comprehensive NEP 2.0 in 2019. NEP 2.0 is an integrated, national-level, data-driven plan that combines the fast-paced grid connection rollout of the earlier NEP—aiming at a 65 percent connection rate by 2025—with a complementary off-grid and mini grid access program targeting the remaining 35 percent of the population in harder-to-reach and more remote areas.

In alignment with the goals and vision of NEP 2.0, on March 29, 2021, the World Bank approved a comprehensive new project: Access to Distributed Electricity and Lighting in Ethiopia (ADELE). At $500 million, ADELE is the largest energy access program on the continent to date.

Component 2 of ADELE, "Mini Grids for Rural Economic Development," is a $270 million commitment to roll out mini grids at scale across the country, both through public- and private-sector-led modalities. The component is implemented by the Ethiopian Electric Utility (EEU), through a dedicated off-grid unit.

The component has earmarked $217 million for the scale-up of the utility-led mini grid model, primarily through the deployment of several modalities of variously bundled engineering, procurement, and construction, plus short- and long-term operation and maintenance contracts. Prior to ADELE, such models have already been successfully tested across the country through various donor-supported programs, such as the 12 mini grids deployed by the EEU with financing from the World Bank's Ethiopia Electrification Program (ELEAP), as well as the 25 systems currently under implementation by the utility with funding support from the African Development Bank.

ADELE's Component 2 equally targets private-sector-led modalities—$53 million under the project is dedicated to the launch of a national-level performance-based grant program. The program, also implemented through the off-grid unit within the EEU, will offer viability gap financing to help close the gap between the cost to the developers of constructing and operating the systems, and the affordability of the local communities. The program aims to engage both local and international developers. At the time of the preparation of this Handbook, the private-sector-focused program is in an active design stage, with the EEU working together with the World Bank and the Ministry of Water and Energy of Ethiopia to refine the planned implementation model, building on lessons learned from experiences within and outside the country.

continued

BOX 5.3, *continued*

In parallel to the preparation of the ADELE project, as part of a holistic approach aimed at targeting nationwide mini grid scale-up along key frontiers (in alignment with the GFMG 10 building blocks philosophy), Ethiopia's Government worked with the World Bank, the United States Agency for International Development, and other key development partners to develop new mini grid regulations. The resulting mini grid directive, which was issued by the Ethiopian Energy Authority in December 2020, is a comprehensive, streamlined, tailored policy document that provides detailed guidance to the sector on minimum technical and performance standards, as well as licensing and tariff setting.

In addition to the ADELE project, a number of other key donor partners and stakeholders are actively growing their presence in the mini grid space in Ethiopia, recognizing the significant opportunity for impact across the country and working on mobilizing local and international private sector and financiers. One important example to note in this context is the Distributed Renewable Energy Agriculture Modalities (DREAM) program, currently being implemented by the country's Ministry of Water and Energy in partnership with Ethiopia's Agricultural Transformation Agency, the Rockefeller Foundation, and African Development Bank's Sustainable Energy Fund for Africa. The program aims to have a transformational impact by leveraging the Agricultural Transformation Agency's ongoing work in supporting household farmer-based Agricultural Commercial Clusters, through facilitating access to reliable and affordable solar mini grid power for large-scale cluster irrigation farming. The program is intended to be implemented in partnership with private-sector mini grid developers. It is currently rolling out a proof-of-concept pilot at nine sites, with a tender underway, with viability gap financing and concessional debt offered to developers interested in bidding on the sites.

- *Combined flat and volumetric tariffs:* Some developers charge a flat fee for all energy and/or power consumed up to a certain threshold, above which the customer pays a volumetric tariff according to how much electricity is consumed.

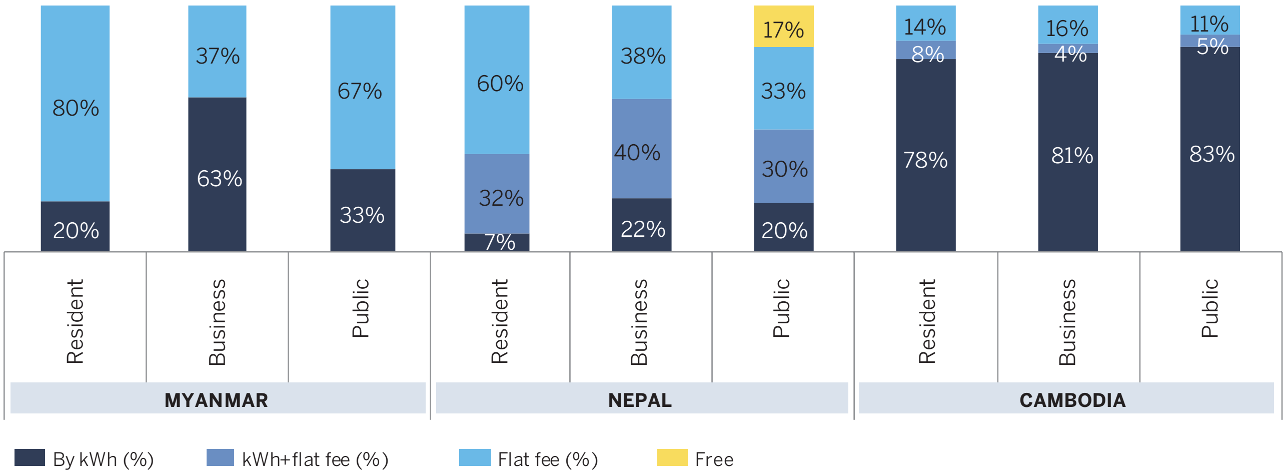
Results from the World Bank's operator surveys provide some examples of how these types of tariffs are implemented. Operators in Myanmar are more likely to charge most customers a flat fee on a regular basis than they are to charge customers by electricity consumption. By contrast, some Nepali operators adopt a flat fee with a consumption-based one, while a large majority of Cambodian operators charge consumers according to their consumption. In Myanmar and Nepal, among all classes of customers, operators have a greater tendency to charge business customers by consumption rather than a weekly or monthly flat rate. Public customers may use electricity by paying a flat fee or even obtain free electricity (figure 5.1).

If charging according to consumption, Nepali operators offer low tariffs in the range of $0.07–$0.08/kWh to all consumers, while the tariff range for Myanmar mini grid customers is $0.10–$0.34/kWh, and for Cambodia it is $0.23–$0.24/kWh. Mini grid operations in Myanmar provide a distinctly lower price to their public customers, including schools, health clinics, and government buildings, on average $0.2/kWh lower than residential and business customers. Nepali and Cambodia operators charge all customers very similar tariffs, according to their consumption (figure 5.2).

Operators provide a wide range of flat-fee tariffs for residential, business, and public customers: $0.34–$5.32/month in Myanmar and $0.94–$5.71/month in Nepal. Business customers are charged apparently much higher than residential and public consumers in Myanmar and Nepal, indicating that serving more business consumers could effectively increase revenue. The flat-fee tariffs for public customers to consume mini grid electricity are markedly low—only $0.34/month in Myanmar and $1.03/month in Nepal (figure 5.3).

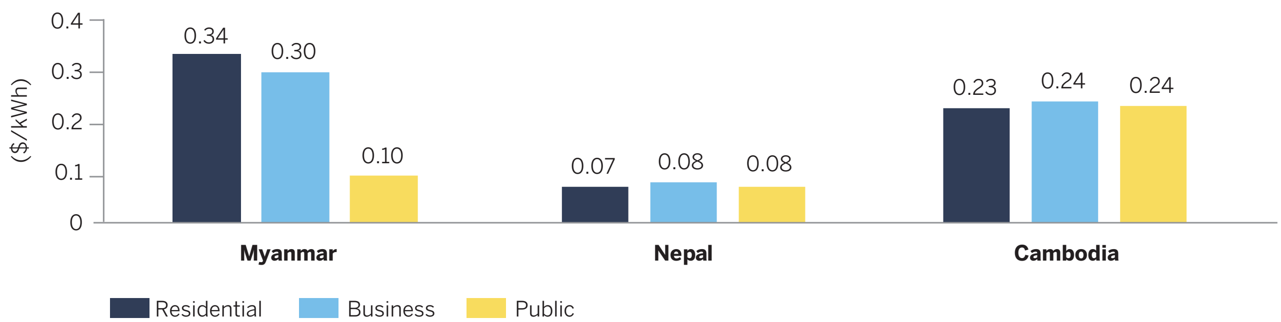
Regardless of how the mini grid operator designs tariffs, money can be collected in two ways: before electricity is delivered (that is, prepaid) and after electricity has been consumed (that is, credit or postpay). Certain tariff approaches naturally lend themselves to a prepay model, such as the flat tariff. Although utilities have traditionally used credit to charge customers volumetric rates, many mini grid operators use prepay models, as they have several benefits over credit mechanisms. With prepay electricity, the risk of noncollection is reduced, and it eliminates the costs associated with sending staff out to collect payment (box 5.4). Prepay electricity also providers the customer greater transparency regarding electricity use and costs

FIGURE 5.1 • Tariff-charging type by customer class



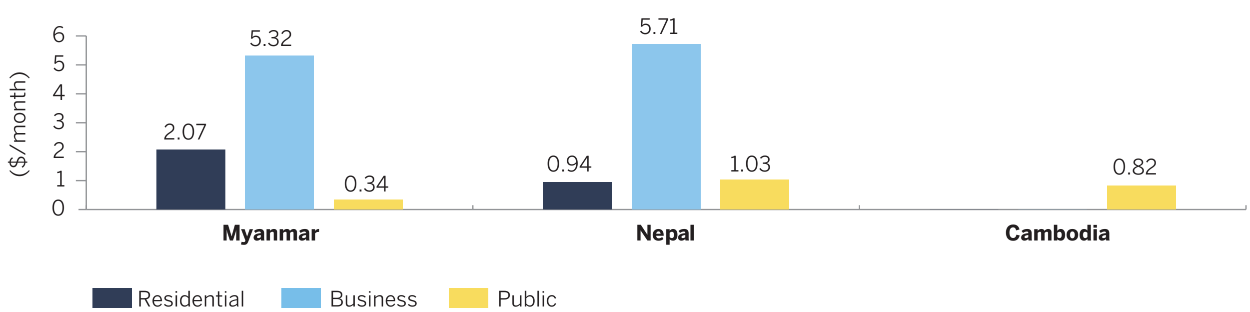
Source: ESMAP analysis.
kWh = kilowatt-hour.

FIGURE 5.2 • Tariffs by customer class ($/kWh, charged by consumption)



Source: ESMAP analysis.

FIGURE 5.3 • Tariffs by customer class ($/month, charged in flat fee)



Source: ESMAP analysis.
— = no responses to the survey for this category of customer.

(Jack and Smith 2017). Where mobile phone coverage is available, mobile payments can also facilitate payment in both prepay and credit schemes.

Regardless of whether a mini grid operator uses a prepay or credit payment scheme, smart meters can help facilitate payment and collection. Companies such as Sparkmeter have developed meters geared toward off-grid mini grid deployments. These meters can remotely connect or disconnect customers, manage customer billing information, integrate with mobile payment plans, and help operators track and limit electricity use in real time.

An important note on tariff levels: mini grid operators need to be able to charge tariffs at a rate that allows for viable operation, and that is commensurate with a community's ability to pay. Where there is a gap between the commercially viable tariff and customers' ability to pay, subsidies will be needed. Dictating tariffs that are below the cost of service in the absence of subsidies will prevent money from being reinvested into operating the system or into subsequent expansion. When service is provided for the first time, customers still have a choice; they might use solar lanterns, install SHSs, or even continue with kerosene lanterns. Therefore, to be commercially viable the mini grid operator needs to offer rates that compete with alternate technologies, and reliable service that will attract customers to sign up for a connection. Chapter 9 provides a detailed discussion of regulating retail mini grid tariffs.

As previously noted, if an operator is to pursue multiple mini grid sites, designing business processes that are replicable will be critical. By developing standard business processes for site assessment, supplier engagement, mini grid operation, and maintenance and repair procedures, mini grid operators are in a better position to efficiently manage multiple sites. Similarly, if a mini grid operator were to target similar customer demographics, such as communities with the presence of a telecommunications anchor tenant, then the operator could reduce the amount of variability, and resulting inefficiency, in its operations.

In the after-sale segment of the value chain, another way to increase revenue is to provide additional goods and services, particularly those that rely on electricity. This provides the added benefit of opening up new revenue streams for the operator; it uses the relationship the operator already has with the end customer, and addresses additional needs or aspirations that the end customer may have.

As an example, the Rockefeller Foundation and CrossBoundary are running a pilot in Sub-Saharan Africa through their joint Mini Grid Innovation Lab, providing capital to mini grid companies, who in turn can provide financing to customers for equipment purchases to increase the productive uses of mini grid electricity. (More information regarding the methods and benefits of increasing demand, particularly through productive uses, can be found in chapter 3.)

Reducing costs for mini grid developers and utilities

In addition to identifying ways the operator can generate additional revenue, it is important to manage costs, as greater profitability is driven both by higher revenue as well as by reducing capital and operating costs. Mini grid operators such as ESCOs and utilities can apply several strategies to manage their costs.

Local staffing. By employing staff who work or live close to the mini grid facility, operators can reduce the cost of transporting personnel to the site, as well as avoid salary adjustments that result from living in higher-cost areas. In addition, having local staff has the added benefits of making an operator more responsive to end customers and addressing potential operational issues.

Procurement. When developing and operating multiple mini grid sites, it is important not only to engage multiple suppliers, but also to buy equipment for more than one mini grid site if possible. Negotiating with multiple suppliers with similar technical specifications can help drive down the initial equipment cost. Ordering multiple units and utilizing volume discounts can help reduce capital expenditures.

Even if an operator is executing a single project, receiving bids from facilitating organizations, such as equipment manufacturers, can help reduce initial capital expenditures. On the online mini grid management platform Odyssey, mini grid operators post project specifications for bidders.

BOX 5.4

PREPAY IS NOT JUST FOR MINI GRIDS—ESKOM'S "POWER FOR ALL" SCHEME

In 1988, the South African power utility company Eskom launched the "Power for All" initiative, intended to supply electricity directly to domestic customers. At the time, Eskom's primary customers were mines and municipalities. When the concept was introduced, many of the target customers were rural, and did not have a bank account or a fixed address. Eskom sought to develop a scheme that would target these customers with the lowest overhead, since many of them would be low-use customers (Eskom n.d.). A recent study in Cape Town found that the investment returns to the utility were 10 percentage points higher in a prepay scheme when compared with a postpay scheme (Jack and Smith 2016, 2017).

Equipment providers, financiers, and others can then offer their services to help complete the project.

Prepaid metering. As noted earlier, by having customers pay for electricity up front (rather than metering and then billing after the electricity has been used), operators can often reduce the amount of staff and overhead dedicated to billing and payment collection. With prepaid systems, the customer pays up front for a certain amount of electricity, and once that has been used, the customer must prepay for another allotment. Prepaid metering is not without challenges, however. Issues to address include the need for cellular data coverage at the mini grid site and methods to protect against customer tampering.

Fuel hedging. For operators using a fuel-based generator, adding a fuel hedge contract may be valuable. Fuel hedging involves entering into a contract with a fuel supplier for a certain amount of fuel at a certain price. In environments where fuel prices are volatile or are expected to rise due to increased demand or a removal of a subsidy, entering into such a contract can make costs more certain and also maybe lower them, relative to a spot market price (Villadsen 2017). However, before entering into a hedge contract, the operator should analyze historical and future price trends to avoid entering into a long-term agreement when spot fuel prices are below historical averages. In addition, hedging and locking in fuel costs will require explaining to users why their bills do not go down when fuel prices fall, and hedges may not be available in some markets. In these cases, fuel spot prices with a fuel surcharge may be more practical.

Digital automation. Digital technologies, such as mobile payment or remote monitoring, can help reduce operational costs, and thus directly improve profitability. As noted earlier, using prepay meters with mobile payment can help reduce overhead by eliminating the need for staff to collect cash or to pursue customers for payment. Remote-monitoring tools can help monitor different mini grid equipment, ensure that it is functional, and proactively address any issues that may arise, reducing overall maintenance costs (Aaron 2014).

For example, using digital twin technology, a virtual model of a product, such as a solar hybrid system, allows for the analysis of operational data to address issues before they occur (Marr 2017). This might increase the availability of operators' assets by up to 15 percent and reduce maintenance costs by up to 25 percent (Bradbury and others 2018). Mini grid equipment providers, such as SMA Solar Technology through its Sunny Portal system, allow for operators to monitor a variety of parameters in real time to assess system performance. The Sunny Portal system is the largest solar monitoring platform, with more than 20 GW of capacity monitored in real time, including both on-grid and off-grid installations (SMA Solar 2019).

Mini grid operators make their money by selling electricity to customers. Some earn additional revenue by selling appliances and electro-mechanical equipment to increase demand for electricity. Strategies they deploy to manage their costs include using local staffing, procuring for a portfolio of mini grids, collecting tariffs through prepay schemes, hedging against fuel cost increases, and deploying digital automation in their operation and maintenance activities.

MINI GRID FACILITATORS

In this second category of private-sector participants, facilitators are not selling electricity directly but are engaged in facilitating the mini grid sector.

Engineering, procurement, and construction companies and system integrators

These companies focus on designing, installing, and commissioning generation or distribution assets. They often design power systems, procure and assemble various subsystems, transport equipment to the site, and oversee installation and commissioning. International EPCs and SIs often have extensive experience operating in remote areas, although they tend to focus on large-scale industrial operations, such as extractive mines. These large EPCs have also, at times, pursued rural electrification programs. For example, when Botswana Power Corporation issued a tender to build 20 solar mini grids, large EPCs such as Japan's Marubeni, China Harbor Engineering Company, and China Mechanical Engineering Company all expressed interest (Benza 2017). Local EPCs may lack the scale to work on large industrial projects, but often have the requisite local knowledge and ability to profitably assist with small-scale power installations. EPCs usually employ local resources to assist with projects; moreover, their capacity to design power systems can be transferred to assisting with mini grid development.

EPCs that tend to specialize in mini grids are sometimes called SIs. These companies buy different solution components from OEMs and package them into a complete solution. For example, an SI might purchase solar panels, batteries, a generator, and power electronics, and bundle these components into a containerized solution. SIs may be independent, or they may affiliate with an OEM, acting as a local channel partner. SIs are generally local entities, and therefore can provide needed fabrication and assembly facilities close to project sites, whereas EPCs are typically international firms.

TABLE 5.7 • Sample mini grid experience of EPC companies

Company	Location of headquarters	Mini grid experience
Hatch	Canada	In Canada, nearly 300 remote communities do not have access to the grid. Generally, these communities have relied on diesel generation. Hatch, a global EPC, has developed its own microgrid controller called HμGrid, which integrates renewables with diesel generation to improve power quality and reliability, and to lower cost as a result of lower diesel consumption.
Clarke Energy	United Kingdom	In February 2018, Clarke developed and installed a hybrid in Nigeria that used 4 megawatts of natural gas engines with 250 kilovolt-ampere of energy storage, and could operate either while connected to the grid or in islanded operation. Clarke integrated GE engines with a FlexGen energy storage system.
Sterling & Wilson	India	Sterling & Wilson is an EPC executing projects of various types— including solar, cogeneration, and diesel generation—in more than 40 countries. In April 2018, the company established a business unit dedicated to developing hybrid systems. In May 2018, the company won an order for three hybrid systems, including one with 17 megawatt-hours of energy storage, across three sites in western Africa.

Source: Sedighy 2017; Clarke Energy 2018; Kenning 2018.

EPC = engineering, procurement, and construction company.

TABLE 5.8 • Sample system integrators with technologies in mini grids

Company	Country	Number of mini grids	Sample project
Tiger Power	Belgium	> 10	In November 2018, Tiger Power signed an agreement with the Ugandan rural electrification agency to develop three mini grids using its own containerized solar and storage system, backed up by a hydrogen generator, to provide power to 3,000 households.
Winch Energy	United Kingdom	> 30	In 2016, Winch Energy installed a 17 kW and 30 kW containerized solar and storage system in the village of Nimjat in Mauritania. It is providing electricity to a school, dispensary, mosque, streetlights, and 70 households.
Nayo	Nigeria	> 10	Nayo Tropical Technology sells individual mini grid components, and also integrates them into containerized systems. In January 2019, NTT won a N96.3 million (approximately $260,000) contract to power the Kare and Dadin Kowa communities with a 90 kW system.

Sources: ARE 2018; Okafor 2019; Winch Energy 2019.

kW = kilowatt.

Sample EPC experiences with mini grids are presented in table 5.7. Table 5.8 describes sample SI projects related to mini grids.

Original equipment manufacturers

OEMs develop subcomponents of or complete mini grid systems. While they may have a business dedicated to providing equipment for mini grids, generally OEMs view mini grids as simply another channel or application to sell their equipment. By pursuing mini grids as another channel, OEMs can improve their business operations, such as by increasing factory or channel use. Often OEMs will establish dealers or will partner with local entities to provide sales and after-sales support to customers. While not a necessity, OEMs generally develop and sell technology with some type of proprietary feature; this enables them to provide a unique value proposition and differentiate themselves from the competition.

As noted earlier, the primary components of a solar hybrid mini grid include solar panels, an energy storage solution, a generator, and power electronics. Table 5.9 lists select OEMs that have deployed their technologies in mini grids.

Generating revenues for mini grid facilitators

Broadly, facilitators have three ways to increase revenue while participating in the mini grid space: sell more of their existing products or services, expand their scope to include new products or services, or develop products or services adjacent to mini grid operations. As the number of mini grids expands, it may be viable to explore all three options. Perhaps the easiest option to manage would be for a facilitator to simply sell more of its existing mini-grid-focused products or services. To do this, it would need to rely on the growth of mini grid deployments. This would necessitate working across multiple geographies; it might also require working closely with regulators and other stakeholders to

TABLE 5.9 • Sample original equipment manufacturers with technologies in mini grids

Company	Equipment provided	Location of headquarters	Company description	Number of mini grids
Jinko Solar	Solar panels	China	100 GW of solar panels to over 160 countries.	107
JA Solar	Solar panels	China	95 GW of solar panels to 135 countries and regions.	46
Canadian Solar	Solar panels	Canada	Over 70 GW of products to over 160 countries.	29
Huawei	Batteries—lithium ion LFP and battery inverters	China	Large information and communications technology infrastructure and smart devices company operating in over 170 countries and regions.	Battery: 85 Battery inverter: 87
Alpha ESS	Batteries—lithium ion LFP	Australia	Energy storage solution provider, 1 GWh annual production capacity, working in 60 countries.	38
Hoppecke	Batteries—lead acid	Germany	Battery manufacturer focusing on power supply backup, renewable energy, and motive power.	20
SMA	Power electronics	Germany	Manufacturer of solar and storage inverters.	45
Victron	Power electronics	Netherlands	Manufacturer of solar and storage inverters.	32
Schneider Electric	Power electronics	France	Manufacturer of low- and medium-voltage industrial products. For mini grids, Schneider provides inverters and controls.	29

Source: ESMAP analysis.

GW = gigawatt; GWh = gigawatt-hour; kW = kilowatt; LFP = lithium ferrophosphate.

establish rules to enable operators to identify and develop mini grid sites. For example, ABB has provided equipment to mini grid operators in India as well as Africa, using its local presence and engineering capability to provide products that are tailored to those markets' unique requirements.

A second way to increase revenue is to provide additional scope to a mini grid product or service. This allows the facilitator to capture additional "wallet share." For example, vendors of individual components can expand their focus to system integration, providing packaged mini grid solutions that can be deployed easily. Schneider Electric recently introduced containerized solar and battery systems, thus expanding beyond individual components. For EPCs, such a move might involve expanding into product development and testing. Financiers might move from project financing into corporate financing, providing debt to project vehicles as well as corporate expansion. To offer another product or service allows companies to establish new partners and develop new competencies. But expanding into adjacent parts of the value chain is best done only after carefully studying customers' needs and economic decision points (Zook and Allen 2003).

The third way to increase revenue is to expand into spaces adjacent to the mini grid value chain. Just as mini grid operators are expanding their offerings into appliances and other goods, so too can facilitators provide products to mini grid customers, perhaps even utilizing the customer relationship that the operator has established. While mini grid facilitators have yet to embrace this strategy, many in the discrete solar space, particularly those who manufacture stand-alone solar systems, have begun to diversify their offerings. For example, SolarKiosk designed an E-HUBB, a stand-alone solar and storage solution that, in addition to generating electricity 24/7, can be customized for various commercial applications, including as a small commercial store, a health center, or even a movie theater.

Reducing costs for mini grid facilitators

To seek maximum profitability across the mini grid value chain, facilitators will need not only to grow revenue, but also to better manage operational costs. Costs can be better managed generally by employing mass customization, replicability, and digital tools.

Mass customization. A key strategy in other industries, from apparel to automobiles, mass customization is the process of combining elements of mass production with those of bespoke tailoring (The Economist 2009). As in mass production, the process uses a few standard platforms that are common across products; this allows large investments to be amortized across a greater number of units. Once these standard components are produced, the remaining pieces of the product can be tailored for individual applications. This allows companies to respond to unique customer requirements without developing bespoke products. In the case of mini grids, OEMs that are producing equipment should consider mass producing components that can apply to multiple applications, but then customize them to suit the mini grid space's unique requirements.

For example, a solar inverter manufacturer might develop a component that can be installed in multiple products or applications, and yet use it in a unique offering for mini grids. Outback Power manufactures individual solar and battery inverters; in addition to offering these as stand-alone products, the company integrates them into packaged offerings with batteries to deploy in off-grid environments. The package itself is scalable based on the project's power requirements. This allows Outback to amortize the fixed investment of building a factory to develop inverter components across multiple applications, from small-scale off-grid systems to large-scale utility inverters. Thus, while performing minor tasks that customize the unit for off-grid duty, the OEM is simultaneously responding to the unique requirements of the mini grid operator. Operators too will benefit from such an arrangement: they will receive a product designed and tested for a variety of environments, and therefore proven effective, yet tailored to their requirements.

Financiers might also consider a mass customized approach to reduce overhead, while still responding to a mini grid operator's unique needs, by establishing a set of standardized, yet flexible, processes or products. When Facebook, Microsoft, and Allotrope Partners established the Microgrid Investment Accelerator in the spring of 2017, its goal was to use a blended capital fund to make grant, equity, and debt investments available at a project or corporate level. Through this one fund, it could access various investment instruments and utilize data analytics to offer a customized financing package based upon a mini grid operator's maturity level.

Replicability. For equipment manufacturers, it is relatively clear how mass customization as a concept can apply; however, it is not as clear for companies that focus on process, such as EPCs. Just as mass customization rests on the ability to mass produce key pieces of a product, so too should process companies such as EPCs focus on replicability. Developing standard processes for site preparation, distribution planning, staffing requirements, and packaging for transport will help reduce variability and, therefore, cost. Using digital inputs and algorithms to process certain tasks quickly, automation can also play a role. For example, geospatial analysis using satellite image processing can aid in the planning and layout of distribution grids.

Given the current stage of the mini grid market, and the relatively few installed projects, it may be difficult to establish tested processes for mass customization and replicability. But the key will be to invest, execute a variety of projects (of which some may not be profitable), and use that experience to develop product strategies and implementation methodologies that can drive down cost. For every doubling of production for a manufactured good, the cost declines by a fixed percentage. Solar panels are an example of this: every time their production doubled, their cost declined by 18–35 percent (d'Avack 2010). By engaging with a variety of successful and high-potential mini grid developers, instead of targeting only the largest ones, facilitators can improve the economics of their product or service offering to the mini grid industry and achieve greater profitability as the market expands.

One important note is that for mass customization and replicability to apply to mini grids, companies that supply technologies and services to the mini grid industry will need as large a market as possible. This means standardizing technical specifications for mini grid equipment across countries. The greater the discrepancy between regulations across regions, the more that customization and a bespoke approach will be required, thus adding cost and reducing the ability of facilitator organizations to scale.

Digital tools. Using digital tools can help facilitator organizations standardize their processes around mini grid development and allow for a more efficient operational cost position. Using remote monitoring and diagnostics technologies, OEMs can analyze a mini grid's performance remotely, diagnose any issues, and dispatch personnel with the right tools and parts. Using such digital capabilities can avoid costly field visits, minimize unplanned downtime, and even allow for future product revisions to be based on operational data. For EPCs, using digital tools such as geospatial analysis can help with process replicability. Financiers can also use digital tools to help drive transparency in the projects and companies they finance. In addition to using tools such as Odyssey to identify projects, financiers can analyze operational data to gain greater insight into projects, benchmark performance against other projects, and work with mini grid operators to implement best practices.

Mini grid facilitators make their money by selling products and services to companies that participate in the mini grid industry value chain, particularly operators. They generally have three ways to increase revenue: sell more of their existing products or services, expand into new products or services, or develop products or services adjacent to mini grid operation. In parallel, facilitators generally use three strategies to manage their costs: mass customization of their products, replicability of their services and processes, and the use of digital tools to increase efficiency.

FACILITATING COLLABORATION BETWEEN AND AMONG LOCAL AND INTERNATIONAL PRIVATE-SECTOR ENTITIES

As the mini grid sector matures, and both international and local private-sector entities begin to specialize in certain aspects of the value chain, establishing partnerships among entities will be critical. There is a natural delineation between (1) the steps of the value chain that are best served by local entities, and (2) those best served by international entities. Facilitating the deployment of mini grids at scale will require collaboration between both types of entities; indeed, a partnership that uses the unique strengths of local and international industry is the only way to maximize overall value chain profitability.

As noted earlier, local entities are best positioned to focus on those aspects of the value chain that require knowledge of local rules and regulations, or that require coordination with customers being served. These local entities might be independent companies or affiliated with a larger international company.

International companies are best suited to elements of the value chain that do not require local context; they are ideally positioned to perform tasks that can be replicated across geographic boundaries. For example, international OEMs can deliver packaged mini grid equipment to operators across countries. For the operator, working with an international company provides assurance of a competitively sourced and manufactured product, with the appropriate service and warranty provisions. For the OEM, being able to sell components or solutions across geographies would enable amortizing fixed costs, such as capital expenditures on more units, reducing the overhead ascribed to each individual unit.

Table 5.10 outlines four types of partnerships among local and international industry, along with the benefits each party receives.

Though beneficial, facilitating partnerships between different local and international industry participants does have certain policy implications, particularly related to trade and local content requirements. While there may be strong justifications for imposing tariffs or local content requirements on certain mini grid components—whereby a certain portion of the mini grid's bill of materials must be manufactured locally—when viewed through the narrow lens of mini grid viability, these policies are typically counterproductive. Mini grid viability is influenced to a significant degree by the ability to procure and install mini grid systems as cheaply as possible; this necessarily means that mini grid components and systems should be procured from wherever they are cheapest to manufacture. Much of the mini grid value chain must be executed by local industry; therefore, it is reasonable to consider removing barriers related to international industry participation in equipment provision.

> There is a natural delineation between the steps of the value chain best served by local entities, and those that are best served by international entities. Local entities are best positioned to focus on aspects of the value chain that require knowledge of local rules and regulations, or that require coordination with the customer being served by the mini grid. International companies are best suited to elements of the value chain that do not require local context; they are ideally positioned to perform tasks that can be replicated across geographic boundaries.

> Facilitating deployment of mini grids at scale requires collaboration between local and international entities; indeed, such a partnership that uses the unique strengths of local and international industry is the only way to maximize overall value chain profitability. Industry associations play an important role in facilitating deal making between local and international companies, and helping the local industry players speak with a unified voice to both policy makers and the broader marketplace alike.

Collaboration between local and international industry does not simply have to be within the bounds of the mini grid space. For facilitators, such as OEMs, that need to develop a local presence to provide after-sales support and generate additional leads, there may be value in partnering with other companies that have already developed such a presence. Likewise, non–mini grid companies may derive value from working closely with mini grid providers, particularly if their products require electricity. For operators, working with companies that sell goods or services to the same end customers may increase demand and help improve the customer experience through a bundled product or service offering.

Productive uses of electricity are another area where collaboration between local and international industry can drive the mini grid sector to scale. For mini grid operators,

TABLE 5.10 • Benefits of local and international partnerships

Structure	Description	Benefit to local industry partnering with international entity	Benefit to international industry partnering with local entity
Buyer–supplier	Local buyer company purchases goods from one or more international supplier companies	Access to technically proven technology with support for warranty, service and repair, etc. Competitively priced components	Additional revenue from new customer segment More product volume reduces amortized fixed cost, improves manufacturing use
Channel partner or distributor	The local company will act as the local agent for an international company, selling goods and services to customers	Access to technically proven technology with support for warranty, service and repair, etc. Branded, differentiated technology improves competitiveness vs. other local companies (especially if exclusive)	Lower-cost mechanism to establish presence in new markets or remote locations (for example, lower base costs from not having full-time staff) Can be more responsive or tailored to local needs
Cross-channel partner	The local company will act as the local agent for an international company in a different industry or market sector than the one in which the local company operates	Access to proven technology that can generate revenues adjacent to core business Increased customer awareness, brand recognition Access to other partners with other complementary services	Access to new distribution partners to increase product sales volume Access to new customer segments Increased customer awareness Access to other complementary products or services to generate revenue adjacent to core
Equity or debt investment	The local company receives an investment from an international entity	Access to lower cost of capital Access to more financial products, earlier-stage capital	Access to investments that can generate higher return Long-term growth potential

Source: ESMAP analysis.

identifying and facilitating productive uses is a key element of generating more revenue. One way to achieve this is taking an ecosystem approach to productive-use development. Companies that can provide goods and services that can generate productive uses can align commercial efforts with mini grid operators, as they are ultimately seeking to address the same customer base. This "channel alignment" can help reduce costs, as it streamlines commercial resources needed, while improving the end customer experience while providing bundled services (for example, selling electricity and refrigeration).

LOCAL AND INTERNATIONAL INDUSTRY PLAYERS ACROSS THE MINI GRID INDUSTRY VALUE CHAIN

The mini grid industry value chain consists of a series of activities, each with one or more participating private-sector entities, that support mini grid design, deployment, and operations, as indicated in figure 5.4.

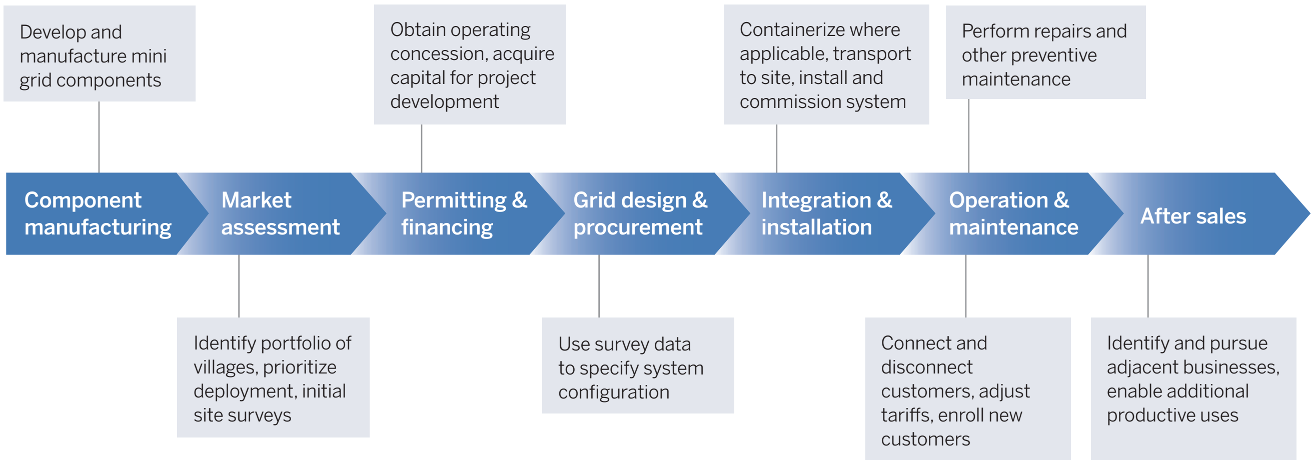
COMPONENT MANUFACTURING

For mini grids, three general categories of technology are needed: generation (which also includes storage), power electronics, and distribution. Generation technologies either produce energy or, in the case of energy storage, can save produced energy for later use. In the case of solar hybrid systems, the key components include solar arrays, energy storage, and backup diesel generation. Power electronics help combine multiple generation sources into a single flow of power, while distribution technology transports the power from the plant to the end customer. Rather than being manufactured specifically for mini grids, these necessary components often are manufactured for general-purpose energy applications that are then adapted for mini grid use.

MARKET ASSESSMENT

This step involves identifying sites that are suitable for mini grid deployment. Generally, mini grid sites that have some combination of commercial and residential loads will be more viable than those that are strictly residential. Commercial customers have higher energy needs and greater ability to pay; they also tend to cluster geographically (IFC

FIGURE 5.4 • Mini grid industry value chain



Source: ESMAP analysis.

2017). Moreover, ideal mini grid sites are typically far from the main grid or have an unreliable and intermittent supply of grid power.

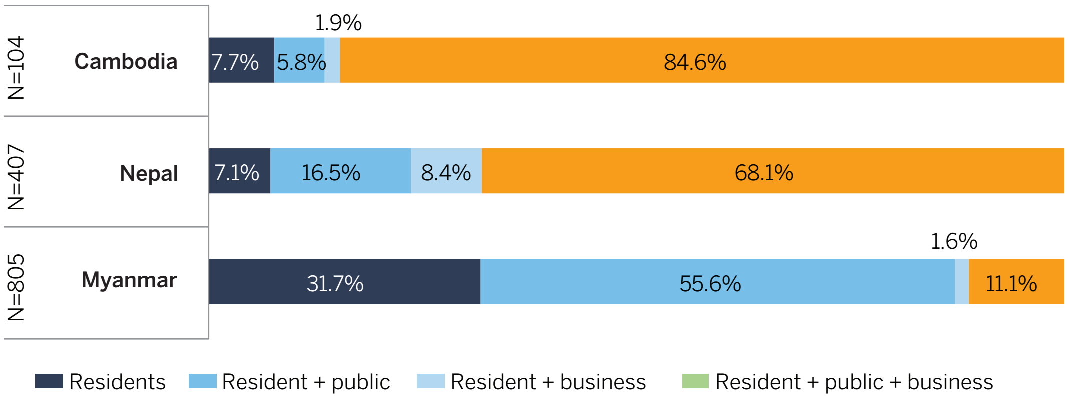
Geospatial analysis can accelerate the identification of multiple potential mini grid deployment sites, and assist with prioritizing those sites best suited for development first. The cost of acquiring relevant data continues to decline. (Chapter 2 provides a detailed discussion of how geospatial analysis can help develop portfolios of economically viable mini grids.)

One key determinant of the mini grid's viability is the mix of end customers. Generally, mini grids were primarily for residential customers who reside too far from the existing grid for service to be economically viable. A mini grid that serves both residential and commercial customers can achieve greater use, in part because commercial loads tend to be active during the day, when solar or solar hybrid mini grids can provide power from the cheapest source they have—solar PV. In contrast, residential loads peak during evening hours or at night, when these mini grids have to rely on more expensive diesel or battery backup power. Larger commercial customers may even enter into a power purchase agreement with the mini grid operator; these agreements can offer the operator a guaranteed revenue, and therefore make it easier to finance the mini grid's development (IFC 2017).

Second-generation mini grids, while primarily serving residential customers, also serve commercial and other customers. Out of three countries in a World Bank survey, mini grid operations in Cambodia serve the most diverse set of customers, including not only residential but also commercial and public clients. Until recently, however, mini grid operations in Cambodia were quite different. In 2001, a mini grid operator survey conducted in Cambodia indicated that mini grid operators in the country were serving mostly residential customers (94 percent) (EDC 2001). Today, 84.6 percent of operators simultaneously serve residential, public, and commercial customers, while 68.1 percent of Nepali and 11.1 percent of Myanmar operators serve these customer groups (figure 5.5). The presence of productive uses and anchor customers, such as small businesses, could diversify the load profile of mini grid operations. In Myanmar, peak demand for residential customers is concentrated during the evening, while commercial and public customers may regularly consume electricity during the day, based on Cambodia's peak-hour profile. This could allow nonresidential customers to function as important daytime loads or as anchor customers. Thus, having nonresidential customers could enable a higher and more balanced distribution of the load, hence increasing the utilization factor of the plant.

Mini grid operators in Cambodia deliver electricity to the largest number of residential, business, and public customers, followed by Nepal and Myanmar operators. The mini grid operations in Nepal and Myanmar typically serve one village of roughly 200–300 households; Cambodian operators serve a cluster of villages containing, on average, 3,842 households. In particular, the Cambodian operations with distribution licenses cover approximately 4,182 households, more than five times the number of households served by consolidated operations. The number of business customers also varies from one country to another: a typical mini grid operator in Myanmar and Nepal serve about 5 and 12 business customers, respectively, while the typical Cambodian mini grid operator with distribution licenses serves around 133 business customers, covering many more than local consolidated operators.

FIGURE 5.5 • Customer types served by mini grids



Source: ESMAP analysis.

PERMITTING AND FINANCING

If after the market assessment phase, a decision is made to further pursue mini grid deployment, the necessary regulatory review must be conducted to receive approval to develop the site. This may involve the operator submitting a proposal to the rural electrification authority or notifying the distribution company of the intent to proceed with a mini grid installation at that site, along with the proposed system configuration. While each mini grid likely may require separate approval, it may be more efficient from both the mini grid developer's and the regulator's perspectives to discuss approval on multiple mini grids in parallel.

Also at this stage, a mini grid operator should make a preliminary determination as to the financial viability of the mini grid or portfolio of mini grids. This includes assessing the revenue potential (a product of the number of customers, the demand, and the tariff rate), as well as working with facilitating organizations to estimate the costs of the mini grid equipment and financing, along with other expenditures, such as fuel and administrative overhead. A more accurate estimate of capital expenditure can be derived during the design phase of the mini grid. However, at this stage, a determination can be made as to whether it would be worthwhile to invest additional money and resources into the design of the mini grid.

In addition, operators may need to demonstrate viability, including both the number of interested customers as well as their ability to pay for the electricity. Operators will often ask customers to prepay a certain amount for an electricity connection, mostly to ensure that customers are indeed able to pay for ongoing electricity provision. For example, to validate customers' interest in receiving electricity, Husk Power in India asks them to provide a deposit for three months' supply.

Mini grid developers are increasingly using a portfolio approach; this reduces the risk of any one project by developing multiple projects in parallel. Assuming each mini grid in the portfolio exhibits different characteristics, financiers may feel more comfortable providing funds to the entire portfolio than to individual projects. If a particular project does not meet expectations, others may provide higher-than-expected returns to compensate. (Chapter 6 provides a more in-depth discussion on financing.)

The second-generation mini grids surveyed by the World Bank employed a diversified approach to raising capital. Mini grids in Nepal are financed by a more diversified funding portfolio than those in Cambodia or Myanmar, which show relatively high reliance on a single type, either an equity or loan. In Nepal, almost 90 percent of operators received both a subsidy from the government or organizations and a contribution from community or private developers, while this share was only 4 percent in Cambodia and 6 percent in Myanmar. Apart from subsidy-based grants and equity investments, bank loans are another important funding type for Cambodia and Nepal; of projects in these countries, 46 and 22 percent, respectively, have ever applied for loans from local banks. Though lending money could increase the risks of capital management, loans are of great importance for some Cambodian operators to cover the cost of large mini grid operations. In Myanmar, since the business scale is comparatively much smaller, operators were likely to start the business with funding from the community, family loans, or their own savings.

The main funding type for mini grid operations varies widely across the three countries. Equity is the main one in Myanmar, with an average share of 37 percent for each operation. Though most Nepali operations receive both subsidy and community-based funding, subsidies from the government and other funding agencies (grants) generally account for a higher percentage than contributions from the community and private developers (equity). In Cambodia, overall, a considerable amount of funding is contributed by loans from banks, relatives, or friends (figure 5.6).

GRID DESIGN AND PROCUREMENT

Once the site has been identified and assessed and the requisite approvals to proceed are in place, the next steps center on finalizing the system design: identifying generation sources, modeling the design, validating the distribution layout, issuing permits, and ensuring regulatory compliance.

Identifying generation sources

Depending on the location of the mini grid, there may be one or more suitable options for electricity generation. Solar and solar hybrid mini grids account for 80 percent of the planned mini grids in ESMAP's database of more than 26,000 installed and planned mini grids around the world. Hydropower remains an important generation technology for mini grid sites located close to a river, in which case a run-of-river mini hydro system is often viable.

In the World Bank's survey of second-generation mini grid operators in Cambodia, Myanmar, and Nepal, most operators used diesel or hydropower as the primary generation source. Cambodia's average generation capacity per mini grid is larger than it is in Myanmar and Nepal, reflecting the difference in the number of customers that the operators serve in each country. The median value of the generation capacity is 19 kW and 23 kW for Myanmar and Nepal, respectively, while the average generation capacity in Cambodia is about 250 kW. About 50 percent and 28 percent of the operations in Myanmar and Nepal, respectively, have imposed the capacity limit (which is, on average, around 100 watts) to end users by limiting the number and type of services they can use.

Mini grid operations in Nepal rely mainly on hydropower, which is affordable and locally available, while most of the mini grid operations in Cambodia Nepal, carried out by consolidated licensees, rely on diesel for electricity generation. Solar PV technology was introduced into diesel-based mini grid operation in Myanmar only recently—in 2017, according to the survey results. In Myanmar, 7 percent of mini grid operations, particularly in Shan state, use hydropower to generate electricity. Mini grids using hydro resources in Myanmar, with an average capacity of 30 kW (median value), have a relatively larger capacity than diesel-based operations, which have an average capacity of 19 kW (median value).

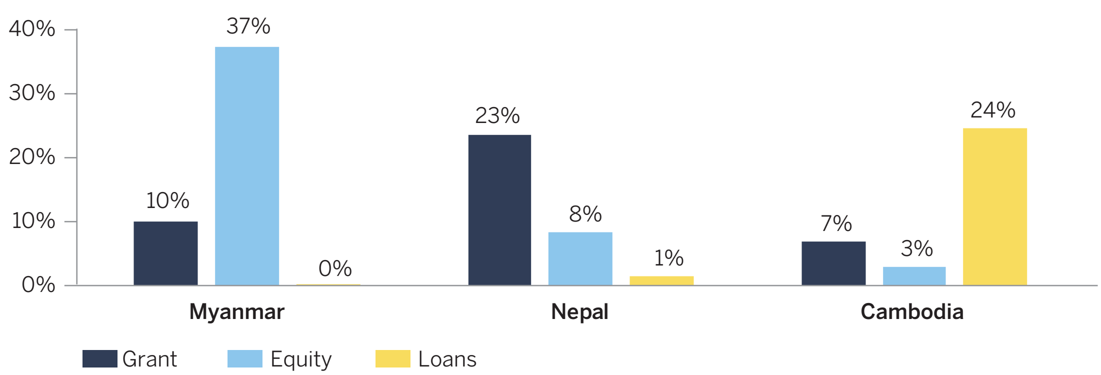
Modeling the design

To determine the appropriate mini grid size and finalize the overall business case, it is necessary to model the mini grid's operation to estimate fixed and variable operational costs. Tools such as the HOMER Energy mini grid modeler can use inputs from the site assessment phase, such as the demand profile, to run an hourly dispatch model that will estimate the configuration and operating costs of the mini grid.

Validating the distribution layout

Another critical element of the mini grid design is the layout of the distribution system, which can add significant up-front costs to the mini grid. Factors that affect the cost

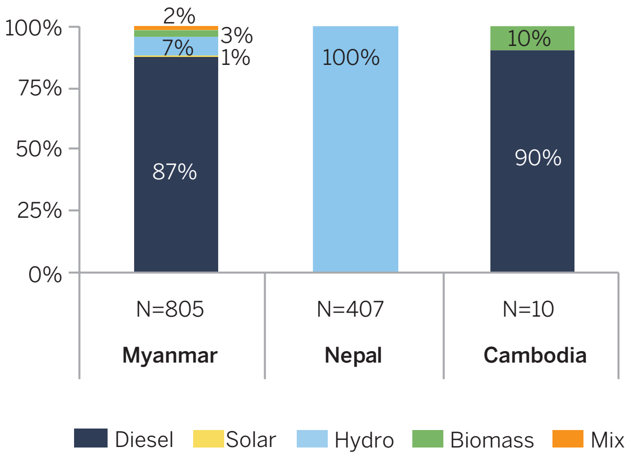
FIGURE 5.6 • Average contribution share of each disclosed funding type



Source: ESMAP analysis.

Note: Many developers did not disclose the sources of all of their funding; as a result, totals in each country do not sum to 100 percent. Funding sources are generally divided into three types: grants, equity, and loans. Grants include government subsidies and other subsidies from nonprofit organizations or funding agencies (for example, the Rural Electrification Fund and Reimbursable Advisory Service in Cambodia). Equity includes community contributions, investment from private developers or banks, as well as company-owned resources. Loans include those from banks, relatives, friends, and others.

FIGURE 5.7 • Generation source of the mini grid



Source: ESMAP analysis.

include the number of houses served, the distance over which electricity must be distributed, and the capacity of the distribution lines. Geospatial analysis can help determine the optimal layout, considering physical barriers and specific customer locations, as discussed in more detail in chapter 2.

Once a distribution layout has been designed, there still remains selection of the materials used to implement the distribution system—namely, the type and size of the poles and wires. Here, and with other mini grid components, we see a wide variety of technologies and materials used around the world. This is partly the result of the different standards and specifications used across countries. According to the results of the World Bank's survey, operators in Cambodia, Myanmar, and Nepal prefer different conductor materials. In Cambodia and Nepal, aluminum is the most prevalent conductor material for the mini grid transmission system, adopted by more than 95 percent of operators, although aluminum is still an important material in Myanmar, the percentage of operators using it is much lower than in the other two countries; instead, copper is used for about 80 percent of operations.

Distribution network poles made of insulated, qualified, and standardized materials can effectively improve the quality and safety of electricity service. In Cambodia, the material for an electric pole is standardized: all of the operators reported that they use concrete for an electric pole. In contrast to Cambodia, it is difficult to find a standard material for an electric pole for the mini grid operations in Myanmar and Nepal. About half of the operators in Nepal use steel poles, while the rest rely on wood poles. Operators in Myanmar use nonstandard wood (50 percent) or bamboo (2 percent) poles, or both (22 percent). In general, around 87 percent of the operations in Myanmar use nonstandard poles for distribution, which may pose a hazard and cause unreliable electricity service with significant voltage fluctuation.

INTEGRATION AND INSTALLATION

Once the design of the power plant and distribution system has been finalized, the various power plant components and distribution infrastructure can be procured. Facilitating organizations, such as equipment manufacturers and system integrators, can play a role in assembling the mini grid according to the operator's requirements, determined through the prior steps. As these companies have experience helping to configure equipment in other applications, they may be able to partner with mini grid operators to ensure that the system is designed to meet the expected load.

System integrators can develop prefabricated containerized mini grids, especially for solar hybrid mini grids. These shipping containers may house much of the necessary technology, including generators, batteries, and power electronics. In some instances, the solar panel array may even be attached to the container. For example, Tiger Power offers a containerized solar and storage system that contains the solar, batteries, and power electronics needed to distribute electricity.

One important consideration when procuring mini grid components or completing integrated systems is the benefit of volume purchases. Component manufacturers, system integrators, and EPCs are likely to offer some form of discount for purchasing more than one unit. Volume purchases allow for greater resource use, potentially lower variable cost, and an ability to amortize fixed costs over more units. For mini grid operators and others purchasing components or systems, procuring for multiple mini grid sites provides greater negotiating leverage when interacting with suppliers.

Once the system has been designed and various components have been procured, the next step in the process involves preparing the mini grid site to receive the mini grid system components and finalizing the installation of the system. Facilitating organizations, such as EPCs, play a key role here as well. These companies can help clear the land to receive the mini grid, arrange for transporting the system to the site, and perform all the installation and wiring according to the system's design. Unlike the prior step related to the design and procurement of the system, this step in the process will rely almost entirely on local resources. To minimize the amount of field resources required, as well as to reduce the amount of time dedicated to installation, mini grids can also be preconfigured into transportable units.

OPERATIONS AND MAINTENANCE

Once the mini grid has been installed and commissioned, operation can commence. Mini grids can be operated either locally or remotely. Local control requires an operator turning on the unit and manually switching between generation sources. With remote operation, the different generation sources automatically turn on or off based on an algorithm that is designed to always dispatch the lowest-cost generation source first. Many second-generation mini grids require a local operator to monitor the system and make adjustments as demand changes. But with third-generation mini grids supplied by international equipment manufacturers, much of the control work is automated through digital controls. This digital system can also send real-time operation data back to a monitoring system, using cellular connectivity, to allow technicians not located near the mini grid to monitor its operation.

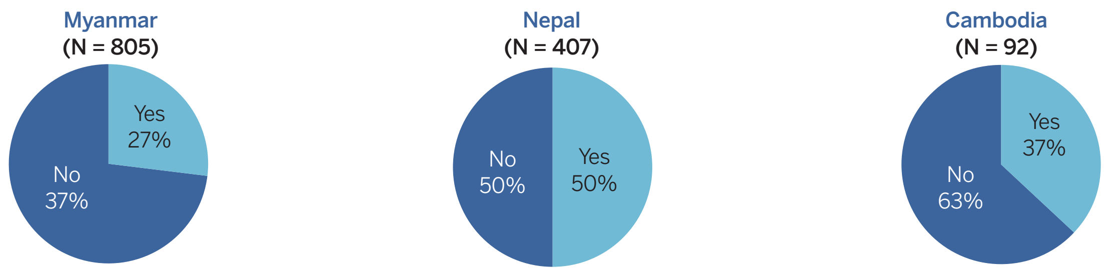
Proper mini grid maintenance boosts system availability and reliability. Proper maintenance procedures are founded upon understanding how the system is performing, identifying issues when they occur, and having the right personnel and parts available to address the issue. Having enough skilled technicians available is one of the biggest challenges facing operators. Husk Power, a mini grid operator in India, has designed its own training programs, educating more than 100 technicians each quarter to supply the needed repair services on the company's mini grids. (Training and skills gaps in the mini grid sector are discussed in chapter 7.)

If an operational issue is caused by a faulty part, finding a suitable replacement part quickly becomes critical. Mini grid equipment manufacturers may be able to provide a replacement part, particularly if that part is still under warranty. It may be prudent, however, to create an inventory of the parts that are most prone to failure so operators can resolve the issue quickly. To do so, it is important to discuss with the equipment manufacturers which critical components would be best to inventory, then procure and store those parts, and develop a process to ensure they do not degrade while in storage (Dyess 2017).

Respondents to the World Bank's survey of second-generation mini grids documented difficulty in providing year-round availability, overcoming resource shortages, natural calamities, or system breakdowns: 37, 27, and 50 percent of mini grid operators in Cambodia, Myanmar, and Nepal, respectively, have experienced operational difficulties in supplying electricity to customers. In Cambodia, threats to service reliability may include system damage from inclement weather and shortages in resources and finances. Operations in Myanmar are greatly affected by resource shortage, mini grid system breakdown, and high diesel fuel prices. For Nepali operators, natural calamities, such as floods and landslides, are the primary concern; they are also bothered by hydro shortages and finance shortage problems. Thus, these multiple challenges could lead to relatively unreliable mini grid operation. Comparison between typical and worst months can indicate the stability with which the operators are able to provide electric services to end users throughout a year (figure 5.8).

FIGURE 5.8 • Causes behind operators' worst months of delivering electricity

Responses to the survey question: "Are there certain months/seasons every year when the mini grid has difficulties in supplying electricity services to its customers?"



Of developers who responded yes . . . (Myanmar)

- **36.4%** Network line was broken
- **36.3%** Shortage of nonmonetary resources
- **18.2%** Resources are expensive

Of developers who responded yes . . . (Nepal)

- **86.1%** Natural calamities like floods and landslides
- **45.5%** Shortage of nonmonetary resources (e.g., inadequate water in case of hydro system)
- **14.4%** Shortage of finances

Of developers who responded yes . . . (Cambodia)

- **44.1%** Heavy rains damage the system
- **29.4%** Shortage of nonmonetary resources
- **23.5%** Shortage of finances

Source: ESMAP analysis.

Note: The three most common causes behind service delivery challenges are shown. Respondents often gave multiple causes; as a result, percentages do not add to 100%.

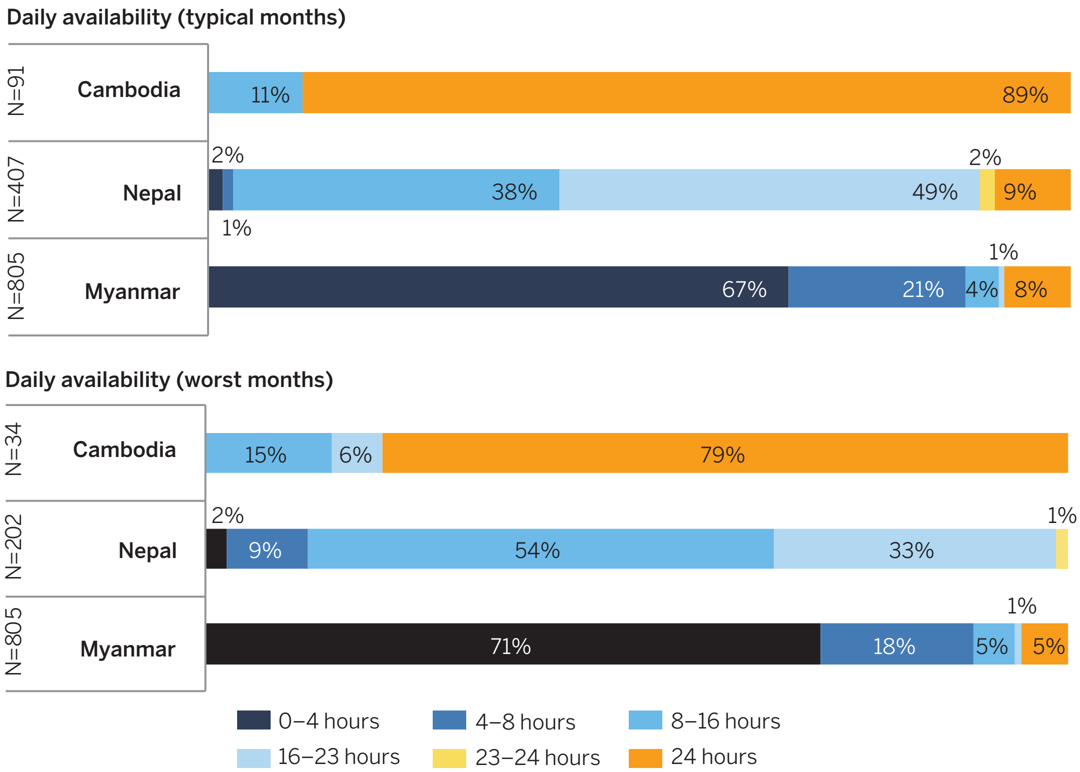
Daily availability of 2nd generation mini grids

Nearly 90 percent of Cambodian mini grid operations provide electricity for 24 hours a day, while less than 10 percent of operations in Nepal and Myanmar are able to do the same during typical months. Large seasonal fluctuations in daily availability between typical and worst months are found among mini grid operations in Nepal: 60 percent of them provide electricity for more than 23 hours a day during typical months, but the share falls to 34 percent during the worst months. On average, mini grid operators in Nepal provide electricity for 17.1 hours a day during typical months and for 13.4 hours during the worst months. In Myanmar, the numbers are 5.2 hours during typical months and 4.5 hours during the worst months. In Cambodia, the operators can provide power for 22.7 hours during typical months and 22 hours during the worst months (figure 5.9).

Evening availability of 2nd generation mini grids

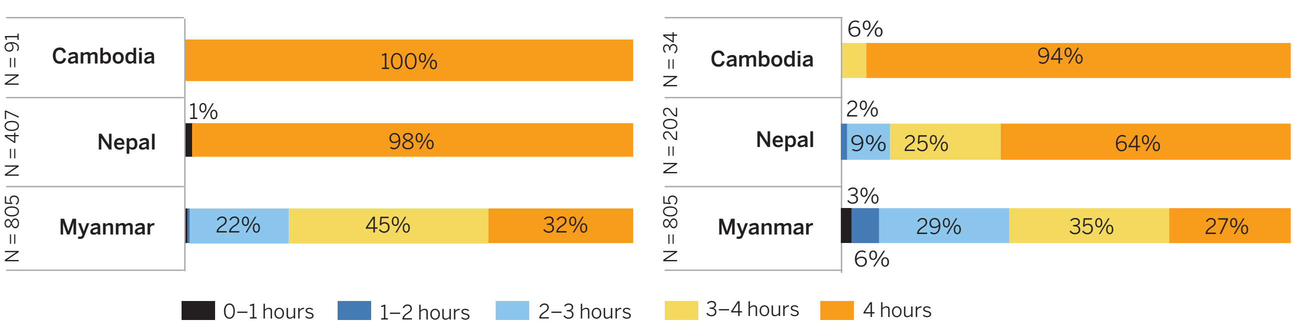
Virtually all Cambodian and Nepali mini grid operators provide four full hours of electricity during the evening; more than three-quarters of mini grid operators in Myanmar provide more than three hours of electricity supply during the evening between 6 and 10 p.m. A comparison between daily availability and evening availability shows that most mini grid operators in Myanmar and Nepal focus more on electricity supply during the evening hours (figure 5.10).

FIGURE 5.9 • Tiers of daily availability in typical and worst months



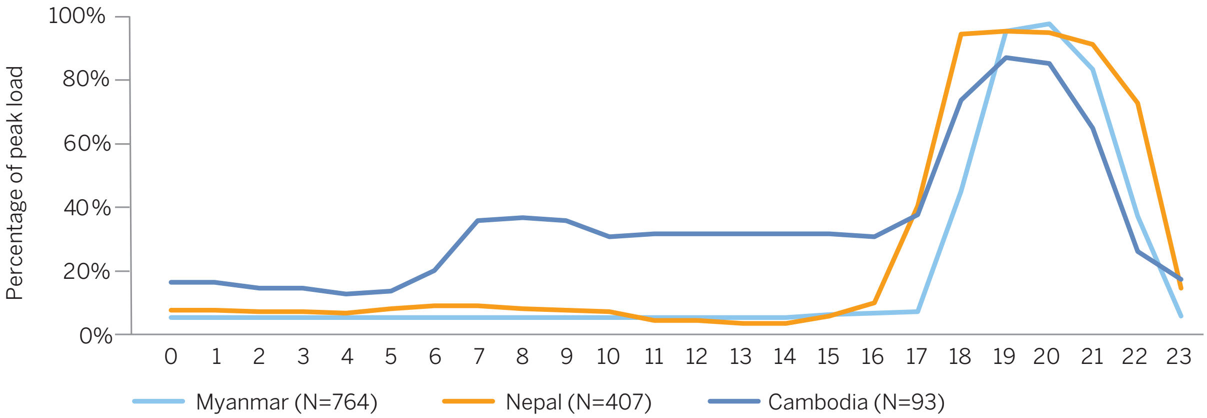
Source: ESMAP analysis.

FIGURE 5.10 • Tiers of evening availability in typical (left) and worst (right) months



Source: ESMAP analysis.

FIGURE 5.11 • Daily peak hour profile



Source: ESMAP analysis.

Evening hours between 6 and 10 p.m. are the peak hours for all three countries (figure 5.11). Apart from these, peak hours can also arise during the day. More operators in Cambodia than the other two countries reported having daytime peak hours in the morning and afternoon. This may be because they serve a relatively more diverse customer base.

Reliability

The majority of mini grids in Myanmar, Nepal, and Cambodia provide electricity at relatively high levels of reliability—fewer than four disruptions per week totaling no more than two hours of outage (figure 5.12). During the worst months, mini grid operators in all three countries have seen more unplanned outages, some lasting a day or more, while service reliability has plunged.

AFTER SALE

From the site identification process through operations and maintenance, mini grid operators build a relationship with the end customer. Operators can provide these customers with additional goods or services—for example, by offering residential or productive-use appliances or by providing a small business a microloan to procure equipment. In some instances, regulators, such as those in Tanzania, actively encourage this type of activity as a way to further enhance cost recovery. Such an approach allows a mini grid operator to act more as a bundled service provider, rather than simply an electricity company.

Bundling such offerings or providing them side by side generates several benefits to the operator as well as the end customer. For the operator, providing and supporting end users that consume more electricity help with the mini grid's economic viability. For customers, a bundled offering of an appliance or commercial product with electricity makes the mini grid's value proposition more accessible, as customers are in the market for energy services, not just the electricity itself (USG 2016).

> The mini grid value chain consists of a series of activities that support the design, deployment, and operations of mini grids. Both local and international companies participate. Upstream activities—those that occur before construction—include component manufacturing, market assessment, permitting and financing, and design and procurement. Downstream activities, which occur mostly on site, include integration and installation, operations and maintenance, and after-sales service.

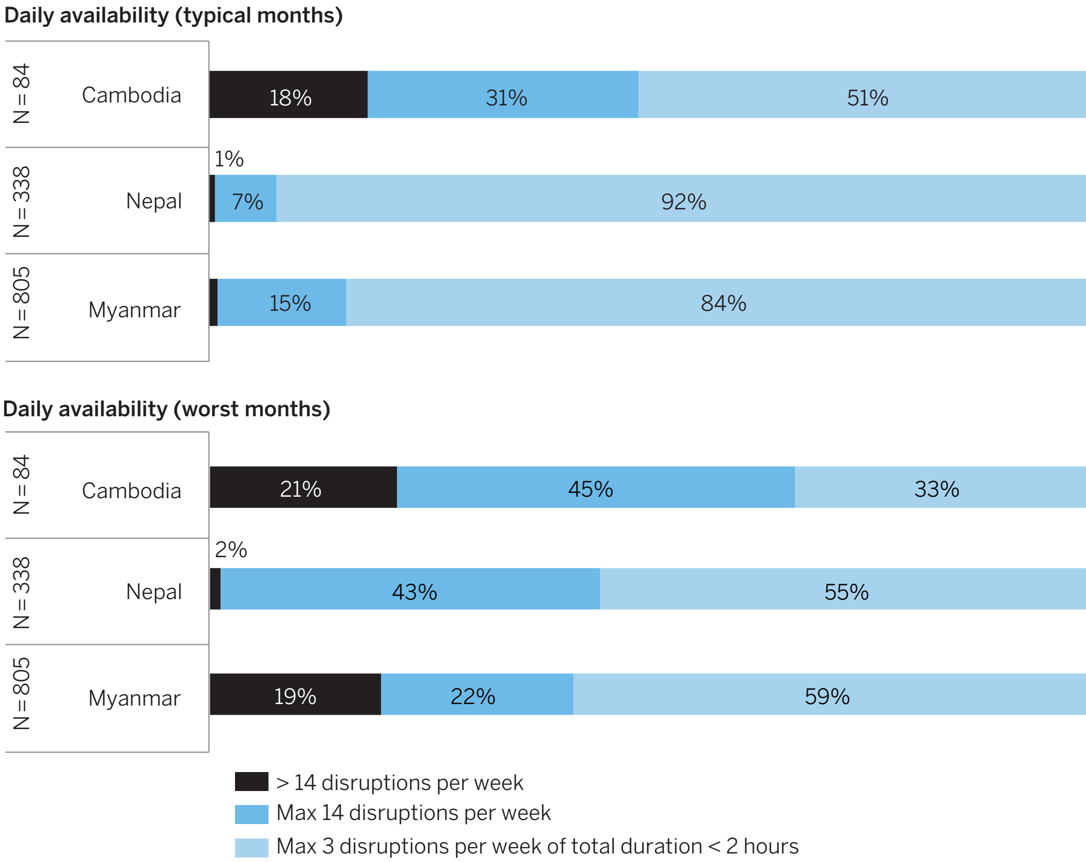
For example, the mini grid operator MeshPower in Rwanda offers its customers three price levels for electricity; each level comes with a different bundle of appliances, which may include television sets, stereos, and fans. PowerGen Renewable in Kenya provides refrigerators and freezers to commercial customers, allowing them to provide cold beverages or keep produce longer while generating needed electricity demand to improve mini grid use (Edwards 2017).

PROFIT POTENTIAL OF THE SOLAR MINI GRID VALUE CHAIN

ESMAP has developed a process for evaluating the private sector's potential profit if mini grids are deployed so as to achieve universal access. It considers the relative profit potential among various stakeholders along the mini grid value chain. For the private sector to accelerate its investment in mini grids, a sufficient profit margin is needed along the entire chain.

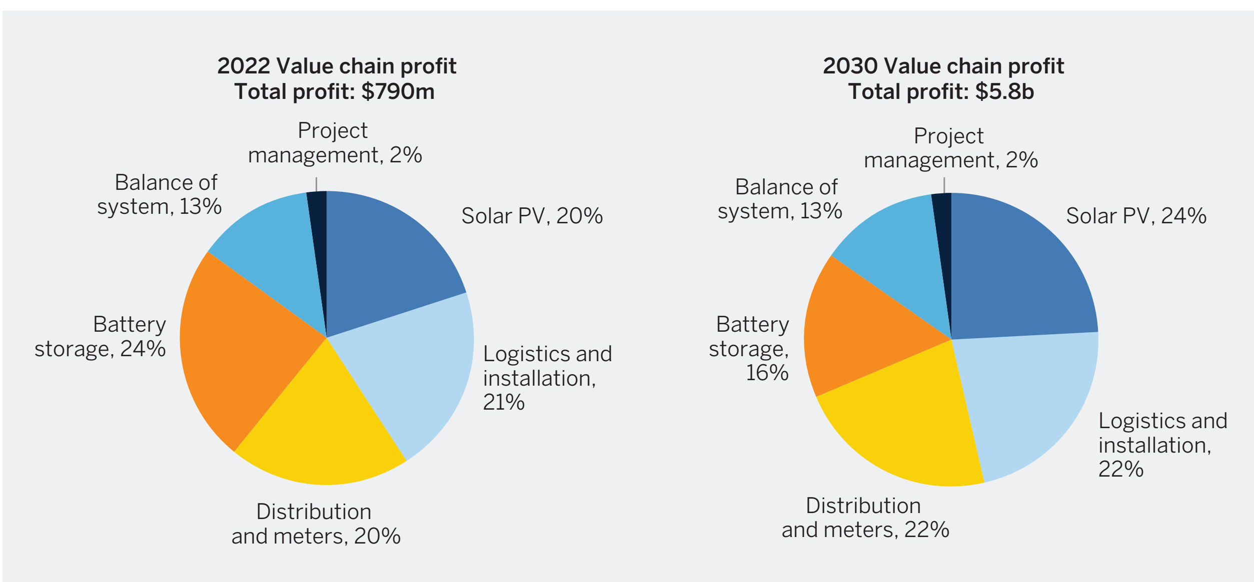
Figure 5.13 depicts this profit potential if SDG 7 is achieved by 2030. It does not show yearly revenue, which would correspond to the total capital expenditure for the mini grids deployed in a particular year, but rather the gross

FIGURE 5.12 • Tiers of reliability in typical and worst months



Source: ESMAP analysis.

FIGURE 5.13 • Profit potential for facilitator organizations across the value chain, 2019 and 2030



Source: ESMAP analysis.

Note: These figures use the 21,557 mini grids installed globally in 2021 and 217,000 in 2030, in line with ESMAP's data and analysis presented in the overview. The figures exclude taxes and financing. Balance of system includes such components as inverters, breakers, gensets, and converters. Estimates of the cost of service are derived from the HOMER analyses presented in chapter 1.

profit after all variable production and manufacturing costs are taken into consideration (costs for taxes, transport, and financing have not been accounted for). The figure also does not show net income, that is, income after all other overhead, such as personnel costs, are accounted for. Detailed assumptions on the cost and manufacturing margins are documented on the companion website of this handbook: www.esmap.org/mini_grids_for_half_a_billion_people.

The mini grid industry offers significant profit potential to private-sector equipment and service suppliers, particularly for solar PV, batteries, and power electronics. ESMAP projects the annual profit potential across the value chain at almost $5.8 billion by 2030 (figure 5.13).[6] Regionally, the largest share (74 percent) of this will be in Africa, where the most new mini grids are needed to achieve universal access to electricity by 2030, followed by South Asia (13 percent of the total profit potential).

To derive these figures, ESMAP used current and projected component costs (as presented in chapter 1). When combined with the forecast for mini grid deployments, the total expected revenue for the different component suppliers was estimated. To determine each component supplier's expected profit margin, ESMAP analyzed recent audited financial statements; conservative estimates for profit margin were then applied to the total revenue derived earlier. The largest profit centers for mini grid components will be solar PV, battery storage, and distribution infrastructure and technologies such as smart meters. As the costs of solar PV and battery storage continue to fall, the fraction of energy produced by solar PV and batteries will approach 100 percent, resulting in the profit potential for diesel dropping to nearly zero over the next decade.

Private-sector equipment providers have an opportunity to generate additional revenue and profit growth in a market segment that has not traditionally played a meaningful role in creating value.

> The largest profit centers along the mini grid industry value chain by 2030 will be solar PV, battery storage, and distribution infrastructure and technology (for example, smart meters). As the costs of solar PV and battery storage continue to fall, the fraction of energy produced by solar PV and batteries will approach 100 percent, resulting in the profit potential for diesel dropping to nearly zero over the next decade.

SUMMARY

Mini grids can play a pivotal role in the transformation of the energy industry. In addition to providing reliable access to electricity, mini grids can help improve power quality and resiliency. Fast-growing countries will need to invest significant resources in expanding and strengthening the electricity infrastructure and should consider facilitating mini grid deployments as a complement to grid extension.

The private sector will be instrumental in ensuring the ongoing viability of the mini grid sector. As the market transitions from first- and second-generation to third-generation mini grids, more local and international industry players will begin focusing on developing, building, and operating mini grids. The market for third-generation mini grids is nascent; however, to achieve universal access, the size of the potential market certainly can provide the opportunity for profit. The estimated revenue for private-sector participants is nearly $100 billion, with a cumulative profit opportunity of nearly $6 billion over the next 10 years.

Deploying and operating mini grids involve a variety of aspects, such as manufacturing mini grid components, integrating them into a complete system, identifying and validating mini grid sites, designing the grid, procuring the relevant components, installing and operating the grid, and further enabling productive uses of electricity. A variety of private-sector entities compete in these aspects of the value chain: ESCOs and IPPs identify sites and procure and operate mini grids; OEMs and SIs develop individual mini grid components and assemble them into prepacked units; and EPCs install and commission the system, and in certain cases also can assist with system design, including distribution line layout.

Successfully scaling mini grids to achieve universal access will require partnership among local and international entities. Those aspects of design and operations that require an in-depth understanding of local environments or require resources near the mini grid will naturally be aligned with the strengths of local industry. Those aspects that rely on scale, such as manufacturing, are naturally aligned with international companies. The viability of mini grids will rely on both local and international companies maximizing profit, through investing and pursuing actions that maximize revenue while minimizing costs.

To that end, removing certain market or regulatory obstacles, such as local content requirements or other import restrictions, will allow private-sector players to minimize cost. Allowing mini grid operators to charge tariffs commensurate with the community's willingness to pay, and using their customer relationships to provide additional services, will enhance their ability to generate revenue.

Implementing digital technology will be key to driving more efficient operations across the value chain. In addition, facilitating organizations are critical actors in seeking a market environment favorable to mini grids, and across geographic boundaries. Ultimately, achieving universal access through mini grids will be achieved only if the private-sector participants active across the mini grid value chain can operate profitably.

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NOTES

1. There is no standard international definition of SMEs. They are defined differently in the legislation across countries, in particular because the dimension "small" and "medium" is relative to the size of the domestic economy. For statistical purposes, the Organisation for Economic Co-operation and Development refers to SMEs as firms employing up to 249 persons, with the following breakdown: micro (1 to 9), small (10 to 49), and medium (50 to 249). This provides for the best comparability given the varying data collection practices across countries, noting that some countries use different conventions. The first four paragraphs in this chapter are drawn from the pages of the World Bank's website devoted to financing for SMEs: https://www.worldbank.org/en/topic/smefinance.
2. RAO Energy in Russia, TANESCO in Tanzania, JIRAMA in Madagascar, and KPLC in Kenya are utility companies that operate dozens of mini grids nationwide. These mini grids are typically diesel powered (or, in the case of JIRAMA, hydro powered). They tend to be large, typically on the order of several hundred kilowatts to a few megawatts. Some utilities (in Niger, for example) have started to hybridize their diesel systems with solar PV panels.
3. These estimates are in line with data from ESMAP's global database of mini grid projects presented in the introduction, and the Global Electrification Platform analysis presented in chapter 2.
4. There are a total of 76 utilities in Sub-Saharan Africa, including transmission and generation utilities of which 61 are vertically integrated utilities, or companies that have a distribution function.
5. The number of mini grids that are modeled to be deployed in 2022 is 6,298, with a cumulative deployment of 27,771. By 2030, more than 49,000 mini grids need to be deployed annually. This is the pace of development required to reach 490 million people by 2030, through more than 217,000 mini grids.
6. Rather than provide a definitive number, this analysis is designed to understand the relative profit potential among different mini grid value chain stakeholders. Such an analysis can be used to determine the viability of establishing business lines focused on the mini grid market. The data reflect the profit potential after all variable production and manufacturing costs are taken into consideration. Detailed assumptions and methodology are documented in the companion website to this handbook: www.esmap.org/mini_grids_for_half_a_billion_people.

CHAPTER 6

FINANCING SOLAR MINI GRID PORTFOLIOS AND END-USE APPLIANCES

CHAPTER OVERVIEW

This chapter lays out the main barriers that private-sector mini grid developers face when trying to finance their mini grid projects and portfolios, the types of financing mechanisms that are available to them, and how different financing mechanisms address the different barriers. The chapter also presents details of the World Bank's mini grid investment portfolio. The fundamental message of this chapter is that governments and their development partners should prepare a package of financial support for mini grid developers. The elements of this financial package are access to equity, debt, subsidies, and risk-sharing mechanisms. The nature and role of these elements will differ with the type of developer being supported.

The economic and social case for promoting mini grids has already been laid out. Many of the Bank's client countries are now looking to private firms to develop mini grids. Some countries will opt for publicly funded mini grids, and some may use a combination of private- and public-sector developers. While the focus of this chapter is access to finance for private developers, publicly funded mini grids are also considered.

The fundamental message of this chapter is that governments and their development partners should prepare a package of financial support for mini grid developers. The elements of this financial package are access to equity, debt, subsidies, and risk-sharing mechanisms. The nature and role of these elements will differ with the type of developer being supported.

WHAT ARE THE FINANCIAL NEEDS OF MINI GRID DEVELOPERS?

All mini grid developers need to finance both preinvestment and initial capital costs. Preinvestment costs include site visits; feasibility studies; discussions with communities, government officials, and other interested partners; and other elements of due diligence. Initial capital costs are very important for mini grids, particularly renewable energy mini grids, which tend to have a high share of initial capital costs, because there are no major fuel costs (though there are some costs for supplemental diesel generation). The payback period for mini grids is long, as most generation and distribution assets have lives of 10–15 years. For example, using costing data from chapter 1, a hybrid solar diesel 120-kilowatt (kW) mini grid that could serve 500 households in Sub-Saharan Africa would have initial capital costs of around $500,000 and variable costs of about $45,000 a year.

It is important that these developers be able to attract significant funding, so that mini grids are developed rapidly on a large enough scale to provide electricity quickly to large numbers of unserved people.

From a financial viewpoint, there are two broad categories of mini grid developers: larger international and local firms that already have significant access to equity and debt, and smaller, mostly local firms that do not have such ready access. Since the financial needs of the two categories are different, the support package for the two will be correspondingly different.

It is important to note that female-led enterprises and project developers may require an expanded support package, as women may face additional barriers in accessing finance (box 6.1).

BOX 6.1

WOMEN'S LIMITED ACCESS TO FINANCE

Female developers face particularly significant challenges in accessing finance. Women own and lead roughly 6.6 million formal small and medium enterprises and 39 million microbusinesses, forming about 28 percent of business establishments in developing countries. However, women-owned small and medium enterprises face a significant credit gap (IFC 2017). Women are 15 percent less likely than men to have a bank account, and significantly lag behind men in saving and borrowing through formal financial institutions, even after controlling for individual characteristics, such as income, education, and age (Demirguc-Kunt, Klapper, and Singer 2013). Drivers can include collateral constraints caused by a lack of land ownership, among other aspects. Further, across regions, legal barriers inhibit women's rights to inheritance, immovable assets, and collateral, which in turn affects their access to finance (World Bank 2020). Women also face discriminatory social and cultural norms and gender biases, which make them less credible to potential investors.

Different financing packages are required for different types of mini grid developers, consisting of a combination of debt, equity, subsidy, and risk-sharing mechanisms. Larger international and local firms tend to already have significant access to equity and debt, while smaller, mostly local firms usually do not have ready access to equity and debt.

Female-led enterprises and project developers may require an expanded support package, as women often face additional barriers to accessing finance. Women own and lead roughly 28 percent of business establishments in developing countries, are 15 percent less likely than men to have a bank account, and significantly lag behind men in saving and borrowing through formal financial institutions.

WHAT TYPES OF FINANCE ARE AVAILABLE?

The funds provided by commercial entities can be classified as *project finance* and *corporate finance*. In nonrecourse project finance, the returns to the financiers come only from the project's revenues; financiers cannot get their returns from anything else the company does or owns. Project finance is normally available only to large companies that have predictable revenues and low risks. However, some of the larger mini grid developers may be able to access project finance funds, and smaller-scale developers may also be able to access project financing if they aggregate individual mini grids into a portfolio.

In corporate finance, also called *balance sheet finance*, the returns to private financiers come from all of the company's assets, not just the revenues from the project. Smaller mini grid developers are likely to get only corporate finance funds.

Private finance can be in the form of debt or equity. In addition, mini grid developers can access direct and indirect subsidies. The sources of these types of finance are shown in table 6.1.

MINI GRID DEBT AND EQUITY INVESTORS

While governments and their development partners, alongside philanthropic entities and other nongovernmental organizations, will continue to play an important role in providing grants and risk mitigation mechanisms to mini grid developers, private-sector investment will be needed to achieve the exponential growth necessary to bring mini grid electricity to half a billion people by 2030. Indeed, a *lack* of access to affordable financing has been highlighted as a barrier to growth by mini grid developers. A reported 37 percent of mini grid developers in Cambodia, Myanmar, and Nepal have said that access to capital is a severe or very severe constraint, and two-thirds rely on their own pools of capital to fund projects, according to World Bank surveys of mini grid developers in these countries.

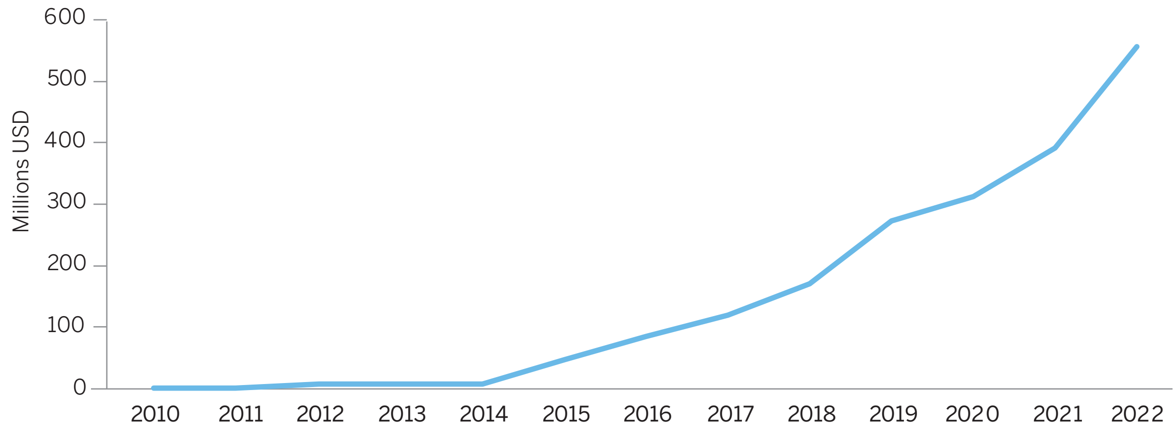
Positive momentum is underway, however, and both the pace and scale of private-sector investment in mini grids are increasing. The Energy Sector Management Assistance Program (ESMAP) identified 188 unique investment deals between investors and active private sector mini grid developers between 2010 and 2022, totaling $557 million

TABLE 6.1 • Types and sources of commercial finance

Type of finance	Source of finance
Debt, including mezzanine, which is a loan that can convert later to equity	Local banks, impact investors
Equity	Impact investors, own funds from project developers and associates, commercial investors
Direct and indirect (risk-sharing) subsidies	Governments, development partners, nonprofit organizations

Source: ESMAP analysis.

FIGURE 6.1 • Cumulative private-sector investment in mini grid companies



Source: ESMAP analysis of 188 deals between investors and mini grid companies between 2010 and 2022, using publicly available data.

in 2022 dollars, adjusted for inflation (figure 6.1). Active developers are those that are registered companies and have built mini grids, are planning mini grids, are members of a mini grid industry association, and/or have secured investment for mini grids.

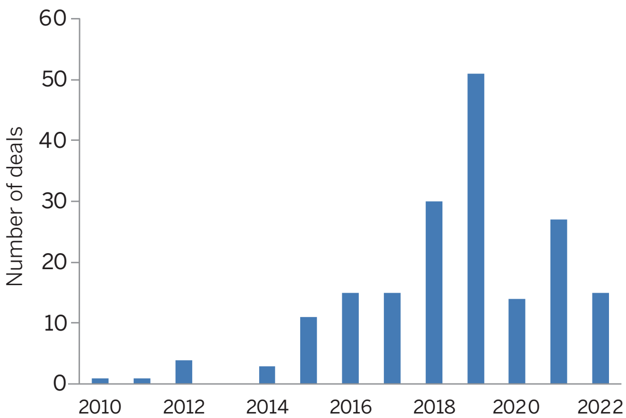
The deals were completed between 54 developers and 100 investors, and averaged $3 million per deal. The largest deal was a $41 million equity investment by the Chubu Electric Power Company in the Indian mini grid developer OMC Power in 2022. It is important to note that these are the totals for investment deals for which we were able to find publicly available data. As a result, these totals may under-represent the full scale of investment in private sector mini grid developers. Indeed, we were able to find information for only 54 of the 177 active mini grid developers, indicating that the investment totals reported here may be just half of the real amount.

The number of deals between investors and private sector developers grew from an average of just 3 per year in 2010–14, to an average of 28 per year in 2017–21. The average deal size also grew, from less than $1 million per deal in 2010–14, to more than $2 million per deal in 2017–21. Almost half—22 out of 54—developers received their first investment in just the past three years. However, there was a marked slowdown in dealmaking during the COVID-19 pandemic (figure 6.2).

The top 20 investors in terms of total investment in mini grid companies account for 54 percent of the cumulative total of $557 million (figure 6.3). None of the current top 20 investors had made any investments in mini grids prior to 2015.

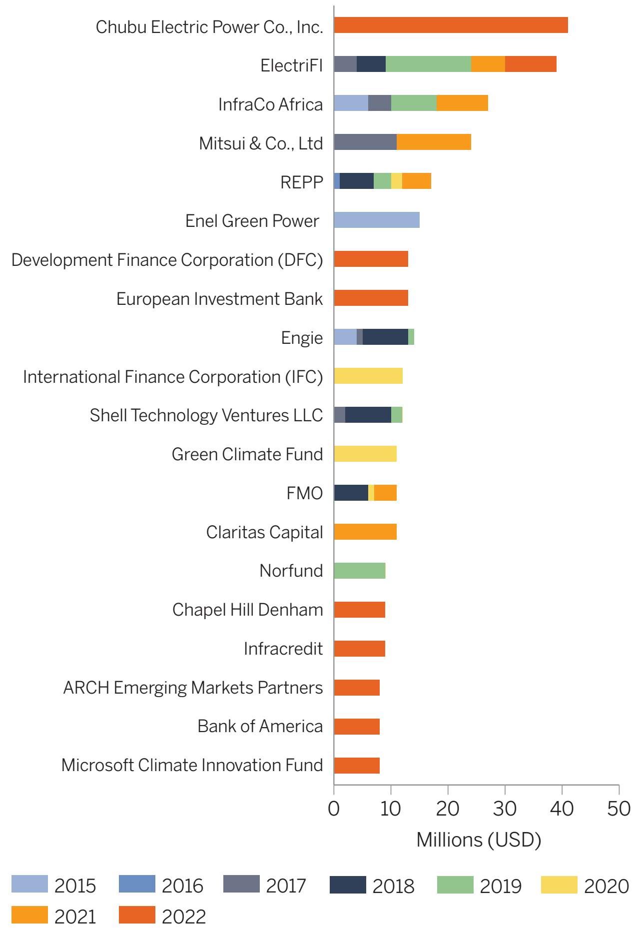
The largest investors are a mix of private companies and organizations and funds supported by governments. Three large electric power companies feature among the top 20: the Chubu Electric Power Company (Japan), Enel Green Power (Italy), and Engie (France). Multinational corporations in the top 20 include Mitsui & Co. (Japan), Bank of America (US), Microsoft through their Climate Innovation Fund (US), and Shell through Shell Technology Ventures LLC (UK). Several government-supported funds and entities are among the top 20 investors as well: ElectriFi, an impact investment fund supported by the European Union; InfraCo Africa, a private investment firm supported by the UK government; REPP—the Renewable Energy Performance Platform, an impact investment fund supported by the UK government and the European Union; the Development Finance Corporation, a US government–supported investment organization; the European Investment Bank;

FIGURE 6.2 • Annual number of deals between investors and mini grid companies, 2010–22



Source: ESMAP analysis of 188 deals between investors and mini grid companies between 2010 and 2022, using publicly available data.

FIGURE 6.3 • Top 20 investors in mini grid companies by cumulative investment



Source: ESMAP analysis of 188 deals between investors and mini grid companies between 2010 and 2022, using publicly available data.

FMO, the Dutch development bank; and Norfund, an investment fund supported by the Norwegian government. Two specialized private funds are also among the top 20: Infracredit, an impact investment fund in Nigeria; and Omidyar Network, an impact investor in the United States. Two multilateral development institutions (the International Finance Corporation and the Green Climate Fund) as well as four private investment firms (CrossBoundary, ARCH Emerging Markets Partners, Claritas Capital, and Chapel Hill Denham) make up the rest of the top 20 investors.

Different categories of investors emerge when they are categorized by their average deal size, and how many investments they have made. Table 6.2 presents some of these categories.

Four of the top five-most-active investors are government-supported impact investment funds or entities: ElectriFi, REPP, the Energy and Environment Partnership Trust Fund (EEP Africa), and InfraCo Africa. All On, the third most active investor, is an impact investment fund based in Nigeria and supported by Shell. The top investors seeking big deals are for the most part large companies (for example, Chubu, Enel, and Mitsui) and international investment institutions (for example, the Development Finance Corporation, European Investment Bank, International Finance Corporation, and Green Climate Fund). Only one is a stand-alone private investment house: Claritas Capital.

The list of investors funding early stage start-ups are grouped together because their average deal size is greater than $5 million, indicating they are looking for well-established companies, but less than $10 million, indicating that they are looking to catalyze the scale-up of small but well-established developers. These investors include a combination of private investment houses (for example, Chapel Hill Denham) and government-supported funds (for example, Norfund), although two large companies also feature in this list: Microsoft and Bank of America.

The last category of investors highlighted in table 6.2 consists of active mini grid developers (having made at least two investments in mini grid companies since 2010) with average deal sizes of less than $5 million. This category comprises various types of investors, but they all focus on impact.

As a final insight gleaned from the database of investment deals in mini grid companies, the number of equity deals has declined, and the number of debt deals has risen (figure 6.4).

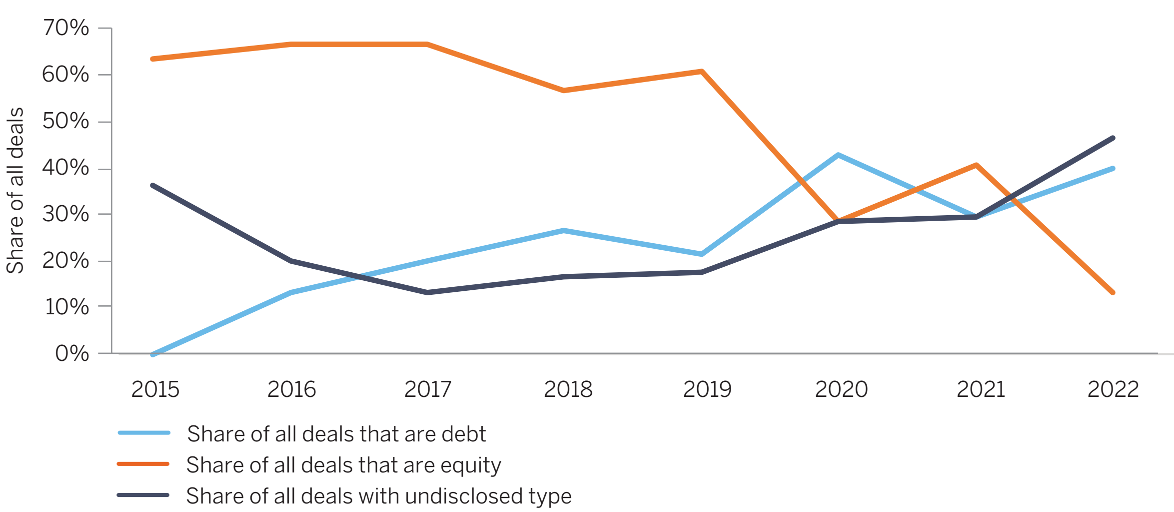
The downward trend in equity combined with the upward trend of debt could be an indication of the maturation of the mini grid industry. As companies develop more exten-

TABLE 6.2 • Categories of investors in mini grid companies, 2010–22

Most active investors *(Top investors with at least three deals, ranked by number of deals)*	**Investors seeking large deal sizes** *(Top investors with an average deal size larger than $10 million, ranked by average deal size)*	**Investors funding early-stage scale-up** *(Top investors with average deal sizes of $5–$10 million, ranked by average deal size)*	**Investors making small but targeted investments** *(Top investors with two or more deals and average deal sizes under $5 million, ranked by deal size)*
ElectriFI	Chubu Electric Power Co., Inc.	Norfund	Shell Technology Ventures LLC
Renewable Energy Performance Platform (REPP)	Enel Green Power	Chapel Hill Denham	Omidyar Network
All On	Development Finance Corporation	Infracredit	FMO
Energy and Environment Partnership Trust Fund (EEP Africa)	European Investment Bank	ARCH Emerging Markets Partners	REPP
InfraCo Africa	International Finance Corporation	Bank of America	Engie
US African Development Foundation	Mitsui & Co., Ltd	Microsoft Climate Innovation Fund	Caterpillar Ventures
Engie	Green Climate Fund	Development Bank of Central African States (BDEAC)	Tao Capital
FMO (Dutch Development Bank)	Claritas Capital	ElectriFI	Total Energy Ventures
CrossBoundary Energy Access		Swedfund	Proparco
Shell Technology Ventures LLC		Beyond the Grid Fund for Zambia	CRE Venture Capital
Omidyar Network		InfraCo Africa	Acumen
SunFunder		Nigeria Infrastructure Debt Fund	Bamboo Capital Partners
Acumen		Pi Investments	Oikocredit
Energy Access Ventures			All On
Charm Impact			Energy Access Ventures
			SunFunder
			EEP Africa
			Facility for Energy Inclusion Off-Grid Energy Access Fund (African Development Bank)
			GReeN Investor Group
			Ashden Trust

Source: ESMAP analysis of 188 deals between investors and mini grid companies from 2010 to 2022, using publicly available data.

FIGURE 6.4 • Trends in debt and equity



Source: ESMAP analysis of 188 deals between investors and mini grid companies between 2010 and 2022, using publicly available data.

Both the pace and scale of investment in mini grids are increasing. ESMAP has identified 188 unique investment deals in active private-sector mini grid developers between 2010 and 2022, totaling $557 million in 2022 dollars (adjusted for inflation). The deals were completed between 54 developers and 100 investors, and averaged $3 million per deal. The number of deals between investors and private-sector developers grew from an average of just 3 per year from 2010 to 2014, to an average of 28 per year from 2017 to 2021. The largest investors are a mix of private companies and organizations and funds supported by governments. Four of the top five most active investors are government-supported impact investment funds or entities.

sive track records, they become more attractive (less risky) investment opportunities for debt investors because the developers have a proven cashflow with which to repay their debt. But the data also demonstrate an upward trend in more undisclosed types of deals—perhaps another sign that the mini grid industry is maturing. As more sophisticated investors participate and as more complex deals are brokered, more and more of the details of individual transactions may remain confidential—particularly for investment entities that are not supported by governments or other donors.

DEVELOPMENT PARTNERS' INVESTMENT IN MINI GRIDS

Development partners, including the World Bank, have increased financing for mini grids, from millions of dollars in the 2000s to billions of dollars in 2018. A group of 15 major international donors and development partners, including the World Bank, has collectively committed more than $2.6 billion just to mini grid investment (that is, excluding funding for technical assistance and research). Six of these organizations have investment commitments for mini grids that total more than $100 million: the Agence Française de Développement, the African Development Bank, the Global Environment Facility, the German Society for International Cooperation, KfW, the Islamic Development Bank, and the World Bank. Moving from commitments to disbursements and investments, however, will require sustained efforts and close collaboration with governments and the private sector. ESMAP estimates that all donor funds committed to mini grids would cover approximately 30 percent of the $8.9 billion total planned investment in mini grids globally, according to ESMAP's analysis of funding commitments from donors and development partners.

Meanwhile, the World Bank has committed more than $1.4 billion to mini grids through at least 2027. At the end of June 2022, its mini grid portfolio consisted of 41 projects approved by the World Bank board, covering 31 countries (table 6.3). The investment plans of this portfolio project the deployment of more than 3,000 mini grids by 2027, with the expectation of bringing electricity to more than 13 million people. Even more important than the direct impact is the expected "crowding in" of private-sector development and investment, which is expected to leverage $1 billion of cofinancing from private-sector, government, and development partners.

With strategic market-enabling work supported by ESMAP (for example, geospatial planning, feasibility studies, and rapid response support to project implementation, among other types of support), the portfolio is expected to catalyze private-sector engagement in mini grid markets worldwide. A recent example of this work in action is the flagship "piloting at scale" project in Nigeria, where the World Bank's financial commitment is crowding in investment from the private sector: $150 million in International Development Association funding for the project's mini grid component will bring in more than $230 million in private-sector investment in mini grids.

When investing in mini grids, the World Bank projects employ various financing mechanisms. The following list highlights some examples:

- The Electricity and Water Access and Governance Project in the Democratic Republic of Congo has the largest expected coinvestment from the private sector in the World Bank's current portfolio. The World Bank team supported the government of the Democratic Republic of Congo to develop the project in close collaboration with the International Finance Corporation's Scaling Mini Grids program. This program is providing significant upstream support to develop strong contractual frameworks that are expected to attract $300 million in cofinancing from the private sector for the construction and operation of several large mini grids under a concession contract, with each mini grid serving tens of thousands of customers. The large investment required for each of these mini grids makes them attractive to infrastructure project investors, who, in contrast to the more venture capital–oriented investors described in the previous section, seek large transactions backed by a strong contractual framework between the mini grid developer and the government.

TABLE 6.3 • World Bank mini grid investment portfolio as of June 30, 2022

Project details				Mini grid investment (US$, millions)			Expected mini grid results		
Country	**Project name**	**Approval date**	**Closing date**	**World Bank**	**Cofinancing**	**Total**	**Mini grids**	**Connections**	**People**
Afghanistan	Herat Electrification Project	13-Jun-17	31-Jan-23	1.0	—	1.0	4	444	2,220
Argentina	Renewable Energy for Rural Areas Project	07-Apr-15	30-Jun-22	6.9	1.2	8.1	14	720	3,600
Bangladesh	Rural Electrification and Renewable Energy Development II (RERED II) Project	20-Sep-12	18-Dec-23	22.6	17.6	40.2	30	15,600	78,000
Burkina Faso	Electricity Sector Support Project	30-Jul-13	31-Dec-22	16.6	—	16.6	18	11,135	55,675
Burkina Faso	Solar Energy and Access Project	21-Jun-21	31-Dec-28	40.0	25.0	65.0	180	78,000	390,000
Burundi	Solar Energy in Local Communities	28-Feb-20	01-Mar-26	37.0	—	37.0	45	31,000	155,000
Cameroon	Rural Electricity Access Project for Underserved Regions	13-Dec-18	30-Jun-25	19.0	—	19.0	12	3,000	15,000
Central African Republic	Water and Electricity Upgrading Project	17-Jan-18	30-Jun-22	5.2	—	5.2	2	1,200	6,000
Central African Republic	Electricity Sector Strengthening and Access Project	03-Jun-22	31-Dec-27	15.0	-	15.0	5	20,100	100,500
Chad	Energy Access Scale Up Project	24-Mar-22	30-Jun-27	100.0	50.0	150.0	25	105,000	525,000
Congo, Dem. Rep.	Electricity Access & Services Expansion (EASE)	04-May-17	31-Oct-23	37.0	0.5	37.5	9	5,500	27,500
Congo, Dem. Rep.	Electricity & Water Access and Governance Project	31-Mar-22	30-Sep-29	263.5	300.0	563.5	123	353,000	1,765,000
Ethiopia	Ethiopia Electrification Program (ELEAP)	01-Mar-18	07-Jul-23	7.5	—	7.5	12	6,240	31,200
Ethiopia	Access to Distributed Electricity and Lighting in Ethiopia	29-Mar-21	31-Mar-27	270.0	50.0	320.0	600	240,000	1,248,000
Gabon	Access to Basic Services in Rural Areas and Capacity Building Project	17-Sep-15	30-Nov-22	8.6	—	8.6	2	1,100	5,500
Guinea	Electricity Access Scale Up Project	15-Feb-19	31-Dec-23	3.5	3.5	7.0	10	10,000	50,000
Haiti	Renewable Energy for All	25-Oct-17	31-Dec-24	15.1	24.0	39.1	43	74,490	100,000
Haiti	Modern Energy Services for All (CTF DPSP)	25-Oct-17	30-Apr-28	5.0	12.5	17.5	n.a.	n.a.	n.a.
Kenya	KE Electricity modernization project	31-Mar-15	31-Dec-22	10.0	11.7	21.7	7	3,640	18,200
Kenya	Off-grid Solar Access Project for Underserved Counties	26-Jul-17	30-Jun-23	40.0	125.0	165.0	137	27,000	135,000
Lesotho	Renewable Energy and Energy Access Project	30-Jan-20	31-Jan-27	20.0	10.0	30.0	40	4,800	24,000
Liberia	Renewable Energy Access Project	11-Jan-16	31-Dec-23	20.4	2.0	22.4	1	10,000	50,000

TABLE 6.3, *continued*

Project details				Mini grid investment (US$, millions)			Expected mini grid results		
Country	**Project name**	**Approval date**	**Closing date**	**World Bank**	**Cofinancing**	**Total**	**Mini grids**	**Connections**	**People**
Liberia	Electricity Sector Strengthening and Access Project (LESSAP)	12-Mar-21	30-Jun-26	4.0	1.0	5.0	39	6,500	32,500
Malawi	Electricity Access Project	20-Jun-19	30-Jun-24	10.0	—	10.0	10	5,200	26,000
Mali	Rural Electrification Hybrid System Project	11-Dec-13	31-Mar-23	51.0	4.9	55.9	42	9,770	48,850
Mozambique	Energy for All (ProEnergia)	28-Mar-19	31-Dec-23	10.0	—	10.0	6	4,000	20,000
Nepal	Business Models for Private Sector–Led Mini Grid Energy Access Project	31-Jan-19	30-Apr-23	5.6	9.6	15.2	28	27,109	126,000
Niger	Solar Electricity Access Project	07-Jun-17	31-Jan-24	34.1	—	34.1	41	16,500	82,500
Niger	Accelerating Electricity Access Project (Haské)	10-Dec-21	31-May-27	40.0	—	40.0	80	15,750	90,860
Nigeria	Electrification Project	27-Jun-18	31-Oct-23	150.0	250.0	400.0	850	330,000	1,650,000
Rwanda	Renewable Energy Fund	20-Jun-17	30-Sep-23	5.0	20.0	25.0	10	26,000	105,000
Sierra Leone	Energy Sector Utility Reform Project Additional Financing	18-Dec-13	31-Dec-22	1.0	—	1.0	—	n.a.	n.a.
Sierra Leone	Renewable Energy Development and Energy Access Project	28-Jan-21	31-Dec-25	6.0	—	6.0	10	5,200	26,000
Solomon Islands	Electricity Access and Renewable Energy Expansion Project (Phase II)	05-Jul-18	31-May-23	11.5	—	11.5	5	1,500	7,500
Somalia	Somali Electricity Access Project	21-Dec-18	30-Jun-22	1.0	—	1.0	—	—	—
Somalia	Somali Electricity Sector Recovery Project	08-Dec-21	31-Dec-26	95.0	—	95.0	382	198,848	5,714,000
Tajikistan	Rural Electrification Project	11-Jul-19	31-Dec-25	23.8	—	23.8	35	2,401	6,694
Tanzania	Rural Electrification Expansion Project	21-Jun-16	31-Jul-23	32.0	120.0	152.0	288	197,635	988,175
Vanuatu	Rural Electrification Project Stage II	31-May-17	30-Jun-22	6.8	4.9	11.7	5	550	2,750
Yemen	Integrated Urban Services Emergency Project	30-Apr-18	30-Dec-22	4.3	—	4.3	1	520	2,600
Zambia	Electricity Services Access Project	27-Jun-17	31-Aug-23	5.9	—	5.9	5	2,200	11,000
Total approved World Bank projects				**1,460.9**	**1,043.4**	**2,504.2**	**3,156**	**1,887,846**	**13,753,834**
Total pipeline World Bank projects (estimated)				200.0	100.0	300.0	300	150,000	750,000
Total approved + pipeline World Bank projects				1,660.9	1,143.4	2,804.2	3,456	2,037,846	14,503,834

Source: ESMAP analysis.
— = 0.
n.a. = not applicable.

- In the Nigeria Electrification Project, the Bank is pursuing top-down and bottom-up approaches simultaneously. Under the top-down approach, private-sector developers bid on the minimum capital cost subsidy required to deliver electricity in areas preselected by the Rural Electrification Agency, given specific regulatory guidance on tariffs. Geospatial planning and socioeconomic analysis helped identify sites that would be suitable for mini grids. Under the bottom-up approach, private-sector mini grid developers can select their own sites and apply for performance-based grants on the basis of new customer connections.
- In Kenya, up to $80 million financing of the Off-grid Solar Access Project for Underserved Counties program, is allocated for private-sector developers to bid on Engineering-Procurement-Construction contracts with the Kenya Power and Lighting Company (KPLC) and the Rural Electrification and Renewable Energy Corporation (REREC). The 137 sites are divided over thirteen lots in 14 low-income counties. Bidders are asked to install the solar mini grids including KPLC certified prepaid/smart meters as well as provide for a social infrastructure project as selected by the county. In addition, the Government is considering expanding the performance grant program for solar systems and cookstoves, to private sector-led solar mini grid projects as well.
- The recently completed National Electrification Project in Myanmar used a tripartite agreement between developers, the community, and the government entity responsible for implementing the World Bank project. The agreement sets out the terms that developers must adhere to as they build, own, operate, and maintain the mini grid. In addition, the agreement stipulates a minimum equity investment from both the developer and the community, as well as the capital cost subsidy amount to be paid by the implementing agency. The capital cost subsidies were technology neutral.

Development partners including the World Bank have committed more than $2.6 billion to mini grids over the next several years. The World Bank's portfolio of mini grid investment commitments includes $1.4 billion in approved funding for 41 projects. This investment is expected to mobilize an additional $1 billion in government, private-sector, and development partner funding for mini grids over the next five to seven years.

Though already significant, the World Bank's investments in mini grids are designed to act as a magnet for private-sector investment to support exponential growth in mini grids to reach universal access.

BARRIERS FACED BY PRIVATE DEVELOPERS IN ACCESSING COMMERCIAL FINANCE

MINI GRIDS ARE PERCEIVED AS RISKY

Many potential private financiers consider mini grids too new and hence too risky to invest in. Most local equity and debt financiers lack experience providing funds for projects with such long payback periods (typically between 7 and 15 years). The absence of relevant financial experience increases the risk perception. In addition, most countries have had limited operational experience with mini grids, which are seen as a new type of investment, increasing the risk perception.

Where operational experience has been gained, it has been for only a few years, making it difficult to prudently assess the risks mini grids may face in later years. For example, it is likely that the main grid will eventually reach the areas where the mini grid is located. What will happen then? Several countries have designed regulatory financial schemes under which the main grid takes over at least some of the mini grid's assets, with compensation. Lack of experience with this compensation scheme creates a significant risk for investors.

DEMAND UNCERTAINTY REMAINS HIGH

Developers estimate future demand for their electricity services not only to appropriately design their mini grids but also to attract external financing. Demand for mini grid electricity varies widely between mini grids in the same country, and between countries, so estimating demand remains challenging for developers. As a result, concerted efforts are still needed to stimulate income-generating uses of electricity during the daytime. In parallel, as we discuss in this chapter, financing mechanisms can help de-risk some of the demand uncertainty.

CONSUMERS ARE UNABLE TO PAY THE FULL COSTS OF SUPPLY AND LACK CREDIT HISTORY

Many potential consumers are unable to pay the full costs of electricity from the mini grid. This implies that, in the absence of subsidies, the mini grid would realize losses, which is not acceptable to private developers. Some countries allow mini grids to charge cost-reflective tariffs. These tariffs create their own problems, as poorer potential consumers may choose to not connect to the mini grid because they are unable to pay the tariff. This would tend to leave the poorer people without electricity, even though electricity is available where they live. Furthermore, many potential mini grid customers do not have a credit history, which is a key risk and potentially a deterrent for institutional investors (especially debt).

Even households that do connect to the mini grid may end up consuming little electricity because of the high tariff. Minimal use will make it more difficult for the mini grid to recover its costs.

The mini grid's revenues may be variable over time in areas where agriculture is a major source of livelihood, as the fluctuations in agricultural output and incomes may lead to corresponding fluctuations in electricity use and revenues. This variability may also be a barrier.

EQUITY IS INADEQUATE

Impact investors and commercial investors, as well as local and national banks, have developed equity, debt, and blended finance options to help developers scale up their mini grid business. While this has driven some innovation in financing mechanisms for mini grids, their combined investment falls far short by an order of magnitude of what is needed to achieve the Sustainable Development Goal 7 objective by 2030.

THE TENORS OF ASSETS AND LIABILITIES ARE MISMATCHED

Mini grid investments (and other infrastructure investments seeking long-term asset financing in low-income countries more generally) often create an unacceptable asset-liability mismatch for local debt financiers. These financiers rarely have access to long-term funds, as they raise their funds from term deposits of a limited number of years. If local debt financiers provide long-term loans (their assets) while their deposits (their liabilities) are for shorter periods, this is an unacceptable asset-liability mismatch. When this mismatch occurs, it makes it difficult for these financiers to provide long-term loans to mini grid developers.

POLITICAL AND REGULATORY RISKS CREATE UNCERTAINTY

In a handful of countries around the world, mini grids operate under well-established regulatory regimes that, while perhaps not perfect, offer guidance to and reduce uncertainty for private-sector developers. However, in many populous countries where many lack access to electricity, regulatory and political risks create uncertainty for developers. Chapter 9 discusses in more detail the key regulatory issues that need to be addressed in any regulatory framework for mini grids, and other steps regulatory agencies can take to reduce uncertainty and create a more favorable regulatory environment for mini grids. In parallel, however, policy decisions such as national electrification plans (see chapter 2) and the roles and responsibilities of the national utility (see chapter 8) will also affect the mini grid sector. The ability of mini grid developers to attract external financing can depend significantly on the political and regulatory environment in which they intend to operate as businesses.

FUTURE MACROECONOMIC CONDITIONS ARE UNCERTAIN

Uncertainty about future macroeconomic conditions discourages investment. One major macroeconomic variable is the exchange rate. It is important because at least some of the equipment used by the mini grid, such as solar panels, will be imported. If the exchange rate depreciates significantly and unexpectedly, the local costs of this imported equipment will rise, reducing the financial viability of new investments in mini grids. In extreme cases, the government may impose foreign exchange controls, reducing the amount of foreign exchange available for importing mini grid equipment.

In extreme cases, when the currency is depreciating, the government may impose foreign exchange controls, and hike up the custom duties or charges for importing mini grid equipment. For example, in 2015, Nigeria imposed foreign exchange controls, which caused concerns about limiting the import of solar panels. We note that this sce-

Private-sector mini grid developers face seven main barriers to accessing finance: (1) many potential private financiers consider mini grids too new and hence too risky as investments; (2) uncertainties around demand for the mini grid's electricity services creates a risk for developers and financiers alike; (3) many potential consumers are unable to pay the full costs of the mini grid's electricity; (4) unlike larger project developers, local for-profit and community developers often do not have enough of their own financial resources to meet the equity requirements imposed by conventional lenders; (5) mini grid investments often create an unacceptable asset-liability mismatch for local debt financiers; (6) political and regulatory risks are prevalent in many countries with large populations that do not have access to electricity; and (7) uncertainty about future macroeconomic conditions—particularly exchange rates, interest rates, and the economic growth rate—discourages investment.

nario would also affect foreign investors' ability to take profits and repay their foreign lenders, which are longer-term issues than importing equipment.

Another relevant variable is the interest rate on local loans. Any unexpected hike in interest rates would increase the financial costs of loans to cover capital and operational costs. While such an increase would not affect fixed-rate loans that were already extended, it would affect future refinancing or the rollover of loans that have a shorter tenor than the developer wants. For example, a developer may want a 10-year loan to finance capital costs. The lender might offer only a 6-year loan with payments calculated as if it were a 10-year loan. At the end of six years, the developer would still owe part of the loan. It could be rolled over into a fresh four-year loan, but the old interest rate would no longer apply. The new loan would be at the interest rate then prevailing.

A third relevant macroeconomic variable is the country's economic growth rate, particularly in rural areas. Significant economic growth would tend to increase the mini grid's revenues and improve its financial viability. A national or regional recession or even slow growth leads to a "demand risk"—that is, a situation where demand would not be adequate to allow the mini grid to turn a profit. This would adversely affect the operation of mini grids and reduce the incentives to invest in them.

OVERCOMING THESE BARRIERS

Mini grid developers and the government must take actions to mitigate these barriers, with the support of development partners and other interested groups. The extent to which these barriers can be mitigated will depend on local conditions.

DEVELOPER ACTIONS

Developers are at the center of the financing package. They need to understand what kind of business plan financiers will view as bankable. In some cases, they may need assistance from experts in developing such plans.

Developers should be able to demonstrate that their business plans have some desired financial features (guarantees, collateral), including the following:

- *Adequate returns on investment,* including in scenarios that reflect some potential adverse external events.
- *Construction performance.* Mini grid developers should be able to demonstrate that they have the skills and resources to construct the mini grid on time and within budget, including by hiring a reliable engineering, procurement, and construction contractor.
- *Operational performance.* Developers should be able to demonstrate that they have the skills and resources to operate the mini grid. Penalties could be imposed for failure to generate and distribute electricity as proposed.
- *Maintenance fund.* Developers should establish and maintain a reserve fund for planned and unplanned maintenance during the operational phase of the project. This fund should be built into the project cost and topped up from project revenues as needed.
- *Debt-service reserve fund and ratio.* The financial plan should include a debt-service reserve fund that allows developers to continue to service the debt in the event of a temporary shortfall in project revenues. The debt-service ratio should be satisfactory to lenders.
- *Financial support from the government or international agencies.* Developers should be able to demonstrate that they will be supported by the government or international agencies. This will give some confidence to potential equity and debt financiers.

GOVERNMENT AND DEVELOPMENT PARTNER ACTIONS

The government and development partners will need to develop a support package containing four elements: debt facilitation, subsidies, equity facilitation, and risk-sharing and other risk-mitigation interventions. Table 6.4 summarizes how the support elements can be used to mitigate the barriers.

> Developers need to understand what kind of business plan financiers will view as bankable, and they should be able to demonstrate that their business plans have some desired financial features (guarantees, collateral), including adequate returns on investment, construction and operational performance, maintenance and debt-service reserve funds, and additional financial support from the government or development partners.

> To be viable, mini grid projects and developers need a complete financial package consisting of debt, equity, grants, and risk-sharing mechanisms. Government support for private-sector mini grids should therefore actively facilitate debt and equity investment and risk sharing through private-sector investors, alongside results-based grants paid directly to the mini grid developers.

TABLE 6.4 • Overcoming barriers to investments in mini grids

Barriers	Debt	Subsidies	Equity	Risk-sharing and other interventions
Mini grids are viewed as too risky	Help potential lenders assess mini grid finances Help local developers prepare bankable business plans	Use preinvestment subsidies to reduce risk by facilitating adequate due diligence Use capital cost—not output-based—subsidies to reduce risk exposure	Help local developers prepare bankable business plans	Develop risk-sharing instruments Provide strong national commitment to mini grids, to reduce risk perception
Demand uncertainty	Provide subordinated concessional loans so that commercial lenders can be repaid first Offer grace periods covering the first year or two of operations to enable the mini grid to reach its expected demand	Reduce capital costs to a level that brings the mini grid's cost of electricity to below the customers' ability to pay	—	Offer first-loss guarantee or minimum revenue guarantee mechanisms that cover a period of expected revenues
Customers cannot pay full costs	Develop new financial instruments that reduce borrowing costs	Use well-designed subsidies Results-based subsidies may be the most suitable for larger firms that have good access to debt and equity	—	Reduce costs by formulating large-scale programs Allow entities to operate multiple mini grids Enter as guarantors, being liable in case of default payment by mini grid customers
Developers lack equity resources	—	Use capital cost subsidies to partly finance initial capital costs of smaller firms	Facilitate "patient capital," which can take later returns from investment Develop new financial instruments that facilitate external equity	Provide financial and technical training to potential developers
Assets and liabilities are mismatched for local debt financiers	Increase the term of liability (deposits) by providing funds, as in World Bank credit lines	Use capital cost—not output-based—subsidies, to reduce debt requirements of smaller firms, which tends to assure local financiers	—	Reduce concerns about long-term loans through schemes such as "future liquidity support"
Political and regulatory risks	Develop mechanisms that facilitate local currency debt	—	—	Develop risk-sharing instruments that protect developers for regulatory or political changes
Macroeconomic uncertainty	Develop risk-sharing instruments for specific events	Provide short-term subsidies to tide over adversely affected firms, to avoid disrupting electricity provision	—	Develop risk-sharing instruments for specific events Provide currency-hedging instruments Develop contracts and agreements that allow developers to pay investors and suppliers in foreign currencies

Source: ESMAP analysis.
— = not applicable.

DEBT FACILITATION

While it is common for commercial debt to be the largest part of the financing package for a typical investment project, most mini grid projects to date have been financed mostly with equity and grants with a smaller portion of debt. Indeed, the International Finance Corporation has been tracking several financing deals with private-sector mini grid developers and found that debt tended to be a relatively small portion of the overall financing package. One of the main reasons for this is that commercial debt—particularly from local financiers—is not readily available because of the local mini grid sector's lack of a track record, or, if it is available, the terms are not financially attractive. Typical debt terms for mini grid developers tend to be between 9 and 12 percent if the debt is in US dollars, with a much broader and higher range for debt in local currency. (We note that high interest rates are an artifact of the country risk and other commercial risks, where private-sector lenders need to ensure an appropriate risk-return ratio.)

As a result, in most countries, the government will need to induce the flow of debt to mini grids, from commercial investors and banks, multilateral agencies, private finance initiatives, local pension funds, and others. The following four principles should guide the design of instruments that assist lenders who participate in financing mini grids:

- If private financiers need their own long-term funds before they can provide long-tenor loans to mini grid developers, the government should be willing to make long-term funds available to them. This intervention would mitigate or even eliminate the asset-liquidity mismatch.
- To the extent possible, interventions should not distort financial markets. In particular, the commercial risk for the debt should remain with the private financiers, not transferred to the government or some other official agency. Further, the interest rates should remain close to the local market rates. Although high interest rates impose a financial burden on the mini grid borrowers, it is recommended to keep debt and subsidy separate. Instead of implicit subsidies through low-rate loans, the subsidy should be explicit and provided separately.
- The government should engage financial experts to help mini grid developers develop their business plans. It may also be useful to assist private financiers with commercial appraisal of mini grid projects if the financiers request this assistance.
- The government should have the option of including nonprice factors in facilitating debt, as has been done in South Africa (box 6.2) for renewable energy projects. In particular, the social and environmental aspects of mini grid projects could be more heavily weighted in bid evaluations, to ensure that winning firms—to whom debt would be channeled—have these important nonprice factors built into their business plans.

Up-front credit lines

One common intervention in government-supported projects is the creation of an up-front credit line, whereby the government makes its funds available to participating financial institutions (PFIs) at the time the loan is issued to the mini grid developer. The typical sequence of an up-front credit line is as follows:

- The government gets funds from development partners, such as the World Bank.

BOX 6.2

NONPRICE FACTORS IN RENEWABLE ENERGY PROJECTS

Public and private procurement of goods and services can act as a lever to incorporate diversity measures and enhance corporate social responsibility. For example, South Africa has a preferential procurement policy framework and regulations for considering nonprice factors for 10–20 percent of its bid scoring. In 2011, these regulations were amended to reflect the Broad-Based Black Economic Empowerment (BBBEE) Act of 2003, which ties award points to BBBEE status levels, adding verification and remedies for fraudulent representation.

In South Africa's power sector, bidding documents under the Renewable Energy Independent Power Procurement Program include **nonprice bid-evaluation factors.** The bidding documents outline requirements for job growth promotion, domestic industrialization, community development, black economic empowerment, and women-owned vendor expenditure. The socioeconomic requirements go beyond the customary nonprice criteria in the government's preferential procurement policy—accounting for 30 percent of total bid value.

Source: ESMAP analysis.

- The government selects local lenders who are interested in financing mini grids and meet some operational financial criteria.
- The government on-lends these funds, usually through a financial intermediary, to participating PFIs in local currency. The loans to the PFIs have a long tenor. The interest rates on the loans are similar to the prevailing local wholesale interest rates. They are adjusted periodically to reflect current market conditions.
- The loans from PFIs to mini grid developers are denominated and repaid in local currency. The interest rates are close to the prevailing market rates. The main difference is that the loan tenor is longer than is locally common. The PFIs assume the commercial risk for the loan, repaying the government even if the mini grid developer fails to repay the loan.
- The PFIs have to put some of their own money into the loan. The government provides only a certain portion (such as 80 percent) of the total loan amount to the mini grid developers.

The need for and design of an up-front credit line requires careful assessment of local conditions and the interests of potential private finance initiatives. The World Bank's Nigeria Electrification Project does not include a credit line or similar facility. Instead, it was agreed that a detailed assessment of the financial conditions and the experience of mini grid developers would be carried out about 18 months after the project became operational. This assessment will then recommend appropriate financial interventions, which could include an up-front credit line, for promoting mini grids in Nigeria.

One common debt facilitation intervention in government-supported projects is an up-front credit line. This is a type of multi-tier lending mechanism in which the government receives funds from development partners such as the World Bank, selects qualified participating financial institutions (PFIs) interested in financing mini grids, and on-lends the development partner funds to the PFIs in local currency using loans with a long tenor and market-conforming interest rates. The PFIs then lend to mini grid developers using loans denominated and repaid in local currency, with market-conforming interest rates and loan tenors that are longer than what is locally common. The PFIs assume the commercial risk for the loan, repaying the government even if the mini grid developer fails to repay the loan.

Market-conforming interest rates

While the ideal design of an up-front credit line would call for interest rates that are close to the prevailing interest rates in the country, in many cases, mini grid developers find these interest rates too high and ask for "soft loans" at reduced interest rates. An example from Bangladesh of loans below market rate is offered in box 6.3.

Such interest rate reductions should be implemented with caution because of the problems they can create. In particular, reduced-rate loans take the credit offered to mini grids out of the system of normal loans. Mainstreaming is needed to provide debt finance to mini grid developers at scale. The closer the mini grid loans are to conventional debt finance, the greater the likelihood that debt finance to mini grids will grow.

One way to address the problem of high rates is to blend concessional debt along with commercial debt in the same financing package. This can help reduce the amount of up-front subsidies required while keeping tariff levels affordable, particularly in countries with a nascent mini grid market where capital costs are high.

BOX 6.3

A FINANCIAL SUPPORT PROGRAM IN BANGLADESH

In Bangladesh, mini grids are developed by private investors who may apply to the Infrastructure Development Company Limited (IDCOL) for funds. IDCOL does due diligence on a proposal. To begin, it consults with the Rural Electrification Board to check on when the main grid is likely to serve the proposed site. IDCOL also undertakes reviews of other factors affecting project viability, including potential customers' willingness to pay and the validity of cost estimates.

IDCOL finances and supports renewable energy and energy access projects in Bangladesh using a variety of financial tools. It has provided $27 million to support 27 mini grids totaling 5 megawatts (peak).

IDCOL provides a grant of 50 percent of the capital costs and loans for another 30 percent. The loan is for 10 years, with a two-year grace period. The interest rate is 6 percent per year, which is below market interest rates.

Source: ESMAP analysis

Governments considering up-front credit lines as a mechanism to make it easier for developers to secure private-sector loans should ensure that the credit line's interest rates are close to the prevailing interest rates in the country. Reduced-rate loans take the credit offered to mini grids out of the system of normal loans. However, mainstreaming is needed to provide debt finance to mini grid developers at scale. The closer the mini grid loans are to conventional debt finance, the greater the likelihood that debt finance to mini grids will grow.

In markets with no shortage of liquidity when governments are set to deploy a debt facilitation mechanism, up-front credit lines may not be the most appropriate option. A better approach would be to use a financial instrument that induces private lenders to make longer-term loans without increasing liquidity in the short term. One way to do this is to set up a financing facility that makes funds available to developers in the years after the commercial loan tenor expires.

Another way to address the problem of high interest rates is to increase capital cost subsidies, so that the total amount of the loan is reduced. Reduced-interest rate loans are an indirect, implicit subsidy for mini grid developers; it is more transparent and sustainable to provide this additional subsidy explicitly outside the loan.

A third option is to introduce some risk-sharing guarantees, under which an independent third party shares the commercial risk with private finance initiatives, as discussed later in this chapter.

Alternatives to up-front credit lines

One drawback of an up-front credit line is that it introduces additional funds into the financial system in a country that often does not have a liquidity shortage. The fact that an up-front credit line adds liquidity in the short term even though there is no shortage of liquidity indicates that it is an overly broad instrument that may distort credit markets. A better approach would be to use a financial instrument that induces private initiatives to make longer-term loans without increasing liquidity in the short term.

One alternative is to set up a financing facility that could make funds available in the years after the normal tenor of commercial loans runs out. Say, for example, a mini grid developer wants a 12-year loan, but the private lender may be willing to lend money from its own funds for only five years. The alternative facility could kick in after five years. It directly addresses the issue of longer-term loans without adding liquidity to a financial system that may not have a liquidity shortage. Another advantage of this mechanism is that the total external funds required would likely be smaller than the amount required by a conventional up-front credit line.

This alternative facility is more complex than an up-front credit line, however. Although it is easily understood by potential private finance initiatives, its longer-term horizon and complexity make it more difficult to design and implement. It has not yet been used for financing mini grids.

Emerging debt options

Significant technical innovation in the financial sector has recently led to new ways for debt funds to flow to borrowers. Funds for mini grids could come from worldwide investors, typically affecting investors interested in promoting renewable energy or rural electrification.

Some of the new financial instruments were recently introduced in Asia and Africa. Although they are still in the early stages of development, they have the potential to raise significant funds for mini grids in the future.

Convertible notes. While not a new debt product *per se*, convertible notes are new to the mini grid sector. A convertible note is a loan that can be converted into company equity at some later point. The loan has a lower interest rate than a conventional loan. The lender can convert the loan into equity under terms favorable to the lender.

The main advantage of convertible notes is that they allow early investors to provide mini grid developers with quick, cheap capital that they can use to launch new companies and execute their growth plans. These early investors will likely participate only if they can sell their converted equity shares reasonably quickly at attractive prices. Once the mini grid company is well established, some people must be willing to buy the shares of these early investors. If the early investors are non-nationals, they must be confident that they will be able to readily convert the money from the sale of their shares into foreign currency.

Convertible notes are suitable for early-stage mini grid developers that have significant growth and profitability potential.

Peer-to-peer business lending. Peer-to-peer business (P2PB) instruments are suitable for companies that have a track record of revenues. In a P2PB scheme, a mini grid developer borrows, without collateral, from a group of individuals or institutional lenders, using an online P2PB lending platform. The lending platform itself does not provide the loan; it is just an intermediary that matches borrowers and lenders.

Two debt financing innovations have emerged recently for private-sector mini grids: convertible notes, in which a loan can be converted into equity on terms that are favorable to the lender, thereby reducing the loan's interest rate; and peer-to-peer business lending, in which a mini grid developer borrows, without collateral, from a group of individuals or institutional lenders, using an online lending platform.

One major advantage of the P2PB system is that it is quick, as limited due diligence is conducted. However, the cost of the loan is likely to be high. If the lenders are foreigners, they must be confident that they will be able to readily convert the money from repayments into foreign currency.

SUBSIDIES

Subsidies should be part of the financial package available to mini grid developers and customers. The subsidy amounts and design should respond to the needs of the following three groups:

- Households and firms, which want an affordable combination of initial (connection and internal wiring) costs and usage charges
- Mini grid developers, who are looking for financial viability
- Subsidy fund providers, who want subsidies to be properly targeted, easy to administer, and not be a financial burden

Subsidies for mini grids come in two broad categories. The first category consists of subsidies that help the developers and customers finance the costs of project preparation, construction, and operations. The second category reduces the financial costs of mini grid developers.

First-category subsidies: Helping developers and customers finance their costs

PREINVESTMENT SUBSIDIES

Mini grid developers face certain expenses before they decide to undertake their investments, such as market assessments and prefeasibility and feasibility studies. Developers may be hesitant to incur these costs because they are not sure that their firm will actually build a mini grid at the site being considered. As a result, the number of mini grids may be smaller than needed for scale-up.

It is important to induce more developers to consider more mini grid sites—that is, to cast a wide net. One way to do so is to meet these costs with preinvestment subsidies. The main elements of preinvestment subsidies include the following:

- *General market and resource assessments,* including geospatial planning (see chapter 2). Governments should undertake these assessments for potential mini grids and provide the information free to all interested developers.
- *Prefeasibility and feasibility studies.* The costs for these studies should be shared with shortlisted firms for projects that pass basic screening criteria set by the government agency responsible for promoting mini grids.
- *Technical and financial information assistance.* This assistance should be provided free to local developers, at least in the early years, so that they can develop bankable business plans.

CAPITAL COST SUBSIDIES

Capital cost subsidies should be designed so that the financial package—consisting of equity, debt, and subsidies—is sufficient to finance all capital costs. If all capital costs cannot be covered, the mini grid will not be constructed.

Capital cost subsidies can be preset as a share of "reasonable" capital costs in contexts where the tariff is not predefined, or is based on lowest-subsidy bids in cases where the tariff is predefined. The preset option tends to be easier for both administrators and mini grid developers, but may lead to higher-than-necessary subsidy levels.

In recent years, many governments have provided output- or results-based capital cost subsidies. These should be applied to mini grids with caution, as relying exclusively on final output makes it difficult for developers to finance the initial, up-front capital costs of mini grids, particularly if affordable debt is not readily available to them. As a consequence, it is reasonable to designate some "intermediate" results as a basis for some of the subsidy payments, such as when goods are purchased and when they arrive on site.

Performance-based subsidies of capital expenditure

ESMAP used HOMER® Pro (Hybrid Optimization of Multiple Energy Resources) to model an optimized "best-in-class" mini grid based on component costs and load magnitude averaged from three high-performing mini grids in Nigeria, Myanmar, and Ethiopia. The software was also used to model a "best-in-class 2030" mini grid reflecting equipment cost reductions expected in 2030 (see chapter 1 for details). The modeling software was used to assess the impacts of reducing initial capital expenditure (CAPEX) costs by 40 and 60 percent under different productive-use and component cost scenarios. The results of this analysis are presented in table 6.5.

TABLE 6.5 • Impact of performance-based subsidies of capital expenses on the levelized cost of energy of a well-designed mini grid

Load factor (%)	Performance-based grants as share of capital expenditure (%)	2021 (US$/kWh)	2030 (US$/kWh)
22	0	0.38	0.30
22	40	0.28	0.20
22	60	0.23	0.15
40	0	0.28	0.21
40	40	0.22	0.16
40	60	0.19	0.12
80	0	0.23	0.17
80	40	0.20	0.14
80	60	0.19	0.13

Source: ESMAP analysis.

Note: Data on the levelized cost of electricity are for a well-designed solar-hybrid mini grid with 231 kilowatts of firm power output serving around 800 customers.

kWh = kilowatt-hour.

Table 6.5 shows how a 40 percent capital cost grant lowers the LCOE from $0.38/kWh to $0.28/kWh in a scenario with low productive use. In a scenario where productive use raises the mini grid's load factor to 40 percent, the same 40 percent capital cost grant reduces the LCOE from $0.28/kWh to $0.22/kWh.

Interactions between performance-based capital cost subsidies and productive use

CAPEX subsidies and increased load factors through productive use both act to lower LCOE. But when used together, their interaction diminishes their cumulative impact. In an unsubsidized mini grid, the impact of shifting from a 22 percent load factor to a load factor of 40 percent greatly lowers LCOE. In the case of the best-in-class mini grid modeled above, a shift from 22 to 40 percent load factor lowers LCOE by $0.10/kWh from $0.38/kWh to $0.28/kWh when the CAPEX subsidy is zero (see table 6.5). With a higher capital subsidy, however, the LCOE-lowering benefits of a higher load factor are diluted. In the case of a 60 percent subsidy, the LCOE of the same mini grid drops only $0.04/kWh, from $0.23/kWh to $0.19/kWh, when the load factor increases from 22 to 40 percent.

The erosion of LCOE benefits in combinations of subsidies and productive use arises because the mini grid must deliver more electricity to meet load. One consequence of more electricity consumed means that the batteries must cycle more electricity, and therefore require more frequent replacement. CAPEX subsidy only covers equipment costs when the mini grid is built but does not cover equipment replacements. More frequent equipment replacements through heavy use increases the overall (unsubsidized) costs that must be covered by electricity sales. A second reason has to do with diesel generators. While higher asset utilization lowers the portion of LCOE associated with investment costs of equipment, it can raise the portion of LCOE associated with operational expenditure (OPEX), especially if that OPEX involves burning expensive diesel fuel. Because OPEX accounts for a larger portion of LCOE than CAPEX in a subsidized system, the higher OPEX costs can outweigh the increased capital utilization benefits that would otherwise lower LCOE.

While the combined impact on LCOE of grants and productive uses is typically greater than either approach on its own, when used together, their cumulative impact is lower than the sum of expected impacts from each intervention when OPEX costs are relatively large with respect to CAPEX.

CONNECTION COST SUBSIDIES

Poorer households will find it difficult to pay the up-front connection and internal wiring costs needed to connect to a mini grid. A special fund can subsidize connection costs for these households.

The subsidy calculation should use a broad definition of connection cost, which includes all the costs to connect, including internal house wiring. It is possible that these costs will vary according to the level/tier of service, as defined by the Multi-Tier Framework.

Low-interest loans may be useful to help households finance their internal wiring and connection costs. Box 6.4 presents an example from the Lao People's Democratic Republic (Lao PDR) of an interest-free loan program, designed with a gender focus, available to low-income households to help them cover the costs of connecting to the mini grid.

Where households are responsible for part of the total connection costs, should the subsidy be paid to the household or the developer? This depends on the specific circumstances of each case. It is typically most convenient to make a single subsidy payment to the developer, which would then be responsible for paying any contractor who does the internal household wiring.

While it is generally desirable that subsidies decline over time, it is unlikely that the household's share of the costs can be increased. One possible exception occurs in locations where the income levels of poor households have risen.

It may also be useful to pay some subsidies after connection is made, to increase the number of households with access to electricity.

BOX 6.4

A REVOLVING FUND FOR CONSUMER FINANCE IN LAO PDR

The "Power to the Poor" (P2P) program of the Lao PDR government is a targeted, subsidized, affordable, and sustainable financing mechanism for connection and indoor wiring for the poorest rural households. It is designed with a gender focus to provide interest-free credit that allows the poorest rural households, which cannot otherwise afford to pay the entire up-front costs of connection and internal wiring, to access the main electricity grid for basic service. The monthly payments for both the credit ($75 per household) and electricity consumption are designed to be about the same as the cost for lighting via candles, diesel lamps, or car batteries, as used before electrification. The pilot results indicate an increase (from 63 to 90 percent) in the connection rate of households headed by women, which was attributed to the P2P program's design.

Finally, in designing consumer connection schemes, it is important to pay attention to equity issues related to gender. For example, are the connection charges too expensive for households headed by women? Do connection requirements such as land titles prohibit women from gaining a connection in their name? If the answer to either of these questions is yes, then the benefits of mini grid electricity will be unequally distributed across the mini grid's potential customer base.

USAGE SUBSIDIES

In some situations, usage subsidies may be built into the tariff, particularly if the mini grids adopt the national tariff that is applied to the main grid. Although mini grid customers may initially agree to pay higher tariffs, they may later change their minds—possibly as a result of statements by local or national-level politicians about fair electricity pricing—and ask to pay a lower tariff. Such a change would threaten the financial viability of the private investment in the mini grid and deter future private investments in mini grids. To prevent this from happening, the government must be prepared to increase the subsidies provided to the private developers.

Regardless of which tariff scheme is applied, it is important to ensure that lifeline rates are provided for poorer households. Lifeline rates charge a low fee for the first few kilowatt-hours used per month. In Uganda, for example, the charge for the first 15 kWh is U Sh 250/kWh (about $0.07/kWh); the rate thereafter is nearly three times higher.

Customer connection schemes need to pay attention to equity issues related to gender. If connection charges are too expensive for households headed by women, or if connecting to the mini grid requires a land title or proof of collateral, the benefits of mini grid electricity will not reach male and female customers equally.

Four types of subsidies can help mini grid developers and customers finance their costs: (1) preinvestment subsidies, such as market and resource assessments, including geospatial planning (see chapter 2), prefeasibility and feasibility studies, and technical assistance; (2) capital cost subsidies, typically either preset as a share of "reasonable" capital costs or based on lowest-subsidy bids; (3) connection cost subsidies, paid either to the developer or to customers, either as grants or as concessionary loans; and (4) usage subsidies, including those built into the tariff structure, such as lifeline tariffs, and those paid to customers to subsidize the purchase of energy-efficient appliances and electromechanical equipment.

Providing usage subsidies to customers may reduce their incentives to limit their energy consumption, leading to the purchase of energy-inefficient appliances. To prevent this from happening, governments can consider providing subsidies for the most efficient appliances and end-use equipment.

Second-category subsidies: Reducing the financial costs of mini grid developers

ABSORPTION OF SOME COSTS BY THE GOVERNMENT

Governments can reduce some of the capital costs of developers by owning part of the mini grid. For example, the government could pay for the distribution system and allow the mini grid developer to use it for a fee. The fee could be subsidized (such as a zero fee in the initial years).

Alternatively, the mini grid developer could build the distribution system and then sell it to the government once it is ready for use.[1] Under such an arrangement, the mini grid developer would not need long-term capital to finance the costs of the distribution system. After the sale, the mini grid developer would lease back the system from the government. Another advantage of this system is that the arrival of the main grid would create less of a financial transaction for the mini grid developer. The developer's lease would end with the arrival of the main grid. At that point, the primary physical assets the developer would be concerned about would be the generation system, which is much easier to sell. The developer would, however, still need to repay its creditors if any debts were outstanding.

For example, in Nigeria, GIZ supports mini grids through the split-asset model.[2] The split is between the generation and distribution assets. The entrepreneur finances and owns the generation facility. The GIZ grant is used to build the distribution grid, which is owned by the state government. This government leases the distribution grid to the entrepreneur, with the lease payment possibly subsidized. The United Nations Office of Project Services is planning a similar approach in Sierra Leone.

The disadvantage of this method is that the government needs to finance the costs of distribution systems. Part of the reason for asking private firms to develop mini grids is because governments do not have adequate funds to finance a rapid scaling up of mini grids. But if the government can raise these funds from development partners, or through a development impact bond scheme,[3] it may be feasible to move forward.

A second way governments could absorb some of the financial costs is through such schemes as tax breaks, import-tax waivers, and tax holidays. Although these schemes are financially helpful, they suffer from two major disadvantages where the aim is to scale up mini grids rapidly. First, these schemes are subject to change and amendment later on because of competing priorities in a country's budget. And second, these implicit subsidies make it difficult to know how much support is being provided to mini grid developers.

WAGE, EMPLOYMENT, AND TRAINING SUBSIDIES

Modern mini grids support firms and entrepreneurs engaged in productive uses of electricity, which in turn creates jobs. At the same time, governments are increasingly looking to create rural employment opportunities, particularly when investment and new technologies are being introduced on a large scale. Subsidy schemes that incentivize or support new employment created by mini grids are therefore of interest. The design of such subsidies would have to draw on broad-based schemes for rural development, as no such subsidies have been provided yet for mini grids.

> Two types of subsidies can lower the financial costs mini grid developers face: (1) the government can absorb some of the costs, typically by owning some of the mini grid's physical assets or by providing developers with tax breaks, import tax waivers, and tax holidays; and (2) wage, employment, and training subsidies can increase employment in rural areas and boost productive uses of mini grid electricity.

REDUCING SUBSIDIES OVER TIME

It is important that a subsidy scheme has an exit, or taper, policy. The need for subsidies should diminish over time as a result of the following factors:

- Experience should allow financiers to assess risks more accurately, reducing the risk perception. Thus, the availability of debt and equity finance is likely to grow.
- The need for preinvestment subsidies should fall as mini grid developers become active in particular markets.
- Costs are likely to fall as firms gain experience and the scale of the industry increases.

However, as mini grids move into poorer, more remote areas, affordability may decline, making it more difficult to taper subsidies.

FACILITATING EQUITY

Mini grid developers invest some of their own money as equity. Project developers also look for equity from other sources.

Over the past few years, infrastructure assets have become a more attractive asset class for international investors, driving competition and hence shrinking investor returns on equity and debt margins. However, compared with several other infrastructure assets, mini grids are relatively small deals with high levels of risk. Such characteristics lead to higher expected returns on equity (RoE), typically in the range of 18–22 percent for commercial investors and around 15 percent for impact investors. But the RoE also depends on a number of other factors, such as the overall risk profile of specific mini grid transactions, contractual and regulatory frameworks, and potential risk mitigants.

Reducing the RoE—and attracting a higher volume of debt—on mini grid projects is achievable. Most mini grid projects are relatively small, so they do not necessarily benefit from economies of scale; competition among investors is rather limited for a variety of reasons; and high up-front CAPEX subsidies are needed to make project economics work.

Subsidy schemes should have an exit, or taper, policy as a country's experience with mini grids increases, more private sector developers become active in a country, and mini grid component costs fall. Also, subsidy policy should be location specific, allowing mini grid developers to move into low-income and remote areas.

Developing mini grids through a portfolio approach would improve the bankability and risk-allocation framework, replicability, and pace of their implementation through some level of standardization. This could also help expand the market potential and increase the size of individual transactions.

In turn, larger and more bankable projects combined with the appropriate risk-mitigation framework, regulatory regime, public-sector intervention, and subsidies will help attract more private investors and lenders, in turn contributing to lower costs of capital and debt margins.

STRUCTURING EQUITY INVESTMENTS

Common stock is the equity issued to founders, family, friends, and early employees. It is usually issued to people who invest their time, effort, and money in the earliest days of a start-up. For financiers who are outside the developer's group of supporters, preferred stock is a suitable option. The most important feature of preferred stock is that its holders come ahead of common stock investors in getting returns on investment.

The terms of preferred stock may be subject to intense negotiation between common stockholders and potential investors who want to become preferred stock investors. It can be helpful if there is a government-approved standard financial model that would be the starting point of discussions between investors and mini grid developers. Simplified models are used in Tanzania and Haiti, among other countries, and a detailed standardized financial model is automatically produced by Odyssey's online platform, based on developers' inputs (see chapter 2 for a discussion on Odyssey). Such models would be particularly helpful when the developer is local and the potential investors are foreigners.

INNOVATIONS IN EQUITY FINANCING FOR THE MINI GRID SECTOR

Various innovations in equity financing can help bring affordable equity investment to the mini grid sector.

Equity crowdfunding. Equity crowdfunding is a way of allowing a large number of people to invest in a mini grid.

Equity usually takes the form of common stock (issued to founders, family, friends, and early employees) and preferred stock (issued to financiers outside the developer's internal group of supporters). Holders of preferred stock have priority over holders of common stock in getting returns on investment, so negotiations between common stockholders and potential investors can often be intense; if the negotiations break down, the developer is unable to raise adequate equity. As a result, governments should consider developing standard financial models to facilitate these negotiations, particularly when the developer is local and the potential investors are international.

The connection between the developer and investors is through online platforms that have been established to channel equity into a variety of investments in developing countries, not just mini grids.

Mini grids appear to have little experience with this model. But given its major potential in the scaling up of mini grid development programs, it would be useful for development partners and their financial experts to help interested governments make it easier for equity crowdfunders to finance mini grids.

Mezzanine finance. Mezzanine finance is a hybrid of equity and debt. It counts as equity when debt lenders consider the debt-equity ratio for financing the capital costs of a mini grid, because payments to mezzanine financiers are made after project operating costs, conventional (senior) debt, and required reserve balances are determined. There appears to be no experience with this type of financing for mini grids in developing countries.

Socially oriented capital. These funds come from investors who are interested in supporting mini grids in a commercial manner but who also recognize the social rationale for mini grids. One way for this social recognition is to accept a lower than commercial return. In other words, the investor expects to get a financial return on the investment but will accept a lower financial return in recognition of the project's social returns. This is called "social impact investment." Other investors may want a commercial return, but are willing to wait for a longer period. This is called "patient capital."

The "AssetCo" Model. Under this model, an investor (the Asset Company, or AssetCo) agrees to purchase a portfolio of mini grids from a developer once certain milestones are achieved, such as obtaining all necessary licenses, successful commissioning, and serving a minimum number of customers for a prespecified amount of time. The mini grids are

Three innovations in equity investment for mini grids are emerging: (1) equity crowdfunding, in which developers offer small amounts of equity to a large number of investors through an online platform; (2) mezzanine finance, such as convertible notes, in which a lender has the right to convert its loan to an equity stake in the company; and (3) socially oriented equity investment, where investors take an equity stake in a company but accept a lower financial return in exchange for a demonstrable social impact.

typically built and operated by the same developer, though in some cases the AssetCo will contract with two different companies – one for construction and initial operations, and one for long-term O&M. The AssetCo, meanwhile, owns the portfolio of projects. A primary advantage of this model is that it enables the AssetCo to tap into low-cost, longer-term debt that is not typically available to a mini grid company.

MITIGATING RISK

Given the perceived riskiness of the mini grid business as an investment opportunity, several mechanisms are designed to mitigate some of the demand and investment risks that international investors might face.

While the existence of latent demand for electricity in unserved and underserved communities is well accepted, the expected demand and associated ability to pay is rather uncertain. In addition, the steady state growth in electricity demand and corresponding payments is likely to be highly dependent on the pace at which value-added products and services, which in turn generate additional need for electricity, become available. This uncertainty is likely to have an adverse effect on the cost of capital and capital structure, further increasing the need for subsidies for commercial viability and to limit the kinds of parties willing to provide equity and debt financing. On the flip side, in the rare cases when demand rises dramatically, exceeding initial installed capacity, the developer may ask for (scarce) additional capital for capacity expansion in order to meet the requisite service levels. The need to develop adequate demand risk–mitigation instruments is thus acute.

Mitigating risk through mini grid design

As highlighted in chapters 1–4, there are ways to design and plan mini grids and engage with customers that can help mitigate against the risk of uncertain demand for electricity. These include the following:

- *Site and portfolio selection:* The rural customer base has low and episodic income (for example, seasonal income for predominantly agricultural economies), leading to affordability issues and potential renegotiation requests. In this context, site selection is key to improve the level of strategic cross-subsidization and hence overall credit and project economics. Measures for achieving such objectives include (1) mixing commercial and industrial customers with residential loads, (2) blending nearby greenfield projects with robust brownfield projects, and (3) aggregating new projects together.
- *Rigorous demand assessment:* Future electricity uptake is uncertain, given the myriad factors that could affect it (such as level of income, access to appliances for mini grid users, and access to microfinance) and the inclusion of biases in initial assessments. While electricity uptake would remain a source of uncertainty, it can be mitigated through (1) rigorous methodology regarding the assessments, (2) a level of standardization to allow comparability between projects, and (3) a postimplementation review to better understand the factors responsible for the uptake and bias. It can also be further enhanced by creating a larger pool of data to look back on.
- *Generation sizing and modular expansion:* Mini grids have traditionally suffered from oversizing generation components as a result of various factors, including misleading demand estimates or misaligned incentives and grant mechanisms. This oversizing has led to the economic and financial underperformance of projects. Sizing a mini grid generation component for the demand expected in the first years of operation with built-in modularity allows mini grid developers to meet demand growth over time, while curtailing early financial losses from underutilization after commissioning.
- *Load factor optimization strategy through stimulation of productive uses:* The appropriate development of productive uses will augment revenues by optimizing the mini grid's load management. Providing incentives to scale up access to appliances and microfinance to mini grid users is key to boosting demand, and these value-added services can even be added up front in the mini grid's value proposition to the community.

Mitigating risk through risk allocation

Just as risk allocation mitigates demand risk through mini grid planning, design, and operations, there are several options that lessen the risk of demand uncertainty and make the mini grid business a more attractive investment. In risk-sharing schemes, a third party shares some of the risks with debt providers and equity investors. The third party could be a development partner or an interested independent foundation or fund. It is common to charge a fee for the risk-mitigation mechanism, though it could be at a subsidized rate, at least initially.

These schemes ease the financial risks private finance initiatives and equity investors face in their fear of high losses. The losses may be from a single mini grid developer or from a pool of mini grids, with pooling generally considered a more workable option. Some risk-sharing mechanisms are discussed below.

Minimum revenue guarantee (MRG). An MRG issued in favor of the mini grid developer can partly reduce the demand risk and would benefit both the lenders (principal and interest) and equity indirectly. The instrument would be sized to cover a percentage of annual projected revenue, and if the demand does not materialize, then the guarantee would be called. In this case, the demand risk is distributed between the developer and the government or a third party, with payouts ultimately benefiting the entire financial equilibrium of the project. Replenishment and renewal modalities would need to be in place to ensure the sustainability of such a mechanism.

Chilean highway concessions (between 1992 and 2004) were among the pioneers integrating MRG mechanisms to provide short-term liquidity essential to cover debt service and other financial obligations. For these projects, the Chilean government was offering an MRG as high as 80–85 percent of expected revenues, with the government paying the MRG if traffic fell under a given year's guarantee level. Developers would pay a guarantee fee of 0.75 percent of the MRG amount, also contributing to the scheme. MRGs were also weighted toward the early years of concessions to reflect lenders' liquidity concerns.

Shadow tolls. Similar to MRGs, these mechanisms were developed for toll roads and entail the government paying the concessionaire service payments calculated based on the number of users within a set time frame. In other words, the concessionaire collects tolls from the government rather than actual infrastructure users. In principle, shadow toll structures enable the government and concessionaire to share the demand risk without affecting end users' service fees and without imposing real tolls on road users. Shadow toll advantages include: (1) minimizing demand risk and hence making it easier for private investment partners to find more advantageous financing; (2) if structured properly, reducing the effect of lower-than-expected demand; (3) capping the public sector's exposure, thereby eliminating the risk of superprofitability by the concessionaire; and (4) capturing the profit-seeking motives of the private sector, often resulting in capital construction cost savings.

This mechanism was used in early road projects in the United Kingdom, and it had a distinguishing feature: the shadow toll rate was not flat but, rather, varied with the volume of traffic relative to the user category. Bidders for the UK projects were asked to bid up to four separate toll rates for four bands of traffic volumes. The main restriction was that the toll rate for the uppermost band of traffic volumes was to be set at zero, effectively capping the government's financial exposure to paying tolls to the concessionaire, even if traffic volumes were well above expectations. The lowest band was set at a level that would cover operating costs and debt service. Bands 2 and 3 would offer a return to equity, and Band 4 set the maximum toll that the government would have to pay, thus capping the government's liability to pay shadow tolls.

Loss-sharing mechanisms. These are generally of three types.

- In a *first-loss guarantee scheme*, the third party agrees to bear the first tranche of loss. If losses extemd beyond the first tranche, the private finance initiative has to bear them. The definition of where the first tranche ends varies, depending on local financial conditions. First-loss schemes are a useful approach from an investment portfolio perspective—for them to work, the investor must have sufficient volume or deal flow to spread risk across a large investment base.
- In a *pari passu guarantee scheme*, the guarantor and the private finance initiative share losses proportionally. The private finance initiative shares the loss right from the start. This scheme may therefore be less attractive to private financiers than is the first-loss scheme.
- In a *last-loss guarantee scheme*, the private finance initiative bears the first tranche of losses, with the guarantor absorbing any further losses. This scheme may be the least attractive to private financiers.

Benefit sharing. In some cases, demand may increase way beyond base case projections. Though rare, this case may lead to the developer realizing excess returns. This would offer an opportunity to implement a benefit-sharing mechanism if the mini grid was developed as part of a public-private partnerships model or was supported by government grants. Depending on the tariff regulation, such mechanisms can transfer benefits directly to end users through tariff reductions or to the government, possibly contributing to a demand risk–mitigation instrument for additional projects.

Subordinated loans. Risk-mitigation instruments can also be designed specifically for debt providers. Subordinated concessional loans can be added to the debt structure to ensure that commercial lenders are repaid in priority if the demand, revenues, and hence debt-coverage ratios are lower than anticipated. In such an event, the developer will be able to defer or even write off its debt repayment to the subordinated debt portion.

Mitigating foreign exchange risk

The future value of the local currency in terms of foreign currency is uncertain, and presents a substantial risk to mini grid developers. During the planning phase, a sharp decline in the value of the local currency would disrupt the financial plans and projections of finance providers as well as mini grid developers. During the construction and operations phases, currency risks stemming from volatile exchange rates and devaluation of the local currency are also present. The up-front investment typically requires hard currency to purchase the equipment (solar panels, cables, and so forth), though revenues are earned in local currency. In addition, financing is often in hard currency, rather than local currency. In some countries, developers can index their tariffs to hard currency if they show evidence that they have creditors and investors to repay in hard currency. This can minimize the exchange rate risk, but increases the risk that the tariffs will no longer be affordable for customers. Currency risks are significant in some countries, where local currency has been devalued by 25 percent or more over a one-year period. This ultimately means that there is 25 percent less revenue in terms of hard currency if developers are not able to increase their tariffs accordingly.

One instrument to mitigate currency risk is a foreign exchange hedge, which allows companies or lenders to mitigate foreign exchange risk by locking in an exchange rate for a transaction that will occur in the future. This lock-in requires the payment of a premium by the party looking to mitigate the risk. Another instrument is a quasi-hedge mechanism, in which the borrower takes the risk of devaluation up to a certain point, with the lender absorbing the loss beyond that. Currency-hedging instruments can be quite costly, though, and help drive up overall investment costs for the mini grid. Finally, any contracts or license agreements that the developer enters into with the government should explicitly state that the developer can pay its investors and suppliers in any currency and make these payments internationally.

> Demand and foreign exchange are the two categories of risk that can be mitigated to make mini grid investments more attractive to debt and equity investors. To mitigate the demand risk—in addition to measures taken during the planning, design, and operations of the mini grid—financial mechanisms include minimum revenue guarantees, shadow tolls, loss sharing, and subordinated debt. Foreign exchange risks can be mitigated by currency-hedging instruments and explicit language in contracts and license agreements that the developer can pay its investors and suppliers in foreign currency and can make these payments internationally. While there have been few significant experiences with these interventions in the mini grid sector, they would be helpful in a large-scale mini grid development plan.

CONCLUSIONS, AND GENERAL RECOMMENDATIONS FOR GOVERNMENTS

First, it is essential that the government, together with its development partners, takes the steps necessary to make sure that potential mini grid developers are able to access a financial package that makes it possible for them to finance their projects, particularly the capital costs, and earn an acceptable rate of return on their investments. This financial package will comprise equity, debt, subsidies, and risk-sharing mechanisms.

Second, the elements of the financial package should be in sync with the stage of development of the mini grid program. In the kickstart phase, the focus should be on formulating a simple package that is easy to administer. Although ideally it should include equity, debt, subsidies, and risk-sharing instruments, the choice should be based on the level of financial development of potential financiers and developers. The focus should be on making it easy for firms to get going, rather than using the most efficient financial instruments.

For example, capital cost subsidies paid in tranches linked to construction results may be more practical than subsidies linked to results after the mini grid is commissioned (for example, actual connections). This is because subsidies paid later increase the up-front debt and equity needs, as capital cost subsidies are a substitute for debt and equity. It may take significant time to develop and implement some of the newer financial interventions that have not been used for mini grids. Relying heavily on them increases the risk of delays in getting the program going. The planning and development of the newer financial interventions should start as soon as possible, however, as these interventions will be critical in the scale-up phase.

Third, financial packages should consider support to poorer households, so that they can connect to the mini grid and use electricity in their homes. Financial assistance to pay for the initial costs can be a combination of subsidies and loans.

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NOTES

1. This approach is being adopted as part of the World Bank–supported Off-grid Solar Access Project for Underserved Counties in Kenya. This project will construct mini grids in 14 counties with low electrification rates. The private sector will bid on Engineering-Procurement-Construction contracts with the Kenya Power and Lighting Company (KPLC) and the Rural Electrification and Renewable Energy Corporation (REREC). Bidders are asked to install the solar mini grids including KPLC certified prepaid/smart meters as well as provide for a social infrastructure project as selected by the county.
2. This model is related to GIZ's procurement rules, which do not permit performance grants.
3. A development impact bond is a performance-based investment instrument intended to finance development outcomes in developing countries.

CHAPTER 7

ATTRACTING EXCEPTIONAL TALENT AND SCALING UP SKILLS DEVELOPMENT

CHAPTER OVERVIEW

This chapter highlights the training and skills needed to connect half a billion people to mini grids by 2030. It surveys the types of training and skill-building initiatives needed in the mini grid sector, identifying skills gaps that can hamper successful scaling. The chapter concludes with suggestions for implementing effective training and skills-building programs and offers selected examples of capacity-enhancing efforts undertaken in several countries. A database of training and skills-development programs relevant to mini grid industry stakeholders is available on the companion website to this handbook: www.esmap.org/mini_grids_for_half_a_billion_people.

Scaling up mini grid deployment to connect 490 million people by 2030 will be possible only if human capital keeps pace with financial capital. However, recent mini grid projects have revealed a gap in skills that impedes the scale-up of mini grids (Energy 4 Impact and INENSUS 2018). Furthermore, most of the second-generation mini grids built to date have been done on a project-by-project basis, which does not incentivize sustainable skills development in the country of implementation. After a project is completed, any skills gained tend to dissipate, and training often must start over again with the next project (IEA 2003).

Strategic, sustainable, and needs-based skill-building and training initiatives are critical to ensure the long-term scalability and sustainability of mini grids. To develop mini grids using a portfolio approach training and skills should be built in from the outset.

In this chapter, we illustrate how skills gaps have been closed, enabling successful electrification through mini grids. We also illustrate some key limitations and inadequacies in how the interventions were designed and carried out, as learning from experience can improve interventions elsewhere and avoid damaging the reputation of mini grid development programs (GIZ 2017b). The chapter concludes with recommendations on how to set up effective training and skill-building programs, with examples of capacity-enhancing efforts undertaken in several countries. A database of training and skill-development programs relevant to industry stakeholders, as well as organizations that implement training programs, is available on the companion website of this handbook: www.esmap.org/mini_grids_for_half_a_billion_people.

The following definitions are important for the purposes of this chapter:

- *Skills building* and *capacity building* are often used interchangeably, and in this chapter they both refer to developing the knowledge, know-how, and capabilities of an organization or an individual.
- *Training* is defined as the process that targets specialized groups to develop specific skills and capacities for certain activities or tasks (Energy 4 Impact and INENSUS 2018), taking into account the interests of all stakeholders, including the local community, government and utility officials, project developers, and operators.

This chapter is intended for policy makers, regulators, development partners, and project developers who seek to understand how their role in electrification can be enhanced by building skills and capacity.

MINI GRID DEVELOPMENT REQUIRES DISTINCTIVE SKILLS AND CAPACITY

Scaling up mini grid deployments successfully requires that actors along the industry value chain possess certain skills attuned to the unique characteristics of mini grids—technical, legal, financial, and political, and others (Ochs and Indriunaite 2019). As mini grid networks grow in scale, the need for specific skills will only grow. Consider the following skills required during three broad phases of mini grid development—preinvestment, construction, and operations and maintenance (O&M).

PREINVESTMENT PHASE

The preinvestment phase requires skills to assess the feasibility of the project, decide on a corporate structure, and hire local staff. Feasibility studies are critical to ensure the technical and financial viability of a project in a specific market (GMG n.d.[d]). Such studies cover site selection, demand assessment, technical system design and system sizing, distribution network mapping, business models, financial modeling, capital raising, community engagement, and legal compliance (AfDB 2016).

Distinctive skills for the preinvestment stage are also required at the policy level. To achieve electrification goals through mini grids, civil servants may be involved in developing national electrification plans and in working with project developers. However, civil servants responsible for giving such support may themselves suffer from a lack of skills and experience in the mini grid market, preventing them from achieving their intended purpose (IRENA 2017). This challenge is pertinent at all staff levels, including policy making, standard setting, company management, finance and accountancy, project management, and engineering (GMG n.d.[d]).

PROJECT CONSTRUCTION

Project construction involves contracting, procurement, installation, commissioning, community engagement, and project management. Foundational principles of the project construction phase are to ensure safety and efficiency, provide adequate power to meet local demand, and build in scalability (GMG n.d.[e]). Developers and government staff play an important role in ensuring that mini grids are built to code and comply with national and local rules and regulations (USAID 2018f).

A robust mini grid system is built with certified components. Similarly, the installation should be conducted under the supervision of certified and experienced technicians. Implementing portfolios of technically sound, safe, and affordable mini grids requires that everyone in the project unit have requisite skills: developers, technicians, suppliers, and electricians.

Generation and distribution systems make up the largest portion of construction. Installing those systems requires site visits by the design team to tailor system design to local conditions (for example, ground conditions, wind strength, and lighting incidence). Customer connections, indoor electrical installations, and metering also need to be considered by designers of the mini grid system, particularly when the system must comply with local codes and standards. Specialized installation tools and manuals in the local language are also needed.

Finally, community engagement is a crucial part of the construction phase so as to build local ownership and avoid future conflicts. Developers and project teams must either possess the skills to engage with the community or hire trained local organizations to deliver awareness programs on tariffs and system use.

PROJECT OPERATIONS AND MAINTENANCE

O&M is a critical phase for the sustainability and reliability of a portfolio of mini grid systems. An operator should incorporate operational spending and maintenance plans as part of overall project development and be able to carry out O&M tasks (e-MPF 2014) across the portfolio. Ideally, such tasks should be set well in advance of the start of operations: even the best-designed mini grids can fail if O&M is not properly prepared and executed (GMG n.d.[b]).

The O&M phase requires many skills, such as O&M process management and software; marketing and customer service; metering; demand-side management; demand stimulation (including micro enterprise development); performance monitoring and evaluation; and enterprise management (Energy 4 Impact and INENSUS 2018). O&M can be managed by the utility or contracted out to local

> Each phase of mini grid development requires specific skills. The preinvestment phase requires skills related to site selection (including through geospatial analysis), demand assessment, technical system design, distribution network mapping, business models, financial modeling, capital formation, community engagement, and legal compliance, among others. Project construction skills include contracting, procurement, installation, commissioning, community engagement, and project management. Some of the key skills for the O&M phase are process management, financial and technical software, marketing and customer service, metering, demand-side management, demand stimulation, and performance monitoring and evaluation.

O&M companies (GMG n.d.[b]). The staff responsible for O&M must be properly trained, have detailed procedures in place, and have access to higher-level technical specialists as required. The local staff require training on customer contract signing, revenue collection, cost reporting, installation and quality control of customer connections, and internal wiring.

In addition, the staff responsible for managing the mini grid system must possess knowledge and skills in customer service, the monitoring software or platform, data management, productive uses of electricity, and demand stimulation. The training needs may vary, depending on whether the developers are local or international.

While some engineering and technical skills are shared more broadly with the renewable energy sector; some are specific to mini grid projects. Developers need to understand national policy and regulations to meet legal requirements for their projects, as these are typically very specific to the mini grid sector. The technical knowledge and skills for system design are also very specific to the sector, as they involve generation and transmission network development and standards. Business models, tariff design, community engagement, and demand stimulation are also very specific to the sector, given that the life span of a mini grid project is 15–20 years. The mini grid will have to be expanded if the load or customer base increases, and the battery bank needs to be replaced every 8–9 years based on the life span of the system. Mini grid development also requires the technical skills involved in connecting to the main grid, when and if it arrives.

IDENTIFYING SKILLS GAPS

A shortfall in the skills required for mini grid development can impede the scale-up of mini grids. Capacity needs assessments are important tools to identify skills gaps along the value chain. They reveal gaps in key areas, including technical expertise, management skills, institutional capacity, policy, knowledge, partnership, and implementation (Pew Charitable Trusts 2014). By identifying gaps early in the development process, developers and their partners can create a plan to address the gaps among key stakeholders and help mitigate potential risks in the project.

For example, DESI Power in Bihar, India, conducts a capacity needs assessment based on market surveys that inform targeted training activities to develop local entrepreneurial and small business capacity. By enhancing the skills and knowledge of local entrepreneurs about how to run businesses that use mini grid electricity, DESI Power overcomes a key barrier: low or nonexistent demand in poor communities (USAID 2018a).

Capacity needs can vary depending on the project's ownership model. For example, in some community-based models, the developer will depend on local expertise to operate and maintain the mini grid system as well as conduct business operations, such as tariff collection, administrative duties, and customer relations (USAID 2018e). In these cases, local technicians may need to know how to install distribution infrastructure and how to perform various O&M activities, so capacity gaps in local technical expertise become particularly important. Capacity needs assessments will therefore vary depending on the specific needs of the project, but they nevertheless generally follow the steps outlined in table 7.1.

Capacity needs assessments demand an honest assessment of the gaps between existing capacity, in terms of human resources and institutions, and what is needed to effectively implement scalable and sustainable projects (Pew Charitable Trusts 2014).

Capacity needs can be assessed using mixed methods applied to existing data or freshly collected quantitative and qualitative data. Information can be gathered using key informant interviews, focused group discussions, and surveys. Interviews can target specific project personnel, such as developers, energy-access country coordinators, project managers, or policy shapers in the responsible government ministries (Kang'ethe and others 2017). If capacity needs are not assessed, developers may face unexpected challenges that delay project development.

TABLE 7.1 • Conducting a project- or portfolio-level capacity needs assessment

Step 1: Identify key actors	**Step 2: Determine the project's or portfolio's capacity needs**	**Step 3: Assess existing capacity**	**Step 4: Identify capacity gaps**
Who will build, own, operate, and maintain the mini grid(s)? Who are the customers, potential investors, upstream suppliers, and relevant government entities?	What technical, financial, managerial, and other capacities will actors need, and at what level of expertise? Key areas to consider include policy, knowledge, partnership, and implementation, among others.	What technical, financial, managerial, and other capacities do actors already have, and at what level of expertise?	Which of the required capacities are in short supply or lacking altogether? Are levels of expertise sufficient?

Source: Adapted from Energy 4 Impact and Inensus (2018).

Capacity needs assessments are a critical early step in designing effective training and skill-building initiatives. They reveal gaps in key areas, including technical expertise, management skills, institutional capacity, policy frameworks, partnerships, knowledge, and know-how. Needs assessments generally follow a four-step process: (1) identify key actors, (2) determine the project's or portfolio's capacity needs, (3) assess existing capacity, and (4) identify capacity gaps. They can be carried out using existing data or data collected from interviews, group discussions, and surveys.

Common gaps in the skills and expertise of key stakeholders can lead to considerable delays or missed opportunities to rapidly deploy mini grids, particularly when the mini grids are to be deployed in portfolios instead of one-off projects. To rapidly scale up mini grid development at the national level, gaps in skills and knowledge should be identified for all stakeholders in the value chain—developers, utilities, banks and financial institutions, systems engineers, regulators, policy makers, suppliers, and local communities. The following sections present some of the more common skills gaps for a selection of these key stakeholders.

PROJECT DEVELOPERS

Many small-scale and local developers are missing core skills in project management, risk assessment, and O&M, particularly when it comes to owning and operating a portfolio of mini grids. For example, most mini grid developers in Tanzania that obtained local finance were foreign-owned businesses. Commercial banks cited the poor quality of documentation submitted by local developers as one reason for not extending credit to local developers (Odarno and others 2017). International developers, by contrast, may have more capacity to raise finance and operate portfolios of mini grids but may lack knowledge and skills about how to operate in the local context (Energy 4 Impact and INENSUS 2018). All developers—both local and international—may also lack the skills needed to integrate productive uses across a portfolio of mini grids.

UTILITIES

In countries where national utilities own or operate mini grids, the utility often lacks the expertise needed for mini grid–specific project development, such as community engagement, planning using geographic information system (GIS) mapping, and payment collection (USAID 2018c). For example, even though the Kenya Power and Lighting Company (KPLC) is mandated with implementing mini grids in Kenya, its focus has remained on industrial users and grid extension (Pedersen 2017). Its diesel off-grid power plants operate at a loss, and the reconciling of off-grid electrification planning with grid extension plans has not always been easy (EUEI PDF, n.d.[a]). Another important skills gap for utilities is how to manage what happens when the main grid arrives in the service area of a private-sector mini grid—including the technical and financial capabilities to interconnect with the mini grid or purchase the mini grid's eligible assets. (See chapter 9 for a detailed discussion of options when the main grid arrives.)

BANKS AND FINANCIAL INSTITUTIONS

Local banks can be reluctant to lend to mini grid projects because of a lack of experience in appraising them (UNDP 2018b). As a result, they often consider financing mini grids to be too risky (Odarno and others 2017).

Financial institutions at the national level, such as national development banks, may not be aware of opportunities to invest in mini grid projects. Even if a financing facility or credit line within a bank is created, a lack of skills in conducting due diligence and project appraisal can prevent funding from flowing to developers. In Zambia, for example, training in financial evaluation and project management led the Development Bank of Zambia to increase financing for mini grid projects. In this case, bank staff received on-the-job training by being involved in the appraisal of the three pilot mini grid projects (Draeck and Kottász 2017).

ENGINEERS

Mini grids require technical knowledge for system design, construction, and O&M, and many projects have failed because of poor technical design, improper sizing, and poor maintenance. In many countries, local engineers may lack experience designing and sizing mini grids to the project-specific context, yet because of limited local resources and capacity, they are often made responsible for the design and maintenance of mini grids (Inversin 2000). Meanwhile, training local engineers to conduct O&M can add significant costs for developers, particularly when they need a relatively large number of people with the right technical capabilities to install, operate, and maintain a portfolio of mini grids.

SUPPLIERS

Like any business, mini grids depend on a well-functioning supply chain—not just for their equipment but also for household and productive-use appliances for their customers. Suppliers of generic electrical equipment are often unfamiliar with certain mini grid–specific technologies, such as smart meters and next-generation power electronics, and may not have the capacity to import such technologies. This can reduce competition in the market for mini grid components and limit the availability of locally tailored hardware (UNDP 2018a, 2018b). When this happens, mini grids can be put at risk: component failure or damage can lead to long periods of system downtime when replacement parts are unavailable, which can be compounded by a lack of local expertise and technical capacity (Ricardo Energy & Environment 2016).

Retailers and distributers of household and productive-use appliances may also lack the knowledge and capacity to reach rural populations, and they may not be familiar with highly efficient appliances or larger equipment that can run on mini grid electricity. Filling these gaps can improve the quality of available products and lead to better services.

POLICY MAKERS AND REGULATORS

Policy makers and regulators often do not have the prior experience and skill sets needed to develop and implement comprehensive policies, regulations, and technical standards to create an enabling environment for mini grid scale-up. A lack of knowledge in GIS planning and resource assessment can prevent policy makers from making data-driven and coordinated decisions on electrification planning. For example, a successful mini grids project implemented in India's Sunderbans Delta by the West Bengal Renewable Energy Development Agency in the late 1990s fell apart because of poor coordination between the Ministry of Power and the Ministry of New and Renewable Energy. The conflicting and overlapping electrification efforts of the two ministries resulted in the central grid arriving at villages where mini grids already existed. In those villages, rather than being integrated and complementing each other, the central grid took over mini grids, rendering them obsolete (IT Power and AETS 2015).

LOCAL COMMUNITIES AND CUSTOMERS

In community-based models, technical expertise may not be available to install, maintain, and operate mini grid systems. Community cooperatives responsible for managing mini grids may lack the skills in business and accounting that are essential in collecting payments and maintaining business operations. For example, between 1997 and 2012, more than 250 isolated community-owned micro hydropower projects came on stream in Sri Lanka. The program was designed to create village-level mini grids that would be owned and operated by community organizations, known as electricity consumer societies. However, the societies lacked the technical expertise to integrate the mini grid systems into the national grid infrastructure. When the main grid arrived, more than 100 of the isolated mini grids were closed, as just three societies converted their mini grids into main grid–connected small power producers (Greacen 2017).

Lack of community engagement at the consumer level, particularly around productive uses of electricity, can also impede mini grid scale-up. There is a growing realization that energy-access projects can have a higher socioeconomic impact by including productive uses (Cabraal, Barnes, and Agarwal 2005). Unfortunately, different stakeholders in the mini grid ecosystem often lack the knowledge or technical skills needed to integrate productive uses into the programs to scale up mini grids.

TRAINING AND SKILL-BUILDING INTERVENTIONS TO ADDRESS SKILLS GAPS

How do you empower thousands of people with the right skills in their specific domains to create an ecosystem capable of supporting hundreds or thousands of mini grids? In the following sections we present examples of training programs and initiatives that answer this question in whole or in part—at the national level, at the project and portfolio levels, and at the community level.

NATIONAL-LEVEL TRAINING AND SKILL BUILDING

At the national level, training and skill-building interventions should target government ministries, regulators, utilities, rural electrification agencies, and other agencies that influence the mini grid sector. (See chapter 8 for a discussion of the different government institutions that interact with mini grids.) Most national-level initiatives are financed and supported by development partners and international financial institutions.

Generally, training interventions at the national level cover the development and implementation of policies and regulations that support mini grids, the planning of mini grid projects, and the monitoring and certification processes required. These training needs are illustrated in figure 7.1, along with the relevant stakeholders, and the benefits that training and skills building can provide.

Policy and regulation

Training sessions on policy and regulations should target regulators, ministries, rural electrification agencies, and any other authority that oversees mini grids and participates in national electrification planning. Training plans also need to be updated at regular intervals to reflect conditions in the country and adapt to current targets and plans (IRENA 2018). Mini grids are most successful when they have the support of the national government. Governments can mandate that mini grids be considered part of formal energy planning processes and help support them with financial resources and incentives where required (USAID 2018b).

Currently, development partners are mostly providing training and skills building to policy makers and regulators. The Energy Sector Management Assistance Program (ESMAP)

FIGURE 7.1 • National-level training needs and relevant stakeholders

Policy	Regulations	Planning	Monitoring	Outcomes from trainings
Training needs • National electrification • Business environment • Mini grid–specific *Relevant stakeholders* • Government ministries • Rural electrification agencies	*Training needs* • Licensing and procurement • Tariffs • Technical standards • Grid interconnections *Relevant stakeholders* • Regulators • Government ministries	*Training need:* • GIS mapping • Resources assessment • Financial planning • Institutional and stake-holder coordination *Relevant stakeholders* • Regulators • Rural electrification agencies • Utilities • Banks	*Training needs* • Stakeholder complaints • Technical metrics • Regulation compliance • Financial metrics *Relevant stakeholders* • Regulators • Rural electrification agencies	*Key outcomers from policy and regulatory level training and skill development* • Mini grid development integrated into national electrificationplan • Enabling environment through regulations and policies for mini grid scale up • Transition from project-level training to programmati approach

Source: ESMAP analysis.
GIS = geographic information system.

provides direct support to regulators and ministries, working alongside these entities to develop workable mini grid regulations and national electrification plans in more than a dozen countries. A good example is Economic Consulting Associates. With support from development partners, it has implemented successful training programs for policy makers and regulators (box 7.1).

- In Senegal, Power Africa focuses on capacity building, primarily for government entities (MEDER, Senelec, and CSRE). Through the United States Energy Association, Power Africa has led training sessions with government stakeholders (including the Agence Sénégalaise d'Electrification Rurale and the Agence Nationale pour les Energies Renouvelables and Agence Sénégalaise d'Electrification Rurale). Power Africa also provides advisory support to help connect independent power producers to Senelec.
- The German Agency for International Cooperation (GIZ) provided technical support and training to the Nigerian Electricity Regulatory Commission in developing mini grid regulations (Dalberg Global Development Advisors 2017).
- In Zambia, the national utility ZESCO and Zambia's Rural Electrification Authority, along with other government staff, received training in sustainable energy regulation and tariff setting. A training program was conducted to train technical staff at the Department of Energy, the Rural Electrification Authority, the Energy Regulation Board, and ZESCO to formulate and implement renewable energy projects in the country. The project has had a catalytic effect on the development of several new mini grids in Zambia, particularly solar (Draeck and Kottász 2017).

BOX 7.1

POLICY AND REGULATORY TRAININGS PROVIDED BY ECONOMIC CONSULTING ASSOCIATES

In recent years, Economic Consulting Associates (a UK-based consulting company), has developed policy and regulatory frameworks for mini grids in Rwanda, The Gambia, Ghana, Kenya, Mozambique, and across the Southern African Development Community region. Each assignment has involved a training course on mini grid policy and regulation. Course participants are typically from the public sector—ministries, regulators, utilities, and rural energy agencies—but courses have also included private-sector representatives. Some courses involve representatives of the regulators as trainers.

Course content has included all key policy and regulatory topics: licensing frameworks, business models, procurement, technical guidelines, and economic issues. Much of each course typically focuses on economic issues, including tariff calculation and design, project financing, and subsidy adjustments, with a series of practical examples and modelling exercises. The goals of the training and skill-building workshops are to fully empower stakeholders to implement policy and regulations without the need for further external support, to ensure effective collaboration between all sector stakeholders, and ultimately to ensure electricity is provided to those without access to it.

Source: Economic Consulting Associates.

Planning

Training on geospatial least-cost electrification planning (see chapter 2 on geospatial planning), resource assessment, and financial planning can help government agencies make informed decisions on mini grid scale-up. Resource planning and assessment can help to accurately predict electricity demand, resource availability (solar, wind, hydro), and market pricing, thereby mitigating risk.

In planning and implementation, it is important to recognize the interaction between electrification solutions (grid extension, mini grids, and stand-alone solar systems) and the rapidly evolving technologies and delivery models of off-grid renewables (efficiency improvements, innovations in metering, and end-user financing). Planning requires an assessment of the renewable resources available, for which there are various private providers of resource assessments, as well as public resource tools, especially for solar and wind resources (IRENA 2018). Some of these tools are listed in table 7.2.

Financial and business model planning can help policy makers understand mini grids' profit potential (EUEI PDF n.d.[b]). Training government staff in project planning can help them make informed decisions about business models (see Chapter 8 on mini grid delivery models), tariff schemes (see chapter 9 on mini grid regulations), and financing schemes (see chapter 6 on access to finance). Table 7.3 presents some tools for financial planning.

Monitoring

Government entities tasked with monitoring mini grids' compliance with rules and regulations also require training to avoid unnecessary red tape. Under the Promotion of Solar-Hybrid Mini Grids (ProSolar) program in Kenya, GIZ developed toolkits for solar photovoltaic (PV) and solar-hybrid mini grids and provided training to enable energy policy makers and regulators to do a better job of monitoring mini grid systems (GIZ 2017a). The training sessions highlighted the importance of avoiding processes that were overly burdensome for private-sector developers.

National training programs

Governments may also elect to establish national training and accreditation programs. By certifying mini grid courses and accrediting local training providers, governments can raise the quality of training and expand delivery of standardized courses through accredited local training institutions. GIZ has helped develop solar PV and mini grid training programs in Nigeria and Kenya. Under the Nigeria Energy Support Program, GIZ, in partnership with the United States Agency for International Development (USAID) and Winrock International (Warren 2018), helped the Nigerian government develop certification courses for solar and hydro mini grid technicians, supervisors, and engineers. In addition to compiling training manuals for trainers, GIZ and its partners facilitated the training of trainers in 12 technical training institutions.

TABLE 7.2 • Selection of tools for resource planning

Application	Tool
Resource assessment	Private: 3TIER, AWS Truepower, Digital Engineering, Meteonorm, SolarGIS, and Windlogic Public: Solar and Wind Energy Resource Assessment (SWERA), IRENA Global Atlas, National Aeronautics and Space Administration Earth Observing System (NASA EOS) Web, and Joint Research Centre (JRC) of the European Commission
PV design	PVSyst, PVWatts, PV Sol, and PVPlanner
Wind design	AWS Truepower's Windographer, Wind Atlas Analysis and Application Program (WAsP) from Risø National Laboratory, and WindSim

Source: Adapted from IRENA (2018).

Note: The tools listed in this table provide general resource data of sufficient quality for national-level planning; however, wind and hydro typically require on-site verification.

TABLE 7.3 • Sample tools for financial planning

Tool	Description
RETScreen	RETScreen is a software system for analyzing energy efficiency, renewable energy, cogeneration project feasibility, and energy performance.
NREL CREST	The National Renewable Energy Laboratory's Cost of Renewable Energy Spreadsheet Tool (CREST) is an economic cash-flow model designed to allow policy makers, regulators, and the renewable energy community to assess project economics, design cost-based incentives (such as feed-in tariffs), and evaluate the impact of various state and federal support structures. CREST has separate tools for solar (photovoltaic and solar thermal), wind, geothermal, and anaerobic digestion technologies.

Source: Adapted from GIZ (n.d.).

Further, training interventions can be developed to train policy makers on implementing policies that promote socioeconomic development. This has been demonstrated by Smart Power India (SPI), a Rockefeller Foundation initiative that supports the government in developing policies and regulations to align the government, investors, and developers. SPI also provides skill-building interventions to mini grid companies (energy service companies) on key aspects of project development, such as financing, business modeling, site and cluster selection, procurement, and training for technicians and customers. SPI's programs have been very successful, leading to more than 178 renewable energy mini grids with 6 megawatts of cumulative capacity. The electricity from these grids is transforming the lives of more than 80,000 people by providing electricity for lighting and to power fans, electric pump sets, and appliances and motors for productive uses (SPI 2019).

PROJECT-LEVEL TRAINING AND SKILLS BUILDING

A comprehensive mini grid training curriculum should aim to cover the whole project life cycle, from project development and construction through operation (Energy 4 Impact and INENSUS 2018). The training and capacity-building needs vary by project and ownership model. At the project level, interventions should target local communities, developers, system designers and engineers, suppliers, and installers. Assessments of capacity needs can help stakeholders develop customized training at the project level.

Training materials should be interactive and appropriate for adult learners. The materials used for training power plant operators, especially, should be practical and adapted to the project context as much as possible. All the materials, including equipment catalogs and O&M manuals, should be translated into the local language (ADB 2017).

Each phase of the project cycle can benefit from specific interventions. Figure 7.2 illustrates the main phases in project and portfolio development, along with the training needs and relevant stakeholders at each phase.

Each phase in the figure and its respective training and capacity-building needs are described in the following sections.

Site identification

Developers, technical experts, and local communities can be trained to identify appropriate projects and sites for mini grid development. Some tools that can help in site identification and development are described below. Their outputs depend on the reliability of the input data. Training for field investigators can improve reliability (Gambino and others 2019).

- HOMER (Hybrid Optimization Model for Multiple Energy Resources) is a software program that facilitates the analysis of planning for distributed generation and mini grid systems. HOMER Energy offers certified training on how to use its software for analysis. Participants learn how HOMER calculates the technical feasibility, economic value, and other metrics of different designs through its powerful sensitivity analyses and its ability to simulate and optimize thousands of systems designs in minutes.[1]
- Odyssey Energy Solutions is an online platform providing a comprehensive suite of tools to help project developers design, build, and operate rigorous, systematic, and data-driven microgrids.[2]
- Powerhive's "Site Wizard for Analysis, Reconnaissance, and Mapping" (SWARM) software enables project developers to remotely identify customers and site locations over broad regions. SWARM analyzes sites based on

FIGURE 7.2 • Project- and portfolio-level training needs and relevant stakeholders

Identification	Feasibility	Construction	Operaton & Maintenance	Outcomes from trainings
Training needs • Site identification • Site selection *Relevant stakeholders* • Developers • Technical experts • Local community	*Training needs* • Technical/ technological assessment • Socio-economic analysis • Financial analysis • Demand estimation *Relevant stakeholders* • Developers • Technical experts • Financial experts • Local community	*Training needs* • Technical design • Business models • Procurement • Construction *Relevant stakeholders* • Developers • Technical experts • Suppliers • Installers • Local community	*Training needs* • O&M software • Customer relations • Demand stimulation *Relevant stakeholders* • Local technician • Local community	*Key outcomes from project-level training and skill development* • Improved capacity and skills of technical experts • Adoption of appropriate and sustainable business models • Trained and certified suppliers and technicians • Informed cusomers and increased ownership at the community level

Source: ESMAP analysis.

financial, technical, and geospatial data. It then calculates optimal mini grid locations, reticulation design, and estimated system size, resulting in a prioritized list of the most viable sites. The data from the analysis are used to streamline the customer acquisition process, saving time and radically lowering project development costs.[3]

Project developers and public agencies responsible for rural electrification planning can benefit from training and skill building in project identification. In Nigeria, the Rural Electrification Agency (REA) benefitted from technical support and skill-building interventions from development partners and organizations such as the Rocky Mountain Institute. Topics included data on households, commercial users, potential system size, peak load, and geospatial analysis to identify sites appropriate for mini grids.[4] The REA is presently engaged in project and site identification for 250 sites throughout Nigeria. By 2030, it will help scale mini grids to more than 10,000 sites powering 14 percent of the population (Ogunbiyi 2017).

Feasibility assessment

Once projects are identified, developers need specific skills and knowledge to assess feasibility. Geospatial analysis is increasingly used for detailed preliminary studies before survey teams are dispatched to the most promising sites (see chapter 2 on geospatial planning). An example of training for these activities at the national level comes from a project in Rwanda. The Private Sector Participation in the Generation and Distribution of Electricity from Renewable Sources project provides training to mini grid developers on assessing the feasibility of renewable energy mini grids, with the goal of increasing the bankability of their project proposals (BRD 2016). At the international level, the Renewables Academy Online (RENAC n.d.) provides online training courses, resulting in professional certificates for PV and PV-diesel–hybrid systems.

Training programs on feasibility assessment have four key components.

- *Technical and technological assessment:* Technical software helps developers design systems to meet existing and projected demand. The key is to ensure that the design is carried out by technicians with skills and experience in the relevant technology for planning, installation, commissioning, and O&M.
- *Socioeconomic analyses:* Socioeconomic data and analysis can provide quantitative and qualitative information that can be helpful in designing projects and estimating current and future demand. Conducting socioeconomic surveys helps developers gather information on mini grid customers, their willingness to pay, and their current spending on alternative sources of electricity.
- *Financial analysis.* Mini grid project developers often lack experience in financial analysis, risk mitigation, and business plan development—and they may not be able to afford outside financial professionals. Developers or their relevant staff members need training and skill-building support in financial modeling, capital accumulation, and proposal writing.
- *Demand estimation and projections.* A critical step in any mini grid project is to gauge demand for electricity. This demand assessment should cover all households, productive users, and social institutions in the service area. The project developers must estimate project costs, connection costs, and the electricity tariffs. To gather more reliable data, developers should set the business model before conducting the surveys (Energypedia 2016).

Construction

Training interventions aimed at imparting the skills and knowledge required to build and commission a mini grid typically assume a minimum level of prior knowledge of electrical systems. As a result, such interventions can be built into, or alongside, existing courses for engineers and technicians. In some cases, depending on the developer's business model, training on how to build and commission a mini grid may also include training on how to operate and maintain the system. Training and skill-building interventions should, at a minimum, cover the following:

- *Technical design.* A mini grid's size dictates its maximum power output. The generation system must have sufficient installed capacity to meet loads. To size the system, planners must calculate load variations in half-hour intervals and estimate future load growth. Estimating and planning for current and future loads are critical steps, especially for financial viability. Developers can estimate current loads by surveying and assessing current and potential customers (USAID 2018d). Anticipating future loads is more difficult.
- *Procurement.* All mini grid projects involve acquiring equipment and services from external sources, often via a tendering or competitive bidding process. Developers may issue tenders for individual components of the mini grid and then install and commission the system themselves (GMG n.d.[c]).
- *Installation.* Mini grids should be operated under the supervision of certified and experienced technicians. It is also important before work begins that the technicians test delivered equipment and locally produced products (such as foundations, channels, and bricks) and provide safety training to all personnel, including local support staff.

The purpose of technical professional development is to ensure that system designers are well trained on all the available technologies, such as solar-hybrid, inverter technologies, storage technologies, and grid connection methods. System designers should also consider available materials, capabilities, and know-how at the community level, which can reduce the implementation cost and, later, the cost of training end users.

System designers and engineers holding university degrees or higher training certificates are well positioned to advance mini grid technology in the country. In addition to engineering training offered through universities and polytechnics, technology companies can provide training in their products and technologies.

For example, to overcome the technical knowledge gap in the mini grid sector in Chad, 35 public and private stakeholders were trained in the use of HOMER software, described earlier. Training included a course for 44 people on the management of mini grids based on renewable energy. Further training was carried out at project sites. Six people per site conducted training sessions on managing solar installations, maintaining and managing technical teams, and financing mini grids. The training prioritized gender mainstreaming.

Operations and maintenance

Training in operating and maintaining mini grid systems is essential to their long-term sustainability. Training and skill building can be done online, face to face, or as a combination of the two. Sessions may be provided by governments (Nepal, Mali), private groups (such as Trama Techno-Ambiental, Mee Paynar, and the Institute of Electrical and Electronics Engineers [IEEE]), universities (University of Strathmore, Arizona State University), training institutes (Renewable Energy Solutions for Africa and the Economic Community of West African States [ECOWAS] Centre for Renewable Energy and Energy Efficiency), as well as some development partners (such as GIZ).

Online training platforms can provide technical training to help solar companies and organizations manage their staff and assets. LEDsafari is a Swiss-based startup in clean energy that develops digital products for such purposes. It has developed a multilingual online training platform called HelioLearn that provides technical and business courses on solar energy. HelioHealth is a cloud-based sensor for solar panels. Panel-level monitoring, combined with advanced machine learning and data analysis, helps solar companies track the performance of their devices and to diagnose faults (LEDsafari n.d.).

To address the lack of qualified candidates for its O&M team, Husk Power has recently established its own university for training technicians. Husk's predicament highlights the frequent absence of comprehensive training programs, which places the burden of training technicians on developers.[5]

COMMUNITY INVOLVEMENT AND AWARENESS

Training programs for communities typically center on raising awareness about mini grid electricity and how it can be used for household activities and for income-generating activities. (See chapter 4 for a full discussion on community engagement and training.)

Awareness of household uses of electricity

Educational campaigns can inform local communities of the range of uses of electricity, which may increase their willingness to pay. For example, sessions might focus on how electricity can improve agriculture and sanitation through water pumping, improve health and education, and support the development of new businesses. Targeted training helps local communities understand their energy use and can move them to a higher tier of energy consumption, including productive uses, as seen in the PowerCorner project in Arusha, Tanzania. PowerCorner goes beyond providing electricity: it not only sells energy-efficient home appliances through loans to the villagers but also invests in training customers on how to use the electricity efficiently (Lebleu 2018). Communitywide education campaigns can teach people to use electricity safely and demonstrate how it can improve their well-being through education and health. Communities new to electricity may need instruction in the safe use of electrical appliances and household wiring.

Various engagement strategies are being tested to increase community involvement in the development of mini grids. Quicksand is a user-fed, video-based digital platform that showcases different users' stories to demonstrate the benefits of mini grids around the world (Quicksand 2018). This digital platform's goal is to propagate the use of mini grid electricity in businesses and homes in communities that receive either irregular or no grid electricity. Quicksand visited 10 communities served by mini grids to learn, share, and test its platform. The project resulted in a smartphone app, a dedicated digital platform to host mini grid videos, and 22 films on individuals' experiences with mini grids. Of the final 22 films produced, 11 were made by users with the developed app, with minimal help from Quicksand, illustrating the potential of this app-plus-website to scale rapidly with minimal intervention (Quicksand 2018).

Trama TechnoAmbiental employs a more hands-on, train-the-trainers approach aimed at communities that will be served by mini grids, as described in box 7.2.

BOX 7.2

LESSONS FROM COMMUNITY TRAINING BY TRAMA TECHNOAMBIENTAL

Trama TechnoAmbiental (TTA) demonstrates how strong capacity building and engagement of the local community from the initial phases of a mini grid project can lead to well-maintained and sustainable mini grid systems. Training and enhanced awareness among the beneficiaries of a mini grid are important in minimizing the vandalism of assets and managing community expectations.

TTA trains in two stages. First, local actors receive a more theoretical training, followed by a second, customized training that reflects the actual operation of the relevant system. In the first stage, training is offered to (1) end users on the possibilities and limitations of the system and on the uses of electricity, (2) the entity that will be responsible for operation and maintenance (O&M), and (3) the local technicians who will perform the O&M work. In the second stage, after about six months, TTA visits the project, addresses any problems that have arisen, and completes the training.

The TTA training model is part of the mini grid project itself and is included in the overall project financing. According to TTA, this model has been cost-effective, has reinforced the governance structure within the community, and has helped build local capacity. Further, local demand has continued to rise, indicating that the consumption categories were correctly estimated and that end users are satisfied with their electricity services.

TTA has also noted some limitations to its approach. Despite the training provided and the small local structure set up for O&M, if a major technical problem occurs, the community is unlikely to be able to resolve the issue or find replacement components quickly. Although a local committee is responsible for ensuring that funds put aside are used as intended, there is always the risk that funds for future replacements may be used for other needs that may arise in the community.

Source: TTA 2019.

Awareness of productive uses of electricity

Providing access to electricity does not guarantee that communities will move on to productive uses of energy, as discussed in chapter 3. Encouraging productive uses requires a multifaceted approach, including strategies to create awareness of how mini grid electricity can help increase revenues for local entrepreneurs and small businesses. Box 7.3 provides an example of such a training program developed by the IEEE.

Trainings targeted at productive-use customers help them identify income-generating electric appliances, access capital to acquire the equipment, and use the mini grid–powered equipment to cut costs, grow the business, and diversify. For example, Energy 4 Impact offers entrepreneurs training in business management skills (such as record keeping, marketing, and customer care), appliance use, and health and safety standards to customers of Mesh Power. Currently, MeshPower operates more than 80 solar mini grids that supply electricity to more than 2,400 households and small businesses across Rwanda (MeshPower 2022). (See chapter 3 for an in-depth look at productive uses of mini grid electricity.) In another example, a United Nations Development Programme (UNDP) initiative in Nepal provided skills training to households and reported that more than 80 percent of the trainees started a business in the community. New activities included bakeries, preparing broiler chickens, agricultural processing mills, sawmills, photo studios, and producing incense sticks (Fishbein 2003).

Mentoring is needed to help build the commercial and technical skills of local entrepreneurs, to train them in using electrical appliances, and to help their businesses navigate the challenges of early development. Mentoring could be provided by governments, nongovernmental organizations, or potentially developers themselves if they had the necessary capacity and knowledge (Booth and others 2018).

The UNDP experience shows that the training and skills development of different local stakeholders lead to not only improved O&M but also increased productive use of energy from mini grid systems. Targeted trainings on productive uses and machinery played a critical role in community capacity building. In Sri Lanka, the mini grid community is fully involved and has received training in mini grid O&M. All assets were transferred to a consumer committee to operate and maintain the system. Since the project was also servicing irrigation systems, the training also included

BOX 7.3

PRODUCTIVE-USE TRAINING FROM IEEE SMART VILLAGE

IEEE Smart Village is an initiative of the Institute of Electrical and Electronics Engineers (IEEE) Foundation. It aims to reach 50 million people by 2025 through electrification, community-based education, and sustainable enterprise centered on productive uses of electricity. IEEE Smart Village supplies philanthropic venture funding, mini grid equipment, pro-bono consulting, and extensive education and training resources to launch and grow locally operated micro-utilities.

Igniting Africa is an IEEE Smart Village program. Launched in Bamenda, Cameroon, it delivers community electrification through mini grids serving 22,500 people. The program provides numerous vocational training programs designed to demonstrate the scalability of technical and business education. A train-the-trainer methodology is combined with hands-on courses for youth who return to their home villages with seed funding to start their own businesses centered on mini grids and productive uses of energy.

Recognizing that electricity is an enabler and a means toward economic empowerment (rather than an end in itself), IEEE Smart Village structures its programs not just to provide electricity, but also to drive community-based education and development of local entrepreneurship. The array of microentrepreneurial activities targeted by IEEE-funded trainings includes artisan crafts, construction, electrical wiring, electronics assembly, electric transportation, information technology services, retail services, sustainable agriculture, and tourism.

Source: IEEE.

FIGURE B7.3.1 • Future community entrepreneurs and mini grid technicians participate in a classroom discussion at a training program offered by Igniting Africa

Source: Used with permission from IEEE.

irrigation infrastructure monitoring and water use management. In India, 30 community members from two project sites received training to use the renewable energy generated from micro-hydro mini grids for productive purposes. These participatory trainings included marketing strategies and business models (Draeck and Kottász 2017).

Gender-related training and capacity building

Mini grid projects have been successful in empowering women and supporting female-led businesses. Training and skills-building interventions can be developed specifically to provide trainings on how to benefit women and should also incorporate gender-sensitive training. For example, the US-based nonprofit Earthspark owns and operates a mini grid in Les Anglais, Haiti, serving 449 homes and businesses with affordable, reliable electricity. Earth Spark has made a commitment to integrate gender equality in every aspect of its operations. Local women have been trained and employed to install parts of the grid, and 4 of the 10 members of the community management committee are women. Earthspark has also supported local female entrepreneurs to start small businesses using power from the grid and has become a strong advocate of gender inclusion for grid operators based on this experience (ESMAP 2017). The Global Environment Facility and United Nations Industrial Development Organization project in The Gambia has also succeeded in building the knowledge and in-depth technical capacity of the regulators and the utility (NAWEC). The project had a training program that focused on women. As a result of this program's success, the government decided to use 50 percent of its overall renewable energy fund for projects focused on skills building for women.

Other initiatives that have been successful in incorporating and customizing gender-based skills building and training support are the Barefoot College and Solar Sisters. Barefoot College stands out because it has recently announced plans to create a network of more than 2,000 female engineers and entrepreneurs and has affected 200,000 households. Together, Barefoot College and Solar Sisters will establish 100 "solar demo hubs" in rural areas, starting in India's Rajasthan state, with plans to expand to five states in India and 10 countries internationally (Power for All 2017). A new study in Ghana by Power Africa and Black Star Energy has revealed the significant impact of electricity access on women-owned businesses and incomes, including helping them move from extreme poverty to near-middle-class status, while allowing them to stay in their rural communities (Poindexter 2018).

LESSONS LEARNED FROM EFFECTIVE TRAINING AND SKILLS-BUILDING PROGRAMS

Skills-building programs are useful for a wide set of stakeholders, including regulators, rural electrification agencies, policy makers, academic institutions, finance institutions, developers, engineers, technicians, and end users. Many governments (for example, Kenya, Ghana, India, and Nepal), private entities (such as Schneider Foundation, SELCO, KITTEC, IEEE), and educational institutions (such as Strathmore University and Arizona State University) are providing training and skills-building programs and courses to mini grid stakeholders worldwide.

There is currently no widely recognized mini grid industry training standard. While nearly all vocational courses are locally certified, professional development courses are often not certified and there is no regional certification system for mini grid training. Many mini grid training programs have a narrow focus on technical training for engineers and do not cover other key factors for developing mini grid projects (Energy 4 Impact and INENSUS 2018). However, to build the skills and capacity of local entrepreneurs in the off-grid and mini grid sector, the SELCO Foundation has started an incubation center that uses SELCO's shared resources, management expertise, intellectual capital, and bottom-up learning to enhance the capacity and vision of potential local entrepreneurs. Their process follows identification, initiation, incubation, growth, and analysis for selected candidates.[6]

A review of training programs conducted by Energy 4 Impact and INENSUS for the African Development Bank indicated that most were offered locally via face-to-face trainings (Energy 4 Impact and INENSUS 2018). Some professional development training providers, however, use a blend of face-to-face and online training. Blended delivery allows for more flexibility in terms of when, where, and how different types of training are conducted. For example, theoretical training can be offered remotely or online, while practical work is done in the classroom or the field. The blended approach helps the training providers keep their costs down and widen the audience of potential students. The success of any program involving online content depends on the training providers and students having access to power, computers, and the internet (Energy 4 Impact and INENSUS 2018). Box 7.4 details the blended approach taken by IEEE.

Standardized training methods and accrediting improve the quality of training and standardize training processes through accredited institutions. However, there is still no clear path on how this certification should be done. Three options that have emerged from ESMAP's conversations with mini grid sector stakeholders are: creating a nationally recognized mini grid certificates similar to the ones for solar engineers; introducing regional as well as national certificates, although this assumes the relevant national institutions can agree on common quality standards; and creating regional training programs that can be delivered through a common platform and integrated through local certification or standardized tests.

In addition, training should not be considered a one-off event, and people trained under any mini grid project or program need follow-up and refresher courses after the training. For example, TTA, a global consulting and engineering company,[7] delivers training in two stages. First, during the project preparation and implementation phases of the project, training on system limitation and use is delivered to end users and training on O&M is provided to local technicians. Second, after about six months, TTA visits the project, responds to any problems that have emerged, and completes the trainings based on the challenges identified in the first six months of operation (Wiemann, Rolland, and Glania 2014).

In another example where training and skills development are undertaken by the state agency, India's Chhattisgarh State Renewable Energy Development Agency (CREDA) runs an Installers Certification Programme, designed for personnel who are specifically assigned to carry out the installation and commissioning of projects. CREDA also provides refresher-training programs every six months for technicians, operators, and Village Energy Committee members. CREDA has electrified around 35,000 households across more than 1,400 villages and hamlets with low-capacity (1–6 kilowatts-peak) solar mini grids in Chhattisgarh (Palit and Sarangi 2014).

BOX 7.4

COMPONENTS OF IEEE SMART VILLAGE'S COMPREHENSIVE TRAINING PROGRAM

Members of a newly electrified community frequently lack not only technical knowledge and business skills, but also education fundamentals, including basic literacy and numeracy. To address this need, the IEEE Smart Village has developed an extensive set of online and classroom-based curricula and education programs spanning from kindergarten to retirement, covering technical skills, vocational training, and K–12 education.

To date, IEEE Smart Village training initiatives have conducted eight comprehensive training programs in seven countries, reaching more than 97,000 people, including almost 12,000 students and youth.

Technical education delivered to communities is developed by local subject matter experts and tailored to the local environment, culture, and language. Technical training provided by IEEE community entrepreneurs covers a broad range of topics, including installation, operation, and maintenance of mini grids; siting and sizing of wind turbines, hydro turbines, and solar arrays; battery system configuration and maintenance; commissioning and use of customer billing and payment systems; computer-aided design; assembly and repair of electronics; and development of computer software and applications.

Vocational training programs are designed to maximize the opportunities for community members to engage in new entrepreneurial activities that are made possible by access to electricity. The course offerings combine hands-on activities with basic business skills and fundamental literacy, numeracy, and social skills.

The majority of schools at all levels in IEEE-funded communities lack critical education resources, including electricity, internet, clean water, safe sanitation, required textbooks, course materials, or access to mandatory government curricula and exams. Access to electricity from mini grids enables the creation of digital classrooms with electronic copies of government curricula, textbooks, and scripted daily classes to assist teachers with limited pedagogical proficiency. IEEE Smart Village entrepreneurs have implemented a range of innovative education technologies, including EmpowerSchool (developed by EmpowerPack Social Purpose Corp.), Rachel PI (by World Possible), Blue Box (by Worldreader), and TalkingBook (by Mavis Computel Ltd.).

All IEEE Smart Village community entrepreneurs actively participate in a collaborative network promoting open sharing of lessons learned, best practices, training curricula, and business plans for both mini grid construction and microbusinesses focused on productive uses of energy. This forum for open innovation and information exchange enables each successive round of new projects to increase the replicability, scalability, and sustainability of mini grid applications worldwide. Additionally, project managers and community leaders have access to a practitioner-oriented Masters of Development Practice online program through Regis University and the IEEE Smart Village global classroom at the Posner Center for International Development in Denver, Colorado, for 2 percent of the cost of a traditional degree. Praxis courses in monitoring and evaluation techniques are also provided to help accelerate collection of metrics and impact data.

Source: IEEE.

DATABASE OF TRAINING PROGRAMS

ESMAP has developed a database of more than 50 training courses and entities that provide trainings that are relevant to the mini grid sector. These training programs are available all over the world—and many can be delivered remotely. They target policy makers and regulators, developers, engineers, and operators. Most of the training programs provide a formal certificate upon satisfactory completion of the course. This database is available on the companion website to this handbook: www.esmap.org/mini_grids_for_half_a_billion_people. The following are some examples:

The **National Power Training Institute of Nigeria (NAPTIN)** is a federal government institution that reports to the Federal Ministry of Power, Works and Housing and operates nearly 10 regional training centers across the country. NAPTIN is also responsible for helping the ministry develop policy to build capacity in the power sector.[8]

NAPTIN increasingly seeks to take a private-sector-driven approach to its training and operations to best meet the demand of the privatized power sector (Ley, Gaines, and Ghatikar 2015).

The **ECOWAS Certification for Sustainable Energy Skills Program** has been established by the ECOWAS Centre for Renewable Energy and Energy Efficiency in partnership with the International Renewable Energy Agency and GIZ. The program aims to improve the technical competency of various renewable energy professions across the ECOWAS member states. The scheme is being piloted in Ghana and Senegal for certification of stand-alone solar PV technicians who will be required to clear a written and practical examination based on a regionally harmonized job-task analysis that details competencies for installation, maintenance, safety, and basic design of off-grid solar systems. Subsequently, the certification will be expanded to other solar PV technician profiles, such as on-grid solar PV and mini grids (IRENA 2019).

The **Micro-Grid Academy** (MGA) is a regional capacity-building platform that provides theoretical and practical training on energy access and decentralized renewable energy solutions to young East African and international technicians, entrepreneurs, and engineers. The project aims to enhance access to energy in rural communities fostering local enterprise and job creation. Located in the KPLC's Institute of Energy Studies & Research in Nairobi, Kenya, the MGA is coordinated by the RES4Africa Foundation, in partnership with Enel Foundation, the national Kenyan utility KPLC, Strathmore University, AVSI Foundation, and St. Kizito Vocational Training Institute, and endorsed by the East Africa Center of Excellence for Renewable Energy and Energy Efficiency. To support the theoretical lectures with practical learning, a real 30-kilowatt hybrid mini grid will be installed on site thanks to the contribution of RES4Africa members.[9]

Founded in 1994, Peru's **Center of Demonstration and Qualification in Appropriate Technologies** (CEDECAP) aims to develop technical and managerial skills in leaders, students, manufacturers, technicians, professionals, and officials of Latin America.[10] The most noteworthy aspect of CEDECAP is the hands-on approach that the training provides in real facilities. Practice lessons are carried out in real systems. As a result, students learn exactly how systems work and how they should be operated once installed in the communities. Their methodology is to spend 70 percent of the training time in fields of expertise and 30 percent in the classroom. The energy module comprises three environments with equipment in hydraulic, solar, and wind energy (Escobar and others 2012).

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NOTES

1. More information about the HOMER Energy training is available at https://www.homerenergy.com/services/training.html.
2. More information is available on the Odyssey Energy Solutions at https://www.odysseyenergysolutions.com/.
3. More information about Powerhive is available at http://www.powerhive.com/our-technology/.
4. Information about the mini grid tender as part of the National Electrification Project is available at http://rea.gov.ng/minigrids/.
5. More information about Husk Power is available at http://www.huskpowersystems.com.
6. More information about SELCO's incubator is available at https://www.selcofoundation.org/incubation-about/.
7. More information about TTA is available at http://tta.com.es/.
8. NAPTIN's 2016 training schedule includes a 15-day course focused on renewable energy (operation and maintenance of solar, wind, and hybrid systems).
9. More information about RES4Africa's Micro-Grid Academy is at https://www.res4africa.org/micro-grid-academy/.
10. More information about Peru's CEDECAP is available at https://www.cedecapltda.cl/aula/.

CHAPTER 8

DELIVERY MODELS AND SUPPORTING INSTITUTIONS

CHAPTER OVERVIEW

This chapter has two principal parts. The first describes models commonly used to deploy mini grids in low-income countries. In most cases, mini grids have been developed with support from and regulation by government institutions. Other entities have also provided support. The second part of the chapter follows from the first. It answers the question: What are the desirable features of an institutional framework to support mini grids?

MINI GRID DELIVERY MODELS

The chief differences among the numerous delivery models for mini grids lie in who finances, builds, and operates them (Tenenbaum, Greacen, and Vaghela 2018). The models discussed in this section are the build-own-operate model; the public-private partnership model; the concession model; utility models with and without private-sector involvement; and the cooperative model.[1] Each is discussed in turn.

THE BUILD-OWN-OPERATE MODEL

In the build-own-operate model, a private mini grid developer carries out all the steps—designing, financing, and operating the mini grid. The developer might subcontract some activities to third parties but retains control over and responsibility for the entire process. In many cases, the government or other entities provide subsidies to the developer, to customers, or both. In instances where the model is implemented by a public institution, that institution is also responsible for program management and implementation (box 8.1 gives an example from Tanzania).

In this model, because developers have full responsibility for all aspects of project development, the role of government institutions, apart from grant finance, is that of facilitator and enforcer, ensuring the developer's compliance with local policies and regulations.

PUBLIC-PRIVATE MODELS

Management and split-asset are two common public-private models.

Under the **management model**, a government entity plans, finances, and implements a mini grid up to the commissioning stage, with a private operator subsequently assuming responsibility. The operator first has to manage, maintain, and operate the entire mini grid, including generation and distribution. Second, it collects revenues from the mini grid's customers. Contractual options can oblige the operator to assume responsibility from the governmental entity, options that range from authorization arrangement to contracted operation, leasing contract, and, finally, transfer to full ownership (EUEI PDF 2014). A recent example is the Rural Renewable Energy Project implemented in Sierra Leone, with the assistance of the United Nations Office for Project Services.[2]

Under the **split-asset model**, a governmental institution procures and owns the distribution assets of a mini grid, while the developer owns the generation assets. This split reduces investment costs for the developer, thus improving the mini grid's financial viability from the developer's perspective. This model has been used by GIZ (the German Society for International Cooperation) in Nigeria.

BOX 8.1

THE BUILD-OWN-OPERATE MODEL IN TANZANIA

Tanzania recently implemented a build-own-operate scheme managed by the country's Rural Energy Agency (REA) and financed by the U.K. Foreign, Commonwealth & Development Office (FCDO) and the Swedish International Development Cooperation Agency (SIDA). FCDO and SIDA have handled the general oversight of the program. REA is the implementer, selecting the grant awardees, managing the distribution of the grant, and monitoring implementation of the program.

Tanzania's Energy and Water Utilities Regulatory Authority ensures the mini grid developer's compliance with local technical and tariff regulations and issues licenses (for sites of 100 kilowatts-peak (kWp) to 1 megawatt) and certification (for sites below 100kWp) to the mini grid developers' sites. The local national environment management councils issue environmental permits for the mini grids deployed. Throughout the whole scheme, the Tanzanian Ministry of Energy takes a back seat, providing guidance and advice to the REA and other institutions only as needed.

Mini grid developers identified and selected their own sites; REA gave them guidance on national electrification plans to ensure that they would not implement projects in areas where the national utility (TANESCO) would soon extend the main grid.

Both models require careful thought regarding risk profiles. Developers responsible for both the construction and operations and maintenance (O&M) of the assets tend to take on more risk over the lifetime of the project. Government entities constructing the mini grid, and then transfering some or all of it to an operator—or as an alternative entering into a management contract with the developer/operator—introduces risks. In response, certain private-sector developers and operators may seek to mitigate these risks because they did not oversee construction of the infrastructure. Without mitigation, operators might incur higher O&M costs resulting from government-built infrastructure.

Moreover, recent experience with the IFC's Scaling Mini Grids program has identified a dearth of investment-ready contractual frameworks arising from public-private partnerships (PPP). In fact, contracts between governments and developers tend to offer scant protection for investors, often blocking large-scale investment: they are, in truth, not bankable for long-term infrastructure capital providers. Moreover, government entities charged with managing the PPP can lack the capacity to develop and deploy the contracts. As a result, technical assistance is often needed to develop investment-ready contracts and to build robust capacity within the government entities that manage the contracts.

In general, the public-private model can be viewed as an effective way to assign responsibilities and, in doing so, to boost capacities, especially since it allows financially constrained mini grid operators entry into the market.

CONCESSION MODEL

Under a concession model, the government issues a concession to a developer providing particular contractual rights to beneficial terms, such as monopoly status, preferential market access for a limited amount of time, or specifically designed tariffs that may differ from those set for the rest of the country (EUEI PDF 2014). Concession models have not attracted much private investment so far. This lack of investment, however, is not likely a function of the model but instead more about risk allocation and mitigation.

Usually, the rural electrification agency plays a central role in initiating mini grids under concession models, whereas the concession contract is usually signed by the concessionaire and the ministry of energy, representing the government.

UTILITY MODELS WITH OR WITHOUT PRIVATE-SECTOR INVOLVEMENT

In a utility model, the national utility usually shoulders all aspects of the mini grid, although the utility may tender out the engineering, delivery, installation, and commissioning of all mini grid assets. In some cases, a private-sector company must operate the mini grid for some time before handing it over to the utility. In other cases, the utility takes over operation right after commissioning.

Kenya is using this model in developing 137 mini grids under the World Bank-supported Off-grid Solar Access Project for Underserved Counties program. Up to $80 million is allocated for private sector developers to bid on Engineering-Procurement-Construction contracts with the Kenya Power and Lighting Company (KPLC) and the Rural Electrification and Renewable Energy Corporation (REREC). The 137 sites are divided over thirteen lots in 14 low-income counties. Bidders are asked to install the solar mini grids including KPLC certified prepaid/smart meters as well as provide for a social infrastructure project as selected by the county.

In Nigeria, some distribution companies (which are privatized) are beginning to consider mini grids as a way to serve their rural areas. We know of one distribution company saying it has a potential portfolio of 340 sites with historical data on consumption patterns. This data could prove valuable in reducing demand risk. The exact construction and operations model is not yet defined in this case, but this is an example of how the utility model in general can encompass private-sector distribution companies looking to engage private-sector mini grid developers.

Government control of mini grid utility models is usually exercised by the energy ministry directly, often through its direct control over the national utility. Therefore, in most cases, no additional institutions are involved in overseeing mini grids under this model.

COOPERATIVE MODEL

Under this model, one or more local communities finance and own mini grids. They procure most of the required capital through grants. The motivation of the cooperative members is to get access to electricity for themselves. In some cases, only members of the cooperative are connected to the mini grid. In other cases, the cooperative connects customers who are not members. Procurement and installation of the mini grid are often contracted out to a third party, either from the community itself or via a nongovernmental organization (NGO) or development partner. Through ongoing training, the cooperative is then capacitated to assume O&M for the mini grid (see also chapter 7).

> There are various delivery models for mini grids, where *delivery model* denotes who finances, builds, owns, and operates the mini grid. The five most common delivery models for mini grids are: (1) build-own-operate, where a private sector entity raises money to carry out all of the activities; (2) public-private partnership model—including models where (a) the government sets up the mini grid and hands it over to a private-sector operator, and (b) a split-asset model where the government and private sector co-own the mini grid; (3) a concession model, where the private sector enters into a contractual relationship with the government to deliver electricity in a specified area; (4) a utility model, where all or part of the mini grid ownership and operations is controlled by the national utility; and (5) a cooperative model, where local cooperatives build, own, and operate mini grids.

Cooperative models have been implemented successfully in Burkina Faso, Indonesia, Peru, and the Philippines, among other countries. This model requires larger cooperatives that operate like a professional company in that they possess adequate management and technical capacity. In the Philippines, some cooperatives resemble professional public utilities in other industrial countries; they run mini grids in parallel to their main grid business. At this size, however, it looks rather more like a utility model than a typical cooperative model as described here.

Cooperatives can operate under various institutional frameworks. They can be strongly government induced and influenced, as in Ethiopia, or independent, as in the Philippines. In the first scenario, the ministry of energy (or a separate ministry for cooperatives) takes the lead from the government side. In the second scenario, the cooperatives are subject to little supervision from the local government or, if several cooperatives are in one country, they report to a dedicated authority. Cooperative-led mini grids can be fully funded by grants or can rely in whole or part on the cooperative's own equity or debt

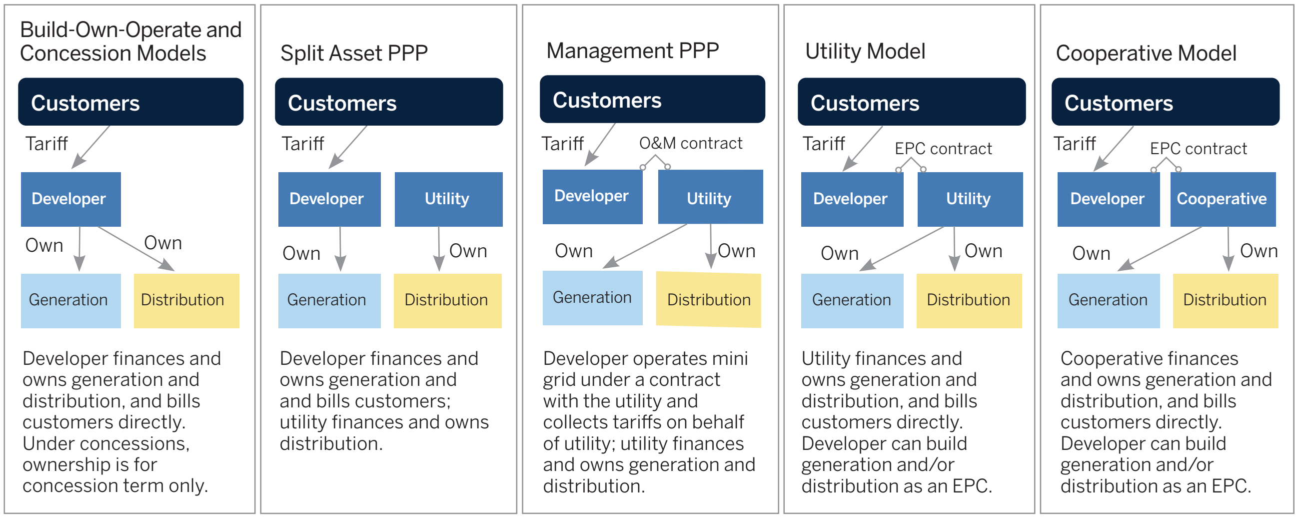
COMPARISON OF VARIOUS MODELS

Figure 8.1 illustrates the different roles for developers and utilities under the various models discussed above.

To help decision-makers weigh the delivery model options when designing a mini grid program, we present in table 8.1 a comparative analysis. Please note that in many countries different models can be implemented in parallel.

> Each of the five main delivery models for mini grids has its own benefits and limitations. Important considerations for each model are profitability for the private sector, government and local capacity, scalability, transaction costs, and availability of subsidies, among others.

FIGURE 8.1 • Roles for developer and utility under different delivery models



Sources: IFC and ESMAP analysis.
EPC = engineering, procurement, and construction company.

TABLE 8.1 • Comparative analysis of mini grid delivery models

Public funding requirement	Benefits	Limitations	Absolutely must-haves	Deal breakers	Key implementation risks
Build-own-operate model					
Low: CAPEX subsidies only	Developers having full control of the value chain means they optimize cost and quality for each step Projects likely to be financially viable with subsidies Low transaction costs overall Highly scalable	Target beneficiaries may be suspicious of private firms Private firms will abandon the mini grid market if conditions change to make it unprofitable (for example, new, unworkable regulations)	Affordable financing Results-based grants Ability for developers to build portfolios instead of one-off projects Workable options for grid arrival	Requirement to sell electricity at below-cost tariff level without adequate subsidy Heavy-handed, case-by-case regulation	Lack of private-sector developer interest Lack of private-sector investor confidence Regulatory or policy changes that make private-sector operations unviable
Contractual or split-asset PPP					
High: pays for all or most of mini grid CAPEX and OPEX.	Where governments have significant financial and technical resources to build mini grids, these programs can be implemented quickly Responsibilities are effectively distributed between financiers/investors and operators, with capacities aligned with the tasks assumed	Both PPP models: high transaction costs, considering various transactions between public and private partners Split-asset PPP: can lead to stop-and-start implementation issues if government-built infrastructure and private-sector–built infrastructure are not developed in sync	Contractual PPP: respect for legal contracts Split-asset PPP: compensation mechanism for expropriation of developer's mini grid assets Both PPP models: procurement of private-sector developer is competitive and transparent, and clearly states requirements for long-term O&M.	Contractual PPP: no government experience building mini grids Split-asset PPP: History of uncompensated expropriation of private-sector assets by government	Procurement can be a bottleneck to progress If government builds some or all of the mini grid infrastructure, external quality control by an independent third party may be necessary

continued

TABLE 8.1, *continued*

Public funding requirement	Benefits	Limitations	Absolutely must-haves	Deal breakers	Key implementation risks
Concession model					
Low: CAPEX subsidies only	Mini grid developer is assured that the main grid will not come into the area Developers have a clear set of responsibilities. Can facilitate a portfolio approach to project development	May be difficult to implement where the local community does not want to be served for a long time by mini grids, or in countries with low levels of trust in contract.	Respect for legal contracts Clear provisions for key regulatory issues: technical and service standards, tariffs, and exclusivity	Main grid has taken over concession areas in the past without compensating developers Requirement to sell electricity at below-cost tariff level without adequate subsidy Different legal and regulatory requirements between concessions	Review and approval of concessionaire activities can be a bottleneck to progress Change in main grid expansion plans New policies or regulations conflict with existing concession agreements
Utility model (with private sector)					
High: pays for all or most of mini grid CAPEX and OPEX.	Keeps overall responsibility for electrification with one entity. Brings in technology innovation and process innovation from the private sector. Highly scalable if utility has high financial and technical capacity.	Transaction costs may be high if contracting with different third parties for various stages of mini grid development. Building and managing mini grids can exacerbate utility losses if mini grid tariffs are not fully cost-reflective.	Source of long-term subsidy (or cross-subsidy) if mini grid tariffs are not fully cost-reflective	Financially insolvent utility Noncompetitive or opaque procurement of private-sector contractors	Procurement of private sector services can be a bottleneck to progress Insufficient long-term allocation of staff and financial resources at the utility
Utility model (without private sector)					
High: pays for all or most of mini grid CAPEX and OPEX.	Keeps responsibility for electrification with a single entity Utility can get economies of scale through bulk purchases Highly scalable if utility has high financial and technical capacity	Building and managing mini grids can exacerbate utility losses if mini grid tariffs are not fully cost-reflective	Utility experience operating isolated rural mini grids Source of long-term subsidy (or cross-subsidy) if mini grid tariffs are not fully cost-reflective	Financially insolvent utility	Insufficient long-term allocation of staff and financial resources at the utility
Cooperative model					
Low: CAPEX subsidies only	Local involvement leads to solutions that consider most of the locally relevant aspects and increases sense of ownership of the local community	Limited local capacities mean that capacity building and potentially third-party oversight need to be put in place to ensure ongoing O&M Local structures need to be created to limit the potential for social conflict as related to the mini grid Not easily scalable or fast in deployment	Cooperatives as a community organizational structure have a strong track record, even if not yet in the mini grid sector	Tariffs are not fully cost-reflective, including costs related to depreciation, replacement, repairs, and maintenance	Insufficient capabilities and financial resources of local cooperatives to successfully operate economically viable mini grid businesses Progress generally tends to be slow unless there are preexisting well-managed cooperatives

Source: ESMAP analysis.
CAPEX = capital expenditure; O&M = operations and maintenance; OPEX = operational expenditure; PPP = private–public partnership.

INSTITUTIONAL FRAMEWORK

The term *institutional framework* broadly refers to the various entities that, through their respective roles and responsibilities, shape the social, economic, and political environment within which a particular sector operates.

THE DESIRABLE FEATURES OF A FRAMEWORK TO SUPPORT MINI GRIDS

Most countries depend on the main grid to increase electricity access. Thus, most countries have developed an institutional framework to support the main grid. In some countries, an institutional framework for solar home systems also exists; but these frameworks have not yet emerged for mini grids. In most low-income countries, mini grids are still early in development stages and lack a comprehensive, supportive institutional framework. Below are five desirable attributes of institutional frameworks that can support large-scale and rapid deployment of mini grids.

1. **Governments need to recognize mini grids as a desirable and viable electrification option.** Any institutional framework must be reinforced by national political and social recognition that mini grids are indeed a viable and desirable option to scale up electricity access. In practical terms, this means the role of mini grids should be recognized and delineated in high-level policy documents, such as national plans for electricity access.

   For example, the Economic Community of West African States' 2015–20 Programme on Access to Sustainable Electricity Services notes the importance of government promotion of mini grids all the way to the level of rural communities. Government promotion at the village level creates willingness to accept and embrace the arrival of mini grids when they are being developed in their area (ECREEE 2015).

2. **Government institutions must support mini grid development through transparent actions and decisions.** They should assign existing or newly created agencies and make them responsible for achieving national electrification targets through mini grids. Institutions should have explicit, transparent, and harmonized roles and responsibilities, allowing mini grid developers to know and understand which actors are involved in which capacity and at which point. In addition, it is particularly important to ensure transparency in the decision-making processes for institutions with direct jurisdiction over mini grids. Institutions supporting mini grid development have broad roles in the following areas:

   - Ensuring that mini grid projects are in compliance with the applicable rules and regulations, including national technical and environmental standards. Government agencies may wish to assist smaller mini grid developers with compliance.
   - Confirming that mini grids are suitably sited (for example, by earmarking specific areas for mini grid development in the rural electrification agenda).
   - Facilitating the flow of financing (equity, debt, and grants) to private-sector mini grids; public-sector mini grids focus more narrowly on grants, as other funds would come from the national budget.
   - Making sure that enough skilled workers are on hand for mini grid deployment.
   - Establishing and regulating tariff regimes as they apply to mini grids.

3. **The framework should be tailored to the country's electrification planning strategies, current and future, which should include geospatial planning.** We have discussed several delivery models above, and other relevant models might be available. In many countries, achieving universal access to electricity will require both private-sector and government-led approaches to mini grid development. For this reason, the institutional framework should be able to support different models—without implementing a multitude of models that would create a fragmented mini grid market. For example, in some countries where the national utility already operates mini grids, it may make sense to ensure that the institutional framework can accommodate a development approach led in some areas by the national utility, and, in others, by an approach fully led by the private sector.

   An important related element of the institutional framework and its ability to accommodate the country's electrification planning strategy is *the electrification plan itself*. Geospatial analysis is a powerful tool for governments to use when developing their electrification plans because it leads to better decision-making around both the mini grid delivery model options and the institutional arrangement supporting these delivery models. Geospatial planning is discussed in chapter 2.

4. **The framework should be stable and should minimize duplication of oversight and conflicting rules.** In some countries with frameworks that already support mini grid development, developers are wrangling with altered institutional frameworks—finding, for example, a newly created government entity with new jurisdiction over mini grids. Instability inhibits private sector investment in mini grids. To the extent possible, governments should refrain from altering the institutional framework other than to streamline or simplify. Additional com-

plexity is not welcome. In addition, in many countries, developers struggle to navigate complex ecosystems of national and international institutions, which include development banks and development partners, rural energy agencies, environmental protection agencies, energy and finance ministries, national energy regulators and utilities (figure 8.2), each having an influence on the developers' ability to start up and operate their businesses. Navigating this web can be a daunting, time-consuming, and costly task for mini grid developers. As we discuss in chapter 10, it is therefore critical to avoid duplication and conflicting rules through clear frameworks, relationships, and contact points.

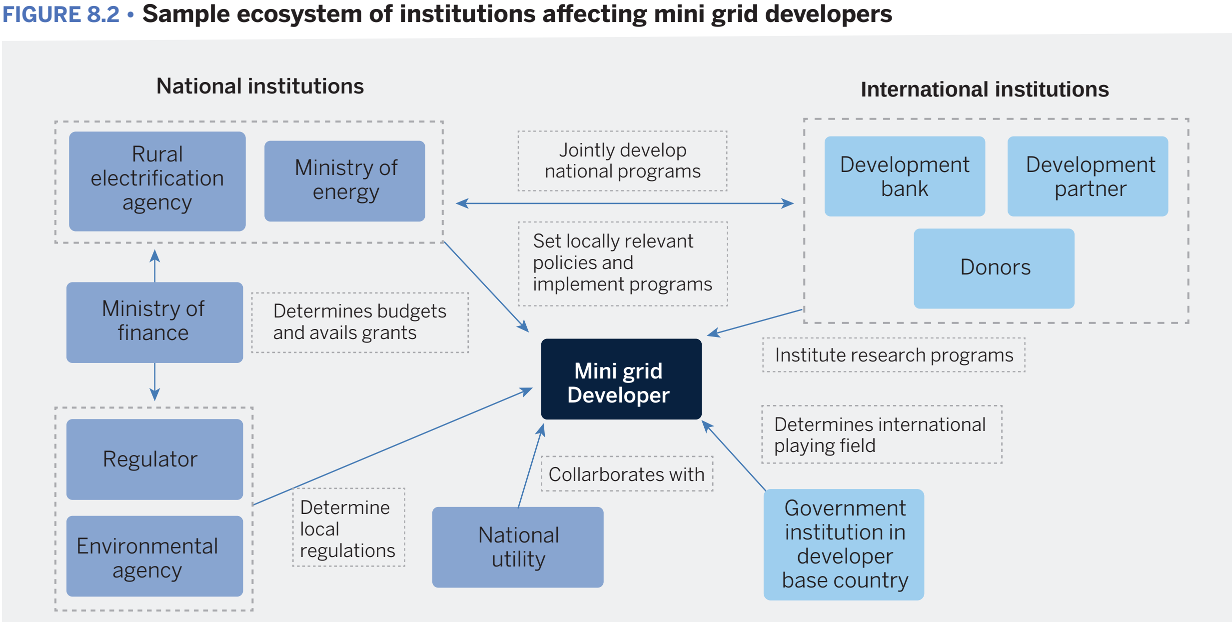
5. **Key institutions should be supported with ongoing capacity building.** Finally, we note the importance of capacity building for each of the institutional actors. Particularly, although not exclusively, in countries with limited mini grid experience and where government and other local entities make up the institutional framework (figure 8.2) will need technical support and training to carry out their roles in a way that is conducive to developing a mini grid sector that can grow at scale. For example, regulatory agencies may need support in developing a light-handed regulatory framework that can help attract private-sector investment, while ministries of energy and planning may need technical assistance to develop and implement national electrification plans that have been informed by robust and detailed geospatial analysis. Chapter 7 discusses capacity building within the mini grid institutional ecosystem.

Figure 8.2 presents an example of the institutional framework that affects mini grid developers and the mini grid sector.

Other stakeholders have not been considered in this overview because of their comparatively minor impact on mini grid delivery models, at least compared with national and international institutions. These more minor stakeholders include regional and local authorities and administrations, the network of local organizations (including NGOs and other potential partners, such as suppliers of biomass), communities, and customers. Also, the institutions dis-

The five main characteristics of an institutional framework that can support mini grids, given the diversity in potential mini grid delivery models, are: (1) mini grids must be recognized by the government as a desirable and viable electrification option; (2) government institutions must support mini grid development through their actions and decisions; (3) the institutional framework needs to be tailored to the country's current and future electrification planning strategies, and should be aided by geospatial planning; (4) the framework should be stable and should minimize duplication of oversight and conflicting roles; and (5), key institutions should be supported with ongoing capacity building.

FIGURE 8.2 • Sample ecosystem of institutions affecting mini grid developers



Source: ESMAP analysis.

played in figure 8.2 are not necessarily present in every country where mini grids are deployed—or are involved in the deployment of mini grids at all. In some countries the regulator, for example, has no impact on the mini grid industry. One of these is Bangladesh, where regulation applies to installations with 6MW or greater of installed capacity.

At the moment, there is no standardized institutional framework for mini grid development. Such standardization may not be desirable, considering the various factors that go into the development of institutional frameworks—not least of which are the wider governmen-

> The institutional framework for mini grids contains various entities, including the ministries of energy, labor, finance, and the environment; the national utility; the energy regulator; the rural electrification (or energy) agency; the environmental agency; the bureau of standards; energy associations; local development banks and financial institutions; social agencies and NGOs; and international development banks and development partners.

TABLE 8.2 • Roles of national and international institutions

Institution	Typical existing roles	Potential mini grid roles
National institutions		
Ministry of energy	Design rural electrification targets, strategy/vision, and mission Design and administer national energy policy and planning Administer public resource allocation	Transparently communicate electrification plans to integrate energy solutions providers, including mini grid developers in the absence of a rural electrification agency Recognize and support mini grids as an option to increase electricity access Initiate mini grid institutional framework
Energy regulator	Issue, monitor, and ensure compliance with local regulations (licensing, permit requirements) Mediate disputes and protect consumers	Formulate and implement economic regulations Formulate and implement technical regulations (for example, standards and interconnection requirements and scenarios), sometimes in collaboration with the bureau of standards and rural electrification agency
National utility	Construct any national mini grids Carry out grid-extension projects	Understand and appreciate the role of mini grids in increasing electricity access Develop mini grids under public-private model
Rural electrification (or energy) agency	Implement rural electrification agenda Perform any regulatory tasks delegated to it	Develop mini grid electrification approach Take overall responsibility for development of mini grids
Environmental agency	Assist with formulating and implementing national environmental regulations Ensure mini grids meet minimum environmental standards and monitor compliance with environmental regulations	Issue environmental rules relevant for mini grids Issue permits as required Monitor compliance with environmental standards
Ministry of finance	Provide rural electrification budget Assist with and coordinate grants and concessionary loans for rural electrification	Provide guidance on national electricity tariffs and subsidies Provide funds for fiscal incentives, including subsidies
Others		Bureau of standards, which may set applicable technical standards Energy associations, which may provide some vocal support and advisory efforts on behalf of mini grid developers Ministry of labor, which may assume the role of ensuring local mini grid skills are developed Local development banks and financial institutions, which may finance mini grid projects Social agencies and NGOs, which may be particularly important for gender issues, community engagement, and promoting productive uses of electricity Other ministries, including the ministry of agriculture, health, and education, which may seek to increase mini grid implementation for the betterment of their respective objectives

TABLE 8.2, *continued*

Institution	Typical existing roles	Potential mini grid roles
International institutions		
Development banks and development partners	Design and implement programs in coordination with national institutions, ensuring alignment of the programs with broader development targets Provide finance for development programs Assist the government in building capacity for all relevant agencies	Possibly assist the government in designing and creating the financial support for mini grids Address financing of national planning initiatives in the context of rural electrification Provide funds to support mini grid development Possibly design programs that they cofinance through a government agency

Source: ESMAP analysis.

tal landscape, the local cultural context and environment, the legal framework, and socioeconomic characteristics (Deshmukh, Carvallo, and Gambhir 2013). Nevertheless, certain roles are typical for most of the institutions, as presented in table 8.2.

INSTITUTIONS INSIDE THE ENERGY SECTOR

Lead agency

An energy ministry or a rural electrification agency is often the lead for mini grids. Its responsibilities may vary according to local circumstances, but under any scenario, the lead agency must have an in-depth understanding of all aspects relating to mini grid development (technical, financial, social, gender, and community-based), in addition to pertinent regulations, procurement and labor rules, and dealings with development partners and other interested stakeholders.

If the lead agency for mini grids is a ministry, an internal unit is typically assigned: mini grids are not ready fits for a ministry's broad responsibilities. This ministerial unit should have adequate staff and capacity and flag relevant emerging issues for high government officials. If a lead agency other than the ministry is appointed to handle mini grids, it should be highly capable, managing the various activities described above and be respected as the highest authority on mini grids, even compared with the ministry of energy. The lead agency must enjoy direct communication vis-à-vis other national institutions (such as the ministry of finance and the legislature). Where capacity is lacking, donors or development partners will need to invest to build country capacity in governance.

One example of a lead agency is Nigeria's Rural Energy Agency (REA). Established in 2005, the REA's main function is to facilitate the provision of modern energy services in rural areas by providing grants, subsidies, technical assistance, training, and capacity building to rural energy project developers. Further, the REA works with the government as well as with development partners, the private sector, NGOs, and community-based organizations. The REA is Nigeria's operational counterpart in the World Bank–supported National Electrification Program.

Other countries that do not have a rural electrification or energy agency rely on different lead agencies. In Myanmar, the lead agency is the Department of Rural Development, located within the Ministry of Agriculture, Livestock, and Irrigation. In Bangladesh, while a Rural Electrification Board actually exists, it is only responsible for the main grid. The lead agency for mini grids is the Infrastructure Development Company Limited, a government-owned company.

In Kenya, under a World Bank cofinanced project, mini grids will be developed jointly by the Rural Electrification Authority and KPLC.

Energy regulator

Many countries have an energy regulatory agency that oversees the main grid. If such an agency exists, it would have responsibility for mini grids also, as in Nigeria and Tanzania. The role of the mini grid regulator is discussed in detail in chapter 9.

Power utilities

Power utilities are often government owned in developing countries. Overall, they need to understand the role and relevance of mini grids in increasing electricity access and not hinder the development of mini grids. In addition, if the national power utility takes ownership of mini grid distribution facilities when the main grid reaches a previously isolated mini grid, the distribution systems of the mini grid will need to be built to grid standards for a successful integration (Kidenda 2018). Further, power utilities need to be aware of and understand the regulatory and financial issues that will affect their operations when the main grid reaches the site of a mini grid.

Energy associations

Some countries may have an association of renewable energy developers, or of solar dealers. The role and relevance of these associations should be considered in each country, with possibly some support provided to develop their ability to facilitate mini grids. In Africa, the Africa Minigrid Developers Association (AMDA) promotes the development of alternating current AC-powered mini grids throughout Africa. AMDA has encouraged the development of uniform mini grid policies and regulations across African countries so private developers do not have different regulations in different countries, which is the current reality. The Tanzania Renewable Energy Association and the Kenya Renewable Energy Association also promote mini grids to the government on behalf of their members, and organize training workshops, building further capacity for their members.

INSTITUTIONS OUTSIDE THE ENERGY SECTOR

Environmental agencies or ministries

Mini grid projects often require environmental approval from the relevant environmental agency or ministry. Carrying out the studies necessary to be granted approval can be a major cost to mini grid developers, delaying the mini grid development timeline. In Tanzania, for example, mini grid developers were facing delays with obtaining the needed environmental clearances and were also having to cover the costs of an environmental consultant. In some cases, this cost approached a hefty $10,000, significant for some developers, particularly local ones. From a timing perspective, some developers had to wait more than 10 months just to obtain the needed environmental clearance, creating further delays and uncertainty in the mini grid project development cycle. Chapter 10 dedicates an entire section to how to reduce the red tape related to environmental clearances.

Bureau of standards

This agency would set many of the technical standards for mini grids. In some cases, it may not have the capacity to set some of the standards, particularly for mini grids whose distribution systems are not compatible with the main grid. In such cases, the bureau would have to work closely with the lead agency and the regulator to develop a suitable, comprehensive set of standards that mini grids must follow.

Finance ministry

One important aspect of this ministry's role would an understanding of, and support for, any set of subsidies that are needed. Further, this ministry may also need to understand and approve of any financial interventions in the debt and equity markets. Finally, it would be involved in any taxes, import duties, and foreign exchange issues. Hence, it is important that the ministry have the capacity needed to support and facilitate mini grids.

Permitting institutions

These institutions handle a broad set of issues that arise over the use of land, water, and other natural resources. One example would be the disposal of batteries by mini grids with solar backup. It is often the case that permitting agencies are not familiar with mini grids. As a consequence, their procedures could become a major bottleneck for mini grid developers. Hence, it is important for the lead government agency to work closely with all the relevant permitting institutions.

Labor ministry

Two issues are relevant to the labor ministry. First, many countries lack the skills needed for a rapid scale-up of mini grids. Hence, it is important to ensure that local skills are developed whenever a new technology like mini grids is introduced. The labor ministry may be the right agency to take on this responsibility. But it is more realistic to expect that the relevant training will have to be performed by the mini grid developer (for example, Husk Power and Mera Gao in India), because the developer will have direct and detailed knowledge of the tasks and skills that will be needed.

Second, when mini grids operate at a small scale, it is uncommon for labor issues to arise. However, when a single developer expands to operate several mini grids with a growing number of employees, employment issues are likely to arise. One frequently encountered issue is whether the mini grid operator's staff will be employed as independent contractors or as employees.

Financial institutions

These institutions are relevant for private and community-owned mini grids only. Some countries have a development bank (such as Bangladesh and Sri Lanka), which may play a major role in financing mini grids, or even establishing technical standards for equipment that the bank will finance. The bank, in turn, will require capacity building. Other relevant financial institutions are banks and nonbank financial institutions comprising equity and debt investors. Some of these institutions may not have the capacity to be involved with mini grids, and their capacities may have to be built over time. In particular, there may be a need to build the capacity of various agencies to understand how the financial risk of mini grids could be shared with interested parties.

Social agencies and NGOs

These agencies would also include community groups. They can be instrumental in the acceptance and promotion of mini grids in the target areas. They may be particularly involved in gender-related issues, community engagement, and the promotion of productive uses of electricity by entrepreneurs and small and mid-sized enterprises.

INVESTORS' PERSPECTIVE ON INSTITUTIONAL FRAMEWORKS

Through conversations with private-sector investors and building on the International Finance Corporation's extensive experience investing in infrastructure projects around the world, we have identified three main barriers that investors perceive in institutional frameworks that would severely constrain investment in mini grids.

- ***Low government capacity:*** Low institutional capacity to run effective procurement, approve permits and licenses in a transparent manner, or undertake any other bureaucratic processes critical for mini grid development is a red flag for mini grid investors. Similarly, unstable government institutions with frequent turnovers within the different government agencies is another signal that government capacity to support mini grids is inadequate.
- ***Limited or nonexistent electrification planning:*** The lack of an agreed and signed-off national electrification plan is a major red flag for investors because it signals that the government has not identified a clear institutional framework within which mini grids would operate. In addition, limited electrification planning capabilities, or national electrification plans based on unrealistic assumptions about main grid expansion, impose major barriers to private-sector investment to the mini grid sector.
- ***Unclear or overly complex institutional relationships:*** Complicated interfaces and allocations of responsibility for oversight of the mini grid sector at specific government agencies and among agencies sends a strong signal to investors that the mini grid sector is fraught with political risk. Similarly, different governmental entities having conflicting political motives with respect to their interactions with mini grid developers and investors is another red flag that would dissuade investment in the mini grid sector. Finally, institutional frameworks that prevent private-sector developers from participating in the mini grid sector, or restrict their participation to limited roles such as engineering, procurement, and construction contractors, would eliminate or severely reduce developers' ability to attract investment, respectively.

Balancing these three barriers are two "must haves" in an institutional framework for mini grids from an investor's perspective.

- ***Clear roles for the appropriate government agencies:*** The existence of a competent governmental body with full authority to implement a rural electrification strategy embedded in a transparent and conducive institutional framework would go a long way toward providing investors with the confidence they would need to invest in the mini grid sector. The presence of an independent and competent energy sector regulator is another factor that can attract investors—the key words being *independent* and *competent*. This would require that the regulator be (1) protected from short-term political interference, (2) appointed on the basis of professional competence and integrity, (3) endowed with sufficient funding to hire personnel of high professional skills while enjoying budgetary independence from the government budget, (4) empowered with a minimum set of competencies, and (5) legally prevented from having personal interests in the regulated industry.
- ***A national electrification plan that emphasizes mini grids:*** A national electrification plan that emphasizes mini grid deployment as a pillar of the government's strategy to increase access to electricity sends one of the strongest signals possible to investors that the government is committed to supporting mini grids. Updating this plan at predefined intervals (for example, every three or five years), using geospatial analysis, and ensuring that it is based on realistic cost assumptions and accurate socioeconomic data are ways to make the national electrification plan even stronger for attracting private-sector investment. (See chapter 2 for an in-depth discussion on geospatial planning.)

ROLE FOR DEVELOPMENT PARTNERS

Development partners play key roles in institutional frameworks conducive to scaling up national mini grid sectors. The following are recommendations for development partner organizations that have been identified in consultation with mini grid sector stakeholders together with ESMAP's experience with World Bank operations teams implementing mini grid projects over the past several years. To establish and support strong institutional frameworks, development partners can act as or assist with:

- Advising on best practices on creating scale and economic sustainability—rapidly—in rural electrification
- Fashioning institutional frameworks to support mini grids, whether funded privately or publicly, in ways that consider a country's resources, constraints, and practices
- Ensuring quick scale-up through capacity building among all the relevant agencies so mini grids can scale up quickly
- Designing the delivery model for mini grid scale-up (countries may choose more than one model)

- Overseeing M&E programs to track deployment
- Securing external evaluations of institutional frameworks and delivery models for mini grids in each country. (Independent, outside groups of regional or international experts must do these assessments
- Navigating the institutional framework to help them design bankable projects[3]
- Cofinancing the above.

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NOTES

1. Other models may also be useful for mini grids, and new models may emerge over time.
2. Information about the UNOPS project is available at https://www.unops.org/news-and-stories/stories/access-to-energy-giving-sierra-leone-the-power-to-change.
3. As part of the Scaling Up Renewable Energy Program, the government of Tanzania, together with multilateral development banks, developed a country investment plan with a component just for mini grids. The implementation of this component was led by the International Finance Corporation and included a Transaction Advisory Services Facility (TASF). This TASF supported mini grid developers to strengthen mini grid operating models and to increase their commercial viability and, ultimately, bankability.

CHAPTER 9

ENACTING REGULATIONS AND POLICIES THAT EMPOWER MINI GRID COMPANIES AND CUSTOMERS

CHAPTER OVERVIEW

Key regulatory decisions for mini grids have a significant impact on whether and how the sector develops. The five key decision areas are market entry, retail tariffs, service standards, technical standards, and the relationship with the main grid. This chapter identifies how different countries have regulated—or not regulated— these areas, presents decision trees that can help regulators and policy makers think through these decisions, provides some "regulatory packages" that combine smart regulatory decisions given different starting conditions, and discusses two innovative regulatory mechanisms that can further incentivize private-sector investment in mini grids.

A smart approach to regulating mini grids can enable them to emerge in countries where they are a viable but untapped solution for electrification and to scale up in countries where they already exist. Regulators can benefit from understanding how other countries have handled regulatory decisions and determining whether similar action can work in their settings.

To provide them with that information, this chapter draws on a research project conducted by the World Bank's Energy Sector Management Assistance Program (ESMAP), Castalia, and Ecoligo. The project included 11 field visits and 70 interviews, conducted between August 2017 and September 2017, and produced a 300-page report; six country-specific case studies (on Bangladesh, Cambodia, Uttar Pradesh [India], Kenya, Nigeria, and Tanzania), which can be found on the companion website to this book: www.esmap.org/mini_grids_for_half_a_billion_people; and two articles on LiveWire, the World Bank's series of online knowledge notes on development issues in the energy and extractives sectors. In each country, the research team interviewed regulators, developers, rural electrification agencies, and consumers, as well as utilities and development partners where appropriate. This chapter also draws on a review of policy and regulatory documents in these countries; on the literature on mini grid regulations; and on research in other countries, including Indonesia, Madagascar, and Sri Lanka. The analysis focuses on privately owned and operated mini grids, because they have more potential than community- or utility-owned mini grids to attract the finance needed for rapid expansion of access to electricity and to operate sustainably.

The chapter provides practical guidance to regulators, rural electrification agencies, and project teams developing mini grid programs. Because no single regulatory solution is optimal in all settings (and regulation has costs as well as benefits), the chapter identifies multiple options and discusses the conditions under which they are suitable. The decision trees provided are not exhaustive or prescriptive; they indicate the choices that might make sense in certain common scenarios. While the focus of this chapter is on regulatory decisions affecting mini grids, general business and environmental regulations also touch on mini grids. These economywide regulations and policies are discussed in chapter 10, Enabling Business Environment.

One limitation of this chapter is that by providing a "deep dive" on regulations, it does not engage much with broader conversations on all the policies that can affect mini grids. While policies signal the market that mini grids are an accepted path to universal electrification, by themselves they rarely provide enough clarity and guidance to private-sector developers and investors need to risk investing in mini grids. Regulations, when done right, can complement policy by providing clarity and guidance on how mini grids can be deployed, thus incentivizing investment.

Still, it is important to acknowledge the impact that policies can have on mini grids. Several countries have integrated national electrification policies that explicitly leverage mini grids as a part of the solution set—Ethiopia, Kenya, Rwanda are examples. These national electrification policies send important signals to developers that the government acknowledges the importance of mini grids for achieving its electrification objectives. Other policies that directly affect mini grids are related to renewable energy and rural economic development, which can incentivize developers to incorporate renewable energy in their generation mix and seek out rural areas for mini grid deployment, respectively. A third type of policy that affects mini grids creates key energy-sector institutions and delegates responsibilities to them. Rural electrification agencies, such as those in Nigeria and Tanzania, and independent regulatory agencies, such as those in Haiti and Rwanda, are often created by acts of parliament as part of energy-sector policy making.

THE IMPORTANCE OF WORKABLE REGULATIONS FOR SCALING UP MINI GRID DEVELOPMENT

Developing a set of workable regulations can set a strong foundation upon which to scale up a mini grid market. At the same time, heavy-handed regulations, or an absence of mini grid–specific regulations that provide clarity to the private sector can hold back a market from its full potential.

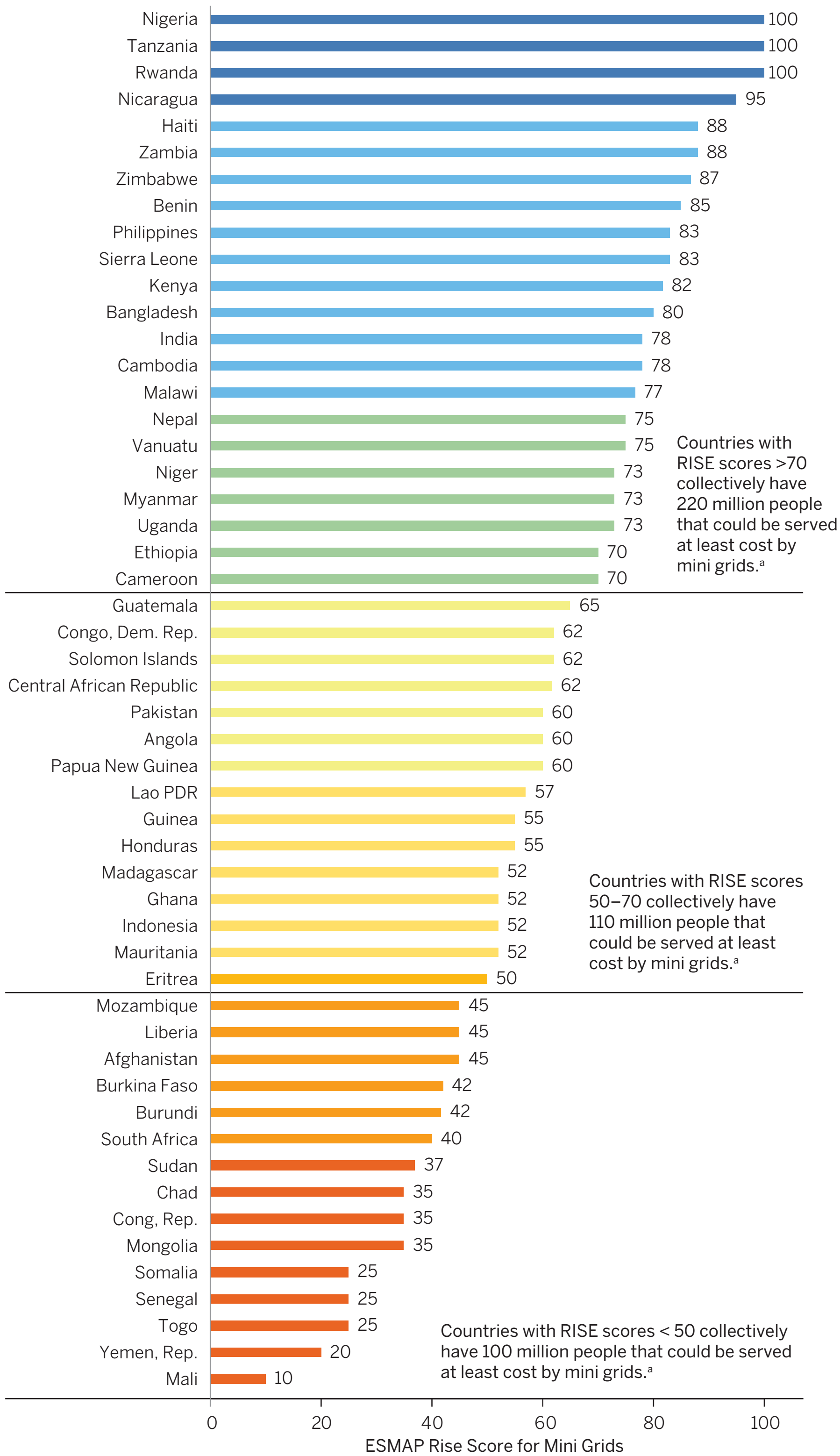
While this may seem intuitive, it is also backed up by real-world data. Using data sets that have never before been compared, we found evidence for a positive correlation between the quality of a country's mini grid–specific regulatory regime and the number of planned mini grids in that country (figure 9.2). For data on the quality of mini grid regulations, we used the World Bank's *Regulatory Indicators for Sustainable Energy* (RISE), an online resource available at https://rise.esmap.org/. This online resource tracks country-specific mini grid regulations and policies in more than 50 countries and is a useful resource to complement this chapter. The RISE program conducts its own analysis of policies and regulations to assign scores to each country based on the comprehensiveness and quality of its policies and regulations.

Of the 52 countries for which RISE has developed a score for a mini grid regulations, 22 have scores of 70 or higher, out of 100 (figure 9.1). These countries have put in place regulatory and political frameworks that at least on paper are conducive to private sector investment, and according to analysis using ESMAP's Global Electrification Platform (https://electrifynow.energydata.info/) they collectively have 224 million people who could be served at least cost by mini grids. Another set of 15 countries with RISE scores between 50 and 70 have made strong progress to strengthen their regulations over the past several years, but still have work to do to put in place a political and regulatory framework that is conducive to private sector investment. Collectively, these countries have 110 million people that would be best served at least cost by mini grids. Finally, a group of 15 countries with RISE scores below 50 represent high priority areas for improving policies and regulations related to mini grids. These lowest-scoring countries collectively have 100 million people that would be best served at least cost by mini grids.

We then plotted each country's RISE score against the number of planned mini grids in that country, using data on planned mini grids in countries with a RISE score from the global database of mini grids that ESMAP compiled for this report (see the overview to this handbook). After removing outliers—following the statistical definition of outliers[1]—we found that the presence of a strong mini grid policy and regulatory environment correlates positively with planning to build mini grids (figure 9.2).

While improved policies and regulations to support mini grids do not automatically lead to more private-sector mini grid investment, we did find a statistical correlation between the number of mini grids installed and planned in a country and the quality of that country's regulatory and policy framework for mini grids. Implicit in this result is that countries with higher RISE scores for their mini grid frameworks have a higher level of government capacity to design and executive good policies and regulations to support mini grids.

FIGURE 9.1 • Regulatory Indicators for Sustainable Energy (RISE) scores for mini grid framework

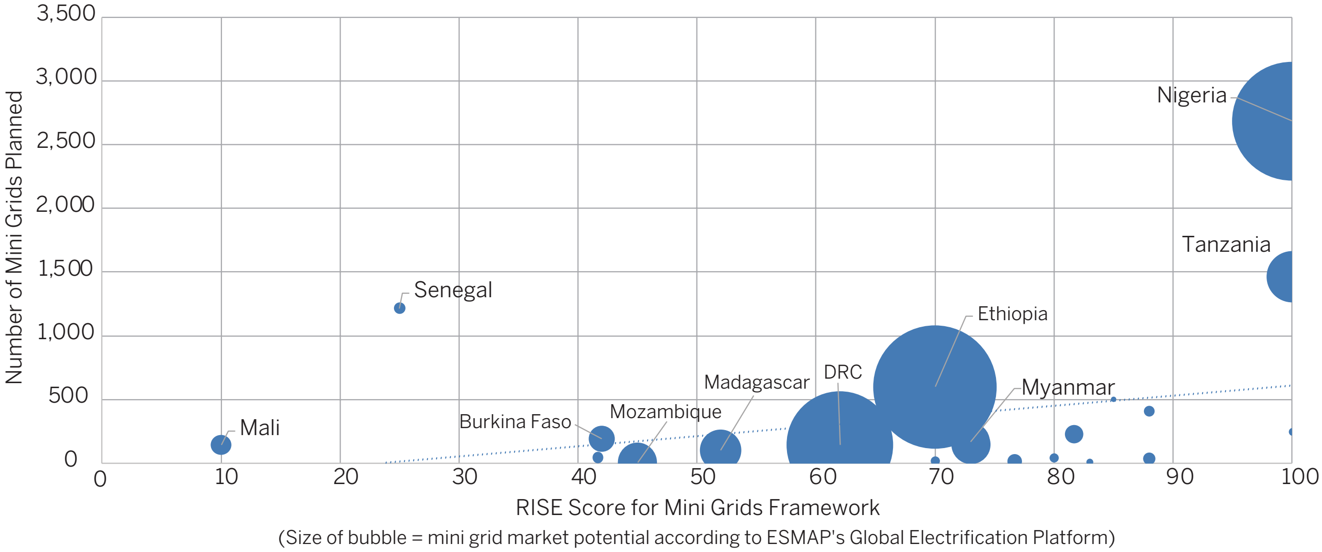


Source: ESMAP 2022.

Note: Scores are based on the comprehensiveness and quality of each country's mini grid policies and regulations.

a. Calculated from the Global Electrification Platform.

FIGURE 9.2 • Correlation between mini grid policies and regulations and number of mini grids planned



Source: ESMAP analysis.

Note: Countries with more than 100 planned mini grids have been identified for reference. DRC = Democratic Republic of Congo.

Implicit in this result is that countries with higher RISE scores for their mini grid frameworks have a higher level of government capacity to design and execute good policies and regulations that support mini grids. We address this element of government capacity throughout the chapter.

> Entities tasked with overseeing mini grids—whether a formal regulator or other entity—will need to make decisions on five key areas: market entry, tariffs, service standards, technical standards, and arrival of the main grid in the service area of a mini grid.

FIVE KEY REGULATORY DECISIONS

In this chapter, we focus on the key decisions a regulatory agency tasked with mini grid oversight will need to make. This does not mean, however, that a formal regulator needs to be in place to make these decisions. As we discuss later in this chapter, regulatory decisions are often embodied in a legal contract between the developer and the government authority tasked with mini grid oversight. In addition, local governments, or a grant-giving entity, such as a rural electrification agency, may be appropriate entities to make regulatory decisions about mini grids. As we discuss in chapter 10, however, it is important not to duplicate government oversight, which adds needless layers of bureaucracy—and hence costs and risks—to private-sector investment in mini grids.

With that said, if a formal regulatory agency has been granted the authority to regulate mini grids, its effectiveness and credibility will depend not only on the decisions it makes in the five areas outlined in this chapter but also on how it makes those decisions (transparency is key) and on the independence with which it makes and implements them (independence from political and private-sector pressure is key).

Mini grids often enter the market as small competitors with limited market power. Over time, they sometimes develop considerable market power in the local market for energy services. Smart regulation can maximize the chances of early entry and growth while protecting against exploitation of market power.

Each element of the regulatory framework—**entry, tariffs, service and technical standards, and what happens when the main grid arrives**—needs to be considered individually, but all need to work together as a coherent package. No element can therefore be designed without considering the others.

REGULATING ENTRY

Entry into the electricity sector is commonly regulated, to ensure the safety of operations, control the attributes of the companies that enter, and prevent multiple operators from supplying different parts of an area that would be more efficiently served by one. Many jurisdictions have made it illegal to supply electricity without a license or a permit.

Obtaining a permit or a license can impose a significant financial burden on developers, for whom administrative costs can represent a large share of project costs. In Kenya, for example, licensing costs can exceed 10 percent of projects' capital costs for solar and solar-diesel hybrid mini grids (Republic of Kenya and World Bank 2016). Delays in the application procedures and the risk that an application may not be approved can also deter developers.

Regulating entry through means other than permitting and licensing may be appropriate in certain circumstances (table 9.1). Such options include no regulation of entry and registration.

A comparison of entry regulations across five countries shows that developers generally offer less detail when

TABLE 9.1 • Options for regulating entry

Option	Description	Suitable where . . .	Examples
No regulation of entry	Leaves investors free to develop mini grids where they want, without providing any information to the government.	Government prioritizes rapid expansion of electricity access through mini grids. Government is willing not to regulate tariffs or standards, or it is willing and able to enforce regulation without a permit or license. Government does not need or desire to collect data on who supplies electricity. Administrative capacity is low. Mini grids are quite small—on the order of a fewkW in capacity.	Cambodia (before 2001 in practice) Uttar Pradesh (most mini grids were not registered as of 2017) Tanzania (mini grids producing less than 15kW or with fewer than 30 customers)
Registration	Requires investors to inform regulator that mini grid is in business and provide information on mini grid at regular intervals, as required by the regulator. Does not require approval by the regulator.	Government prioritizes rapid expansion of electricity access through mini grids and does not want to control who enters the market. Regulator wants to proactively supervise compliance of mini grids with other regulation (tariffs, service standards). Government wants to collect information on who supplies electricity and the level of service provided. There is a low level of administrative capacity.	Uttar Pradesh (required for all mini grids in 2016 regulation but not enforced as of 2017) Nigeria (required for isolated mini grids producing less than 100bkW of distributed power [a]) Tanzania (required for mini grids with an installed capacity of 15kW–1 MW and with at least 30 customers)
Permitting	Administrative procedure to approve entry of a mini grid business in the market. It is intended to be less onerous than a license (less information required and less scrutiny).	Government wants to control entry. Government wants to use permits to enforce regulation of tariff and standards. Administrative capacity is high. Mini grids are larger.	Nigeria (required for isolated mini grids that produce at least 100kW of distributed power and have less than 1 MW of generation capacity). Kenya (required for mini grids with 1–3MW of installed capacity.
Licensing	Administrative procedure to approve entry of a mini grid business in the market, typically similar to licenses that normal distribution utilities are required to obtain.	Government wants to control entry. Supply of electricity is illegal without a license. Administrative capacity is high. Mini grids are larger.	Cambodia (required for all mini grids since 2001) Kenya (required for mini grids with installed capacity of more than 3MW) Tanzania (required for mini grids with installed capacity of 1–10MW) Nigeria (required for mini grids that produce more than 100kW of distributed power and have more than 1 MW of generation capacity).

Source: ESMAP analysis.
Note: "Suitable where" in this table and the tables that follow does not mean that wherever this condition is fulfilled, the option should be selected. Rather it means that under these conditions, this option may be well suited, while under other conditions, another option may be better suited. kW = kilowatts; MW = megawatts.

a. Annex 5 of the mini grid regulations in Nigeria defines *distributed power* as "the average active power fed into the distribution network in each 15-minute interval of its operation period" (NERC 2016).

registering for entry than when applying for permits and licenses (table 9.2).

The decision tree in figure 9.3 highlights the conditions under which the four regulatory options are likely to be suitable.

The first question determining the type of entry regulation is whether electricity supply is legal without a license. Where it is legal, regulators can choose among the four entry regulation options. If it is not legal, they will be limited to the license option.

Where governments do not desire to control who enters the mini grid market, the regulator's choice will first be guided by whether it needs to know who is operating in the market. If it does not need to know, it may opt for no regulation of entry.

If the regulator does want to know which mini grid operators are in the market, its choice may be guided by whether it regulates tariffs, service standards, and technical standards and whether it can do so without a permit or a license. Registration is best suited if tariffs, service standards, or

TABLE 9.2 • Information requirements for registration, permitting, and licensing of mini grids in five countries

	Registration			Permitting	Permitting and licensing	Licensing		
Information requirement	**Uttar Pradesh (India)[a]**	**Nigeria**	**Tanzania**	**Nigeria**	**Kenya**	**Cambodia**	**Nigeria**	**Tanzania**
Intended location and site description	✔ (simplified)	✔ (simplified)	✔ (simplified)	✔ (map)	✔ (simplified)	✔ (detailed)	✔ (map)	✔ (map)
Financial projections	Not required	✔ (simplified)	✔ (simplified)	✔ (detailed)	✔ (five-year business plan)	✔ (detailed)	✔ (10-year business plan)	✔ (detailed)
Details on proposed distribution system	✔ (simplified)	✔ (simplified)	✔ (detailed)	✔ (detailed)	✔ (detailed with map)	✔ (detailed)	✔ (detailed)	✔ (if applicable, detailed)
Details on generation system	✔ (simplified) a	✔ (simplified)	✔ (simplified)	✔ (detailed)	✔ (detailed)	✔ (detailed)	✔ (detailed)	✔ (detailed)
Spreadsheet for tariff calculation	Not required	Not required	Not required	✔	✔	✔ (detailed)	✔	✔
Land certificate and building permit	Not required	Not required	✔ (proof of land-use right)	✔ (building permit and land-use right)	✔	Not required	✔	✔ (proof of land-use right)
Environmental impact assessment	Not required	✔	✔[b]	✔	✔	Not required	✔	✔
Declaration of compliance with health and safety standards	Not required	Not required	Not required	✔	✔	Not required	✔	Not required

Source: ESMAP analysis.

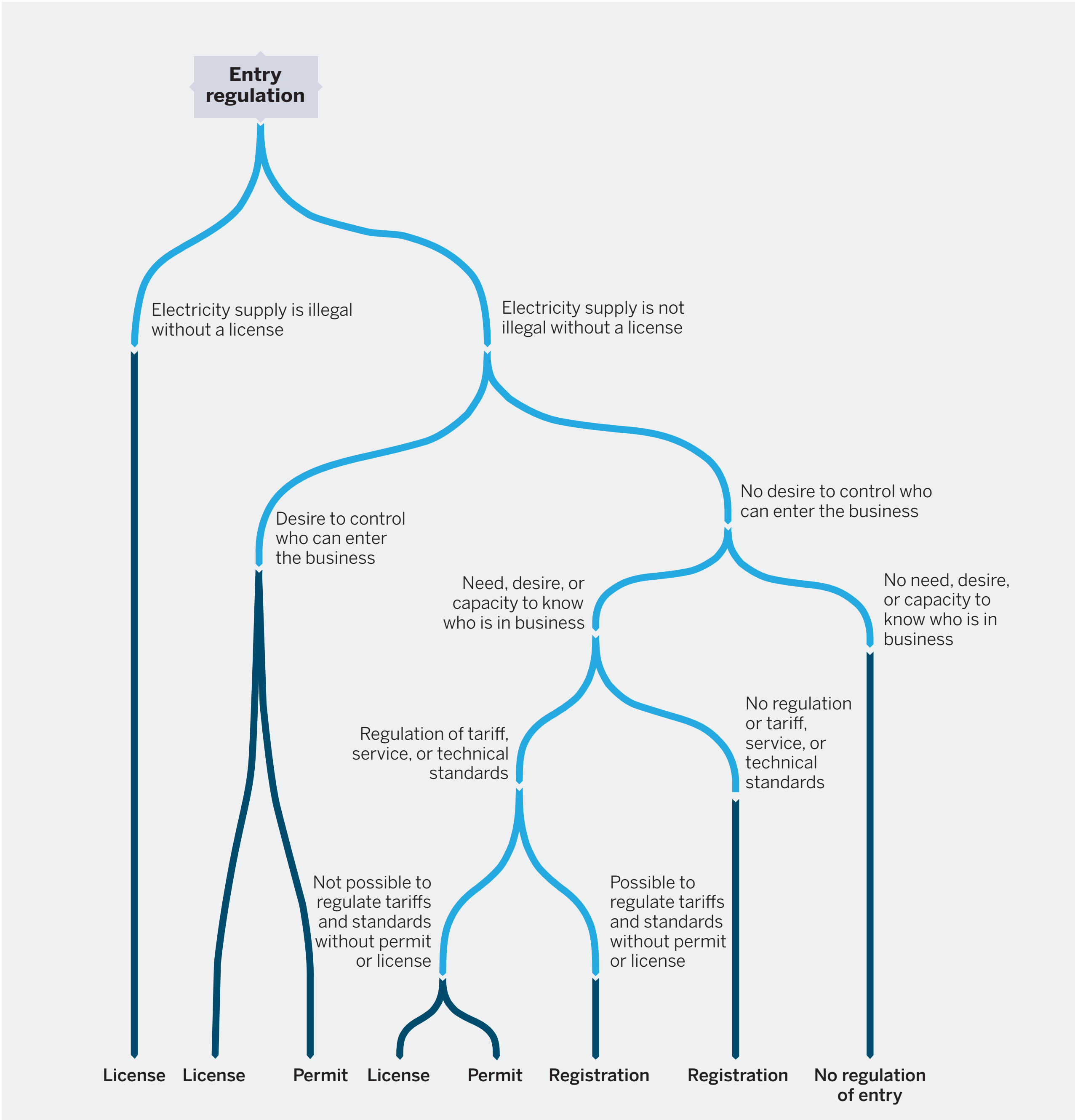
Note: "Simplified and detailed" refer to the level of detail the developer must provide as part of the information requirement.

a. Procedure is envisaged in the Draft Implementation Guidelines for the Mini Grid Projects in the State of Uttar Pradesh. The document refers only to "project details" as the information required.

b. Developer may receive provisional registration from the Energy and Water Utilities Regulatory Authority before the commissioning of the project and before submitting the Environmental Impact Assessment certificate, by submitting proof of initiation of the process to obtain the certificate.

√ = required

FIGURE 9.3 • Decision tree for regulating entry



Source: ESMAP analysis.

Four options regulate mini grids entry to the market: (1) choosing unregulated market entry; (2) requiring that mini grids register with the appropriate government entity; (3) requiring that mini grids obtain a permit to operate, granted by the regulator; and (4) requiring mini grids obtain a license to operate, usually granted by the regulator. Registration, permitting, and licensing usually require more information from the developer and review from the regulator. In some countries, variously sized mini grids have different market entry requirements (for example, smaller mini grids need only register, while larger mini grids must get a permit or license).

technical standards are not regulated or if they are regulated but enforcement mechanisms other than a permit or a license (such as a grievance mechanism) can be used.

Where regulators want to control who enters the mini grid market, they may opt for a permit or a license. The level of administrative capacity may guide the choice between permit and license. Generally, entry control that does not demand a great deal of information, is relatively easy to obtain, and does not grant exclusivity is termed a *permit*. *Licenses* normally refer to documents that are more formal, take more time to complete, and, in some cases, confer exclusivity, particularly in cases where the license is part of a concession. But there are no strict distinctions among the terms.

REGULATING RETAIL TARIFFS

Retail tariffs on the main grid tend to be regulated in order to protect customers from monopoly power, as the main grid is usually the sole supplier of electricity. The decision to regulate retail tariffs for mini grids is not as clear-cut. On the one hand, there are valid reasons not to regulate the retail tariffs of mini grids:

- They're competing with kerosene lanterns and backup diesel generators
- Tariffs are already constrained by customers' scant disposable income
- Regulating tariffs requires financial and human resources, which the regulatory agency may not have.

On the other hand, regulating the retail tariffs of mini grids makes sense when

- Mini grids have gained pricing power locally
- Government subsidies are provided as a way to bring down the cost of electricity
- Government policy mandates a national uniform tariff.

In this section, we present options for regulating mini grid tariffs that take into account these factors.

How (or if) tariffs are regulated has major implications for the economic viability of mini grids and for developers' ability to attract financing. As a result, without clarity on how (or if) mini grid tariffs are regulated (and if they are regulated how they will be reviewed), investors will hesitate to finance mini grid projects.

Options for regulating retail tariffs include willing buyer, willing seller, efficient new entrant price cap, individualized cost-based tariff limits, bid tariffs, and uniform national tariff. Table 9.3 describes these options and the contexts in which they likely to be suitable.

The five options presented in table 9.3 address the *level* of retail tariffs but not their *structure*, a vital distinction from the standpoint of business development. Retail tariffs may be based on energy, power, or the number of devices per household. Collection methods also vary, as tariffs can be prepaid or postpaid. Retail tariff structure may differ for each project depending on technology, developers' costs, and customer's ability to pay. One country may host several tariff structures.

This section focuses on regulating the tariff *level* rather than the tariff *structure*, but it is generally recommended to leave the flexibility to developers to adopt the tariff structure that best fits their technology and market. In particular, mini grid developers will need to find the proper tariff structure and payment model adapted to the local context to ensure that they will be able to collect payments.[2] Not regulating tariff structure, at least initially, may also foster innovation and redound to the country's benefit. When designing their tariff regulations, regulators should adopt a light-handed approach so developers can set the tariff structure that best meets the needs of their business (Tenenbaum and others 2014).

Let us consider each of the five options for regulating the level of retail tariff.

Willing buyer, willing seller

Under this option, the level of retail tariff is based on an agreement between the mini grid developer and its customers. In Nigeria (for systems up to 100 kilowatts [kW] of distributed power), Haiti, and Madagascar, an agreement with the community is a regulatory requirement—a form of regulation by contract, as discussed later in this chapter. In Nigeria and Haiti, the government has developed template agreements between the developer and the community that developers can use. Community agreements are also something mini grid operators consider good business sense.

TABLE 9.3 • Options for regulating tariffs

Option	Description	Suitable where…	Examples
Willing buyer, willing seller	Tariff set at price that the mini grid developer and its customers agree on (that is, the retail tariff is not regulated). Note that household disposable income sets a de facto limit to what the developer can charge for electricity.	Mini grid operators are unlikely to make supernormal profits if given pricing freedom (where competition with traditional energy sources sets upper limit on mini grid prices or mini grids are small). A policy objective is to expand electrification as rapidly as possible. Mini grids compete with a distribution company that does not provide reliable supply of electricity. Administrative capacity is low.	Cambodia (all mini grids before 2001) Uttar Pradesh (mini grids that do not receive state subsidies [in practice all mini grids as of 2017]) Nigeria (isolated mini grids with less than 100kW of distributed power) Tanzania (mini grids with less than 100kW of generation capacity)
Efficient new entrant price cap	Regulator sets single benchmark tariff for all mini grids, based on cost of service of efficient new entrant in the market.	Cost of service is expected to be uniform across communities. Administrative capacity to set the benchmark is moderate to high.	Bangladesh (all solar PV–diesel mini grids)
Individualized cost-based tariff limits	Regulator sets limits on tariffs for each mini grid individually, based on full cost of service.	There is a risk of monopoly pricing. The cost of service is not expected to be uniform across communities. Administrative capacity is high.	Cambodia (all mini grids as of 2017) Nigeria (isolated mini grids with more than 100 kW of distributed power) Kenya (all mini grids as of 2017) Tanzania (mini grids with more than 100kW of generation capacity)
Bid tariffs	Mini grid investor obtains right to serve an area by bidding lowest tariff in competitive tender (either where bid tariff is single criterion or in multiattribute bidding processes).	There is a centrally coordinated approach to scaling up electrification through mini grids. Market data are available. There are enough mini grid developers to compete for each area. Administrative capacity is high. Regulator is willing to accept the winning bid price.	Madagascar (65 projects as of 2015) Uganda (one tender in 2003; another in 2017 to electrify 25 villages)
Uniform national tariff	Regulator sets mini grid tariff at national main grid tariff.	There is strong political pressure for uniform electricity prices. The subsidy provider is creditworthy. Administrative and financial capacity are high.	Cambodia (grid-connected small power distributors, as of 2017) Kenya (plans for mini grids to operate under contract to national utility and charge national utility's tariff)

Source: ESMAP analysis.
kW = kilowatts; PV = photovoltaic.

> Most private operators clearly recognize that they will be able to construct and operate mini grid systems only if there is "buy-in" or acceptance from the villages that will be served. While the private operators may be legally required to get a license or permit from the national regulator, the document will be of little or no value unless the local government and villagers also support the project (Tenenbaum and others 2014, 78).

Variants of the willing buyer, willing seller model include (1) announcement of a tariff by the mini grid, with interested customers signing up for service; (2) individually negotiated tariffs for each customer; and (3) use of a regulatory safety valve, as in Tanzania, where developers need only make their tariff public before installing the mini grid, but the regulator may review their tariffs if 15 percent of customers complain (EWURA 2017b).

Efficient new-entrant price cap

Under this approach, a regulator calculates the tariff that a typical, efficient, newly built mini grid would have to charge to cover its costs (generation and distribution) and earn a reasonable return on capital invested (a return equal to the opportunity cost of capital) over a specified time period. This tariff is then set as the price cap for all mini grids. The tariff is generally set using a financial model of a typical mini grid.[3] The tariff could also be set by observing the tariffs bid in tenders, if the country has awarded mini grid concessions competitively using tariffs as the bidding variable.

The efficient new entrant price cap approach is used in Bangladesh for solar-diesel mini grids. The Infrastructure Development Company Limited (IDCOL) set the tariff at the national level of taka (Tk) 30 to Tk 32/kilowatt-hour (kWh) ($0.37–$0.39), plus a monthly line rent.[4] The tariff is set based on efficient cost assumptions (competitively procured equipment) and allows for a return on equity of 13–15 percent (World Bank 2017a).

The efficient new-entrant price cap approach can be indexed to inflation, the exchange rate, fuel prices, or tax changes if they are expected to affect the costs of mini grids in operation. Such adjustments can be done automatically and periodically (for instance, once a year). The tariff can also be adjusted from time to time in response to changes in the typical costs and efficiency of capital equipment (for example, decreases in the cost of solar panels and batteries). This type of adjustment should be applied, however, only to new mini grids, not to mini grids already in operation. It would be unfair to existing operators to require them to start charging a lower tariff based on lower-cost equipment not available when they built their mini grids.

Individualized cost-based tariffs

These tariffs are set for each mini grid individually at a level calculated to allow the mini grid to recover its reasonable costs of service and earn a reasonable return on capital invested. This approach applies the concepts used for setting the tariffs of large distribution utilities to mini grids. Individualized cost-based limits have been used for mini grids in Cambodia since the early 2000s. They are the mechanism prescribed for larger mini grids in Nigeria and Tanzania and for government-subsidized mini grids in Uttar Pradesh.

Regulators use various methods to set the cost-recovery tariff. Most are variants of rate of return regulation (also called *cost of service regulation*). Under rate of return regulation, companies may recover their operating expenses, depreciation on their assets, and a rate of return on the undepreciated asset base. The rate of return allowed by the regulators is based on the cost of debt and an allowed return on equity. The allowed return on equity is estimated from investors' opportunity cost of capital and the riskiness of the investment. Companies can recover from customers only costs that were prudently incurred and expenditures on assets that are used and useful (Brown 2010).

Setting individualized tariffs on a cost-of-service basis is a balancing act: allowing mini grids to recover their costs while ensuring they do not charge for costs they did not incur in providing the service, while not charging unreasonably high costs because of the mini grid's own inefficiencies. To get this balance right while being clear and predictable, most mini grid tariff regulations spell out the approach to a variety of common issues, including calculating the asset base, setting the rate of return, estimating depreciation, and taking account of subsidies (box 9.1).

Bid tariff

- In the bid tariffs option, the government defines areas (sometimes towns or villages) to be electrified by mini grids and competitively tenders the right to supply each area. The winning bidder is the firm that offers the lowest tariff to supply the area. The tender documents normally define coverage, service levels, subsidy levels, and other parameters.
- The bid tariff approach aims to reveal the efficient cost of service. Bidders would not knowingly bid a tariff that is below their cost of service, as doing so would fail to make the rate of return investors require. Bidders would not bid above their estimated cost of service, for fear that another firm would undercut them and win the tender. Madagascar used a bid approach to award mini grid concessions and set tariffs.

Nigeria, Sierra Leone, and Uganda are moving toward multiattribute bidding for competitive tenders for mini grids. In 2017 Sierra Leone's Ministry of Energy initiated procurement for mini grids in 90 communities. The bids from five prequalified bidders were judged on more than 20 attributes.[5] If the tariff is one of the bidding criteria, such a multiattribute bidding process could also be considered a tariff-setting method if the regulator commits to setting allowed tariffs equal to the bid price. Regulators may be reluctant to commit to approving the bid price without first seeing evidence that there are an adequate number of bidders who compete rather than collude.

Uniform national tariff

Under this tariff-setting approach, all customers in the same tariff category pay the same tariff for electricity regardless of where they live (Tenenbaum and others 2014). Mini grids are generally required to charge the tariff that applies on the main grid. Uniform national tariffs are most often used for residential customers (although they may apply to all customers), because residential tariffs have high political visibility. Notably, a uniform tariff regime will require significant subsidies to make mini grids a viable option for electrification. Consider the following two examples in Cambodia and Peru.

In the most recent stage of Cambodia's regulatory evolution, former isolated mini grids that are converted to small power distributors are required to charge the same tariff as Electricité du Cambodge (EDC), the utility that supplies most of the country. These tariffs are made possible by a subsidy fund that covers the difference between each mini grid's own cost-recovery tariff and the uniform national tariff.

BOX 9.1

SETTING INDIVIDUALIZED TARIFF CONTROLS

Individualized tariff control has many variants. Jurisdictions may take different approaches to each of the following components:

- regulatory asset base, or the value of the regulated assets on which the mini grid operator may earn a return.
- rate of return, or the profit the operator may earn on its capital investment. (The value may be set at the weighted average cost of capital, which is then multiplied by the regulatory asset base.)
- depreciation, or the cost of using assets the operator may recover through its cost of service.
- treatment of capital subsidies, or permitting operators "to take depreciation" but not "to earn a profit or return on the equity provided by the grant" (Tenenbaum and others 2014), because capital subsidies increase the operator's regulatory asset base at no cost for the operator, but the operator will need to replace the subsidized assets once they are fully used.

Table B9.1.1 provides examples of choices countries have made in setting individualized tariffs.

TABLE B9.1.1 • Individualized tariff features in four countries

Feature	Cambodia	Kenya	Nigeria	Tanzania
Regulatory asset base	Value of assets is cost at time of acquisition; costs should be prudently incurred	Not defined	Not defined	All assets that are used and useful in provision of regulated services
Rate of return	Return on asset base of 10 percent	Internal rate of return of 18 percent	"Usual non-recourse commercial debt interest rate in local currency [...] +plus 6 percent"	Reasonable return on capital, calculated by the regulator
Depreciation	Straight line based on standard individual asset lifetime	Not defined	Straight line based on individual asset lifetime	Straight line over useful economic life of the asset
Treatment of capital subsidies	Excluded from asset base but included for depreciation	Not defined	Subtracted from the capital asset base	Excluded from asset base but included for depreciation

Source: Cambodia, EAC 2007; Kenya, GIZ 2015; Nigeria, NERC 2016, 2017; Tanzania, EWURA 2017a, 2017b.

In Peru, the government's Electric Social Compensation Fund provides subsidies to main grid and mini grid consumers in rural areas who consume less than 100kWh a month. The subsidies allow these rural customers to pay tariffs in line with those paid by similar customers in urban areas. Funding for the consumption subsidies comes from a 2.5 percent surcharge on the bills of residential, commercial, and industrial customers with a consumption of more than 100kWh a month (Tenenbaum and others 2014).

Decision tree for regulating retail tariffs

Which approach to tariff regulation may be appropriate will depend on a country's objectives for mini grids, the government's administrative capacity, the availability of subsidies, and the regulator's legal and policy constraints. As a rule, regulators use seven criteria to evaluate their options (table 9.4).

- *Tariff accuracy*: Does the tariff reflect costs? Individualized cost-based tariffs ensure that the regulated tariff is cost-reflective and therefore has high accuracy; a uniform national tariff is not based on mini grids' costs and therefore has low accuracy.
- *Risk of monopoly pricing*: Under the willing buyer, willing seller mechanism, the risk that the operators charge monopoly pricing is higher than in other tariff regimes. An individualized cost-based tariff presents a low risk, given that each mini grid's tariff is set based on its costs.
- *Suitability for rapid expansion of access*: A bid tariff approach aims to rapidly scale up access in specific

areas. A uniform national tariff may not be appropriate in this context, because it aims primarily to ensure equity among customers in the country and its implementation is likely to take time (it requires setting up a subsidy program to finance the gap between main grid tariffs and cost-recovery tariffs). The worst outcome would be to impose a uniform national tariff without any backup subsidy mechanism.

- *Time to implemen*t: An efficient new-entrant price cap may require time for the regulator to set the benchmark. An individualized cost-based tariff takes significant time (to design the tariff model and then calculate the tariff for each mini grid).
- *Regulatory capacity needed*: The willing buyer, willing seller approach requires no regulatory capacity. Design of a competitive tender in the case of a bid tariff requires high regulatory (and government) capacity.
- *Compliance cost for the developer*: An efficient new-entrant price cap adds little cost (other than knowing the regulation). Submitting a bid in a competitive tender adds significant costs to the developer (with the risk of not being selected).
- *Tariff flexibility*: The willing buyer, willing seller approach offers the most flexibility, as the operator can opt for any tariff structure (for instance, tariffs varying depending on the time of day or the level of demand). At the other end of the spectrum, a uniform national tariff provides the least flexibility.
- Some mini grid regulations also explicitly consider the structure of retail tariffs, whether—for example, customers are charged per kWh, a flat fee, or per kW; tariffs increase as consumption rises; or there is a lifeline tariff. In general, though, a light-handed approach to tariff regulation leaves these tariff structure choices to the discretion of the developer.

Figure 9.4 presents a decision tree to guide policy makers in regulating tariffs.

Some countries want uniformity in tariffs across geographic regions, a politically appealing policy. But for regulators to implement such a policy, the only option available is uniform national tariffs. Regarding this option, therefore, governments should consider prerequisites for success. Fiscal capacity ensures the subsidies are available to bridge the gap between the mini grids' cost of service and the uniform national tariff. Administrative capacity allows governments to calculate the required subsidy and disburse it.

If a uniform national tariff is not a policy requirement, the next question is whether subsidies are available. Where subsidies are not available (the topmost branch of the decision tree), any option for tariff regulation must allow mini grids to recover the full cost of service through the tariff. The following four regulatory approaches can do this:

- Willing buyer, willing seller
- Efficient new-entrant price cap
- Individualized, cost-based tariff limits
- Bid tariff

Among these four options, the choice depends both on the capacity of the regulatory agency and the importance government places on reducing the risk of monopoly pricing compared with its emphasis on rapid expansion by cutting red tape and allowing attractive returns on investment.

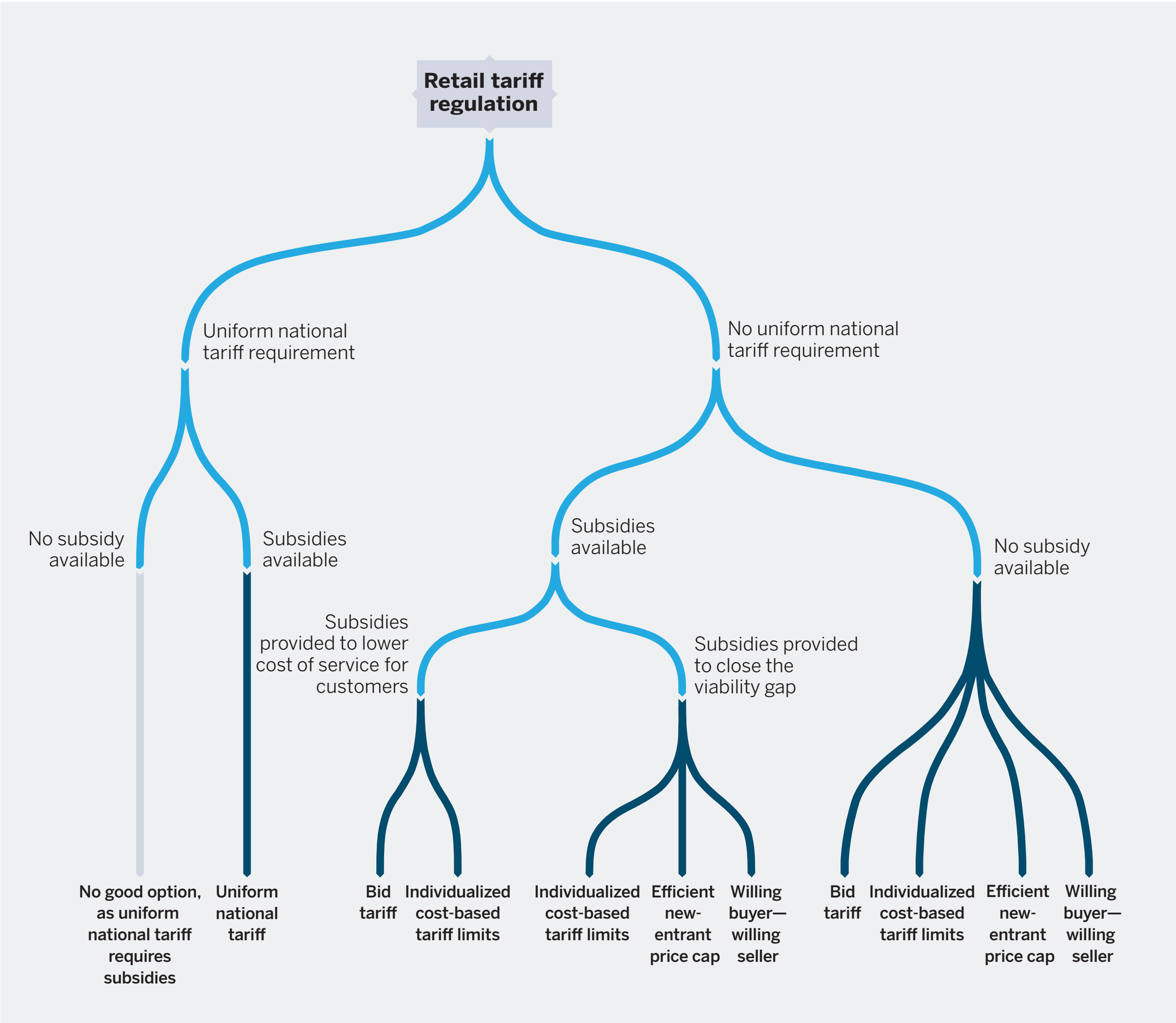
If a uniform national tariff is not a policy requirement (and subsidies are available), all four options above are also possible. Slight preferences emerge for one approach over another depending on the objective of the subsidy. If the overriding objective is to expand access to as much of the population as possible, then subsidies should be

TABLE 9.4 • Assessment of tariff options

Option	Tariff accuracy (cost-reflection)	Risk of monopoly pricing	Suitability to rapidly expand access	Time to implement (for regulator)	Regulatory capacity needed	Compliance cost (for developer)	Tariff flexibility
Willing buyer–willing seller	Low	Medium	High	Low/ medium	Low	Low	High
Efficient new-entrant price cap	Medium	Medium	High	Medium	Medium	Low	Medium
Individualized cost-based tariff limits	High	Low	Medium	High	High	Medium	Medium
Bid tariff	High	Low	High	Medium	High	High	Medium
Uniform national tariff[a]	Low	Low	Low	High[a]	High	Low	Low

Source: ESMAP analysis.
a. A uniform national tariff can be imposed quickly, given that the tariffs are already set by the electricity utility. But designing a subsidy mechanism to make this option viable is likely to take time.

Figure 9.4 • Decision tree for regulating tariffs



Source: ESMAP analysis.

devoted to closing the viability gap in serving certain areas. A viability gap arises when it costs more to supply an area or household than the revenue that will be generated from that area or household. If the overriding objective is to bring the cost of electricity down for as many people as possible around the country, then subsidies would be provided to developers or their customers with the primary objective of reducing costs. The tariff options better suited to one subsidy scenario or the other are shown in the decision tree. But any of the four approaches in the bullet list above would be possible in either subsidy scenario.

Tariff review and automatic adjustment clauses

Not all mini grid tariffs need to be regulated, even in countries that regulate mini grid tariffs. It is increasingly common that mini grids below a certain capacity threshold can set their tariffs without regulatory review and approval. When tariffs are regulated, however, they usually undergo periodic review by the regulatory agency. These reviews should occur at regular, predefined intervals (usually not more than every two years and not less than every five years).

> There are five options for regulating mini grid tariffs: (1) willing buyer, willing seller, (2) efficient new-entrant price cap, (3) bid tariff, (4) individualized cost-based tariff limits, and (5) national uniform tariff. The uniform national tariff option is only possible for mini grids if significant and sustainable subsidies are available. The choice among the remaining four options, each of which can in theory enable mini grid developers to recover their costs, depends on both the capacity of the regulatory agency and the importance the government places on reducing the risk of monopoly pricing, compared with the emphasis it places on driving rapid expansion by minimizing red tape and allowing attractive returns on investment.

Developers are usually not allowed to change their tariffs once the tariff schedule has been approved after a periodic review, but a common practice is to allow developers to adjust their tariffs without a full review by the regulator for the following reasons: an increase in the fuel price; an increase in taxes; inflation; and depreciation of the local currency with respect to the currency or currencies in which the developer pays its creditors, investors, and suppliers. In these instances, developers are often required to show documentary evidence of the impact that the change in fuel, tax, inflation, or exchange rate has on the developer's costs.

Furthermore, because mini grid developers are competing against self-generation by larger customers, good regulatory practice suggests that developers should be able to enter into tariff agreements with larger customers without having to receive regulatory approval for these tariffs.

There may be instances in which the regulator is compelled to conduct a review of the tariff outside of the periodic review process. Because one of their roles is to protect consumers, regulators need to be responsive to customer complaints. However, because it is common for customers to complain about their tariffs (particularly if the developer must increase them for one of the four reasons stated above), it is helpful to set a predefined threshold above which a review of tariffs is triggered. Regulations in Haiti, Rwanda, and Tanzania, for example, set this threshold in terms of a percentage of a mini grid's customers.

To facilitate the tariff review process, regulators and developers should use the same methodology to calculate and review tariffs. This can be achieved by having, for example, a tariff calculation template in Microsoft Excel that is used by the developer to submit its tariffs and by the regulator to review them. Using a tariff calculation template that shows the costs (capital, operating, and finance), revenues, and other key inputs can also mitigate the risk that the regulator assesses mini grid tariffs against what the tariffs are on the main grid.

In general, the only reason a regulator should be allowed to reject a developer's proposed tariffs is if they do not conform to the tariff guidelines or rules as stated in the regulation. This highlights the point made at the beginning of this section: developers need clarity on how their tariffs will be reviewed, and what rules govern how they can set their tariffs.

An additional consideration for regulating retail tariffs: regulatory treatment of subsidies

A final consideration for regulators when making decisions about retail tariffs is how to treat subsidies. In most populous countries lacking sufficient, equitable access to electricity, there will be a "viability gap" between the tariff that the developer would need to charge its customers to be economically viable and the tariff that customers can afford to pay given their disposable household income (or the tariff that developers would be required to charge under a national uniform tariff regime). In these cases, subsidies will be required. (Chapter 6 provides a detailed discussion on the types and sources of subsidies.) When a government mandates, authorizes, allows, or provides a subsidy, it usually does so as part of a specific policy designed to close this viability gap to achieve a social objective, such as increasing access to electricity for low-income households.

Regulators should adhere to the general principle, below in italics, when accounting for subsidies in their regulation of retail tariffs:

> If the government authorized, mandated, provided, or allowed a subsidy, the regulator should refrain from actions that would nullify or reduce the effect of the subsidy. Instead, the regulator should take regulatory actions that help to ensure that the subsidy is delivered to its intended target as efficiently as possible. The regulator, however, should periodically inform the government of the costs and benefits of the subsidy (Tenenbaum and others 2014, 122).

This principle can be applied to two types of subsidies: connection-cost subsidies and cross-subsidies in tariffs. High connection costs are a major barrier to accelerating the pace of connecting new customers to mini grids, particularly in rural and low-income areas, so governments and donors sometimes provide grants to mini grid developers to reduce the capital costs involved in connecting new customers (Tenenbaum and others 2014). Meanwhile, cross-subsidizing different groups of customers enables mini grid developers to provide electricity to the lowest-income customers within their service area.

For connection cost subsidies, if a mini grid developer receives a grant from an outside entity to reduce its capital costs, the developer should be allowed to take depreciation on the equity provided by the grant, but should not be allowed to earn a profit or return on this equity. For cross-subsidies across groups of customers, regulators should explicitly allow developers to charge different tariffs to different customer classes, with the objective of expanding access to a larger number of customers in the mini grid service area. National utilities routinely cross-subsidize their residential customers by charging commercial and industrial customers higher tariffs, so this same option should be available to mini grid developers.

As a final point, some developers lower the underlying capital costs of connecting new customers in innovative ways (for example, the use of ready boards) and allow customers to pay their connection charges over time in smaller monthly installments. In these cases, the developer may incur additional financing and administrative costs associated with these activities. The general recommendation here is if a mini grid developer offers its customers the ability to repay the costs of: (1) their connection charge, (2) internal wiring, (3) house-improvements to meet minimum electricity-connection standards, and (4) purchasing electricity-powered appliances and machinery through monthly on-bill installments, then the regulator should allow the provider to recover both the financing and administrative costs it incurs to provide these loans. This can also help incentivize developers to encourage productive uses of their electricity, as described in chapter 3.

> Regulators should adhere to the following general principle when accounting for subsidies in their regulation of retail tariffs:
>
> If a subsidy is authorized, mandated, provided, or allowed by the government, the regulator should not take actions that would nullify or reduce the effect of the subsidy. Instead, the regulator should take regulatory actions that help to ensure that the subsidy is delivered to its intended target as efficiently as possible. The regulator should, however, periodically inform the government of the costs and benefits of the subsidy (Tenenbaum and others 2014).

REGULATING SERVICE STANDARDS

Service standards are usually regulated on the main grid to protect customers from monopoly power and ensure good service. They are commonly divided into quality of power (such as voltage and frequency stability), quality of supply (such as hours or service and reliability), and quality of commercial services (such as connection time and customer service).

Regulating service standards may be warranted where mini grids have gained market power, since such mini grids may have little incentive to improve their service quality and may not provide the level of service the market wants. The regulation of service standards, however, risks hindering the development of mini grids, or connection of certain customers, by hiking the cost of energy or connection. It may limit the flexibility of developers to offer service levels adapted to customers' needs and willingness to pay. Establishing service standards also creates additional compliance costs for developers.

Options for regulating service standards include (1) no service standards, (2) reporting standards, (3) differentiated standards, (4) uniform mini grid–specific standards, and (5) main grid–level standards (table 9.5).

Reporting

In the reporting option, mini grids are not bound to comply with any service standards, but they need to report their quality of service to customers and to a central body (regulator or other). Information provided to the central body should be available to the public upon request. In developing the reporting requirements, regulators should keep in mind that mini grids are much smaller than national grid utilities and should adjust their reporting expectations accordingly. Regulators need to determine how much information is needed to effectively manage the sector while avoiding overburdening mini grids. One variant is to gradually phase in reporting requirements as mini grid operators increase their capacity or specific data become necessary (USAID 2017). The "Quality Assurance Framework for Mini-Grids," developed by the U.S. National Renewable Energy Laboratory, provides additional information on how developers can measure and report their quality of service (Baring-Gould and others 2016).

Differentiated standards

In this option, service standards are regulated and mini grid–specific, but they are not uniform across areas, mini grids, or customer types. Service standards may differ across mini grids depending on their size, whether they are subsidized, or the type of authorization they are required to obtain. In Nigeria, for example, registered mini grids are subject to recommended service standards that are lower

TABLE 9.5 • Options for regulating service standards

Option	Description	Suitable where...	Examples
No service standards	Mini grids are not bound to any service standards or reporting requirements.	Mini grids are in active competition with other energy providers. The mini grid market is incipient. Administrative capacity is low.	Cambodia (no service standard regulation before 2001) Uttar Pradesh (basic service standards for all mini grids were created in 2016, but as of 2017 they were not enforced)
Reporting	Mini grids are not bound to comply with service standards, but they must report their quality of service on specified indicators to a central body and customers.	Mini grids are in active competition with other providers of energy. The mini grid market is incipient. Administrative capacity is low.	None identified
Differentiated standards	Service standards are regulated but differentiated across mini grids, areas, or customers. Regulator may add reporting requirements as a variant.	Mini grids have market power, tariffs are regulated, and/or subsidies are provided. Service needs, willingness to pay, cost of service, and ability of operators to manage regulatory compliance differ across areas. Administrative capacity is high.	Nigeria (differentiated standards based on type of authorization; registered mini grids may follow recommended service standards that are less stringent than standards for mini grids with permits) Peru (differentiation of service standards between urban and rural areas and based on population density)
Uniform mini grid–specific standards	All mini grids must provide a uniform, regulated level of service that is different from the required service on the main grid. Regulator may add reporting requirements as a variant.	There is an established market where mini grids have market power. Tariffs are regulated and/or subsidies are provided, and the combination of tariffs and subsidies can cover the cost of service at regulated standards. Administrative capacity is high.	Uttar Pradesh (since 2016 basic standard regulation has been in place for all mini grids; more stringent service standards are required of state-subsidized mini grids, but as of 2017, no operator had applied for the subsidy)
Main grid–level standards	Mini grids must comply with main grid-level service standards.	Providing the same quality of service across the country is a core policy objective.	Bangladesh (hours of service, reliability, billing, and metering) Cambodia (since 2001, hours of service, power reliability, power quality, billing, metering, and customer service) Kenya (power quality and reliability)

Source: ESMAP analysis.

than the mandatory service standards for mini grids with a permit. The regulator may consider reporting requirements in combination with service standards. In Nigeria mini grids with permits must report their incidents and accidents to the regulator every two years (NERC 2016).

Service standards may also differ across areas, based on the cost of service and customers' willingness to pay. "The standards should be based on customers' preferences and their willingness to pay for the costs of providing the specified level of quality. The standards need not be uniform across all customer categories or geographic areas" (Reiche, Tenenbaum, and Torres de Mästle 2006). In Peru, service standards differ for urban and rural areas based on the cost of service and willingness to pay.

Uniform mini grid–specific standards

In this option, all mini grids must provide a uniform level of service. The regulator defines mini grid–specific standards that are different from main grid standards. The Multi-Tier Framework used by the World Bank to track energy access (Bhatia and Angelou 2015) presents different levels of access that regulators could use to define the service level. In this framework, Tier 1 corresponds to supply of at least four hours during the day and one hour in the evening. Tier 4 corresponds to supply of at least 16 hours of electricity during the day and 4 hours in the evening, with no more than 14 disruptions a week and voltage variations that do not affect the use of appliances. The regulator may opt for reporting requirements in combination with service standards.

Traditionally, the regulator enforces service standards; in the case of isolated mini grids, the community could do so. The community may directly negotiate the service agreement contract with the developer and then monitor compliance (Tenenbaum and others 2014). The local government or a rural electrification agency could also monitor service standards. In Cambodia the regulator delegated the monitoring of compliance of technical standards to the Provincial Department of Mines and Energy, which has staff in the field (Tenenbaum, Greacen, and Vaghela 2018). Similar synergies could be exploited for service standards.

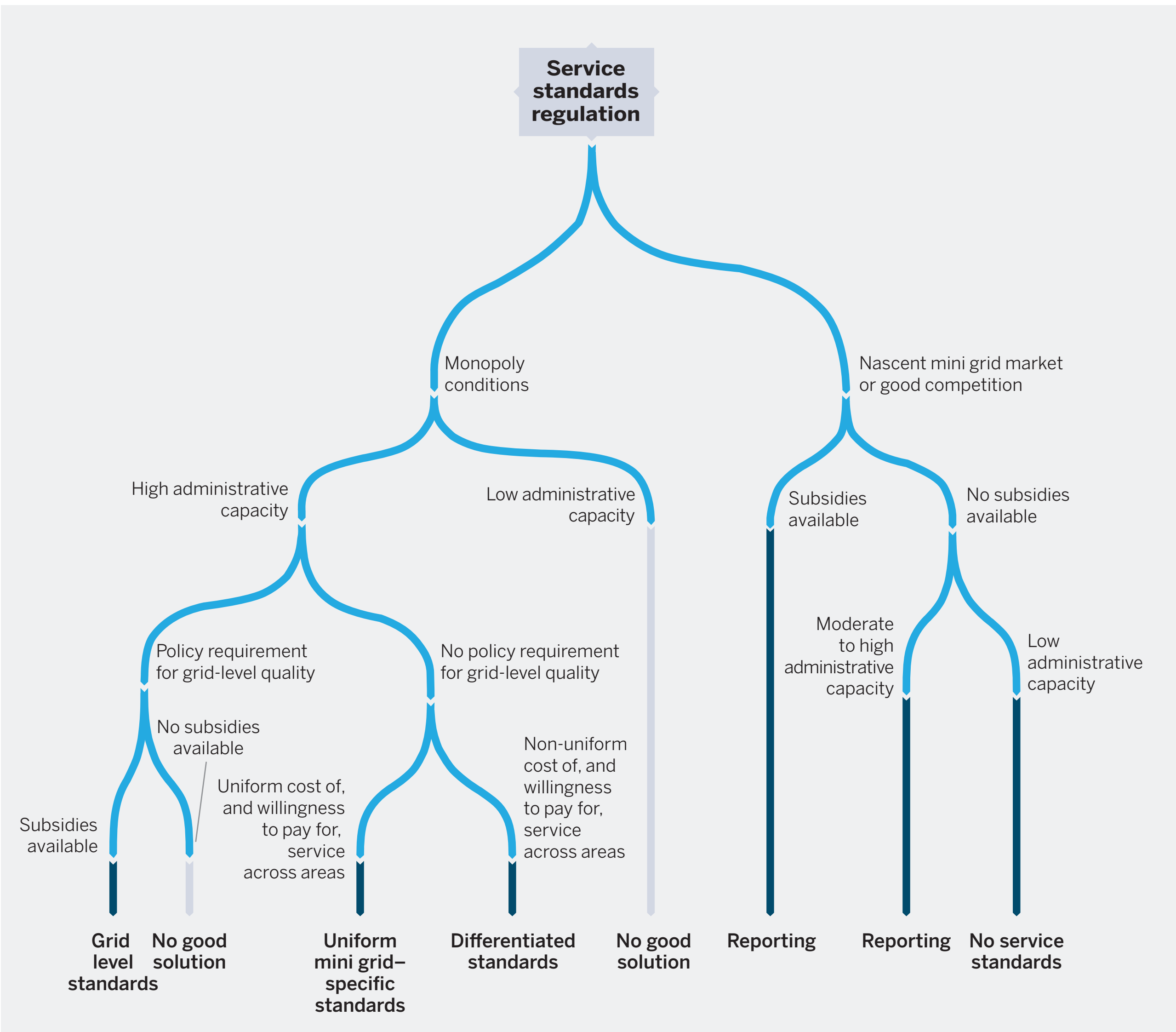
Main grid–level standards

In this option, mini grids must comply with standards set for the main grid. Bangladesh, Cambodia, and Kenya have adopted this option. The regulator may consider reporting requirements in combination with service standards.

Main grid–level standards can be set in various ways. In Kenya service standards are lower in rural areas than in urban areas (ERC 2016). Cambodia illustrates the continuum between uniform service–standard regulation and differentiated service–standard regulation: service standards are uniform, with some exceptions. Mini grids must provide power 24 hours a day, except where this is not viable (ERC 2016).

A variant of main grid–level standards could be to impose main grid–level standards when a mini grid connects to the main grid (and starts operating as small power distributor or small power distributor plus small power producer).

FIGURE 9.5 • Decision tree for regulating service standards



Source: ESMAP analysis.

Note: "Good competition" refers to the situation where mini grid developers are still competing with alternative technologies in communities they serve, such as backup diesel generators.

Such a mechanism should be defined from the start, to provide certainty to mini grid developers.

Decision tree for regulating service standards

Figure 9.5 summarizes the conditions under which different types of standards may be suitable.

The first question that will determine what type of service standards regulation is appropriate is whether the mini grids are competitive entrants or in a monopoly situation.

When mini grids are competitive entrants, the choice of service standards could be guided by whether the government provides subsidies. Given the fragile economics of many mini grids, imposing service standards regulation without subsidies may harm the development of the market. Thus, if the market is competitive and there are no government subsidies, the regulator may opt either for no service standards regulation if administrative capacity is low, or for reporting if administrative capacity is moderate to high. If subsidies are provided, the regulator may require reporting of service standards to monitor the quality of service.

In a monopoly situation, the regulator may consider regulating service standards to protect customers from abuse of monopoly power. If administrative capacity is low, the regulator would need to build up capacity to design and enforce service standards. Alternatively, the regulator may design the service standards and delegate their enforcement to local governments, communities, or a rural electrification/energy agency. If administrative capacity is adequate to develop and enforce service standards, decisions about how to regulate the standards will depend on the developer's cost of supply and customer willingness to pay. Grid-level standards tend to require not just administrative capacity but also fiscal capacity for subsidies to cover the high costs that grid-level standards may impose. Therefore, there will be no good solution if there is a policy requirement for grid-level standards and subsidies are unavailable.

> There are four options for regulating the service standards of mini grids: (1) requiring only that developers report their service levels, (2) developing and enforcing standards specific to a particular mini grid or portfolio of mini grids, (3) developing and enforcing standards that are uniform for all mini grids, and (4) requiring mini grids to adhere to main grid–level standards. Requiring main grid–level standards is possible only for mini grids if subsidies are available. The choice among the other options depends on whether mini grids are operating in a monopoly situation, and the level of the regulatory agency's administrative capacity.

REGULATING TECHNICAL STANDARDS

Regulation of technical standards can help ensure safety, the quality of equipment and construction, compliance with environmental standards, and future connection of mini grids to the main grid. Technical standards regulate mini grids' inputs. They differ from service standards, which regulate outputs (such as the quality of power and supply). If mini grids are already built to grid-compatible standards, connection to the main grid will be straightforward. Equipment that meets these standards may be more expensive than needed to serve the area in the short term, however, and requirements to use grid-compatible equipment may limit innovation.

Options for regulating technical standards include safety standards only, mini grid–specific standards, optional grid-compatible standards, mandatory grid-compatible standards, and main grid standards (table 9.6).

Safety standards only

In this option, only safety is regulated. Safety standards can be designed specifically for mini grids, or safety standards developed for the main grid can be applied. In Uttar Pradesh, our in-country research indicated that mini grids are required to follow standards defined in both the state's electricity regulations and its mini grid regulations.

Some jurisdictions may choose to recommend but not mandate safety standards, as in Nigeria's mini grid regulations. But given the risks to personal safety posed by electrical systems, mini grid technical standards minimum generally spell out safety requirements.

Mini grid–specific standards

In this option, technical standards are designed specifically for mini grids. These standards do not guarantee future connection to the main grid. Mini grid–specific standards are not necessarily lower than main grid standards. For example, Nigeria's regulations for the mini grid include health and safety rules that apply specifically to mini grids.

Optional grid-compatible standards

Mini grids have the option to comply with grid-compatible standards if they want their assets to be protected when the main grid arrives. These standards are generally lower than those of the main grid. Under Tanzania's regulations for small power producers (SPPs), the mini grid's distribution assets are not eligible to be bought out by the main grid if they are not built to the (grid-compatible) standards of the Tanzania Bureau of Standards. Meters are considered part of the distribution assets only if they are grid compatible.

TABLE 9.6 • Options for regulating technical standards

Option	Description	Suitable where...	Examples
Safety standards only	Only safety standards are regulated.	Communities are not expected to be connected to the main grid in the near future. Entrepreneurs have adequate information and the incentive to select appropriate equipment. Government subsidies are minimal. There is enough capacity to regulate dangerous equipment.	Uttar Pradesh (mini grids that generate less than 50kW must comply with safety standards only) Nigeria (recommended safety standards for registered mini grids)
Mini grid–specific standards	Mini grids must comply with standards designed specifically for mini grids. Compatibility with main grid is not required.	Willingness to pay or desired service levels is not consistent with use of main grid–compatible technology. Communities are not expected to be connected to the main grid in the near future. Subsidies are provided (to ensure that projects receiving subsidies meet minimum standards appropriate for mini grids). Administrative capacity is adequate.	Nigeria (specific health and safety standards apply to all mini grids) Sri Lanka (government-subsidized mini grid must comply with technical standards that are lower than the standards for the main grid)
Optional grid-compatible standards	Mini grids have the option to comply with grid-compatible standards (which are lower than main grid standards). If they do, they are eligible to choose an economically attractive option when the main grid arrives.	There is a reasonable likelihood that at least some mini grids will connect to the main grid in the future. The administrative capacity to design the standards exists.	Tanzania (before 2017, the regulation provided that distribution assets had to be at least grid compatible to be bought out by the utility when the main grid arrives)
Mandatory grid-compatible standards	Mini grids must comply with grid-compatible standards.	There is a reasonable likelihood that many mini grids will connect to the main grid in the future or integration of mini grids with the main grid is a policy objective. Subsidies are provided (to ensure that projects receiving subsidies meet minimum standards appropriate for mini grids). Administrative capacity is high.	Tanzania (2017 regulation requires mini grids with more than 30 customers or at least 15kW of installed capacity to follow standards defined by the Tanzania Bureau of Standards) Sri Lanka (mandatory standards for interconnection of hydro mini grids to main grid)
Main grid standards	Mini grids must comply with main grid technical standards.	Mini grids are expected to be taken over by the main grid within the asset life of the mini grid. Standards can be shown to be justified in terms of economic costs and benefits in the area. Combination of tariffs and subsidies (tariffs only or tariffs plus subsidies) can cover the mini grid's cost of providing electricity. Administrative capacity is sufficient to enforce the standards.	Bangladesh (mini grids must follow main grid standards for rural areas) Nigeria (mini grids with permits must comply with standards that apply to the main grid) Cambodia (all licensees must comply with main grid codes and standards) Kenya (all mini grids must comply with the national grid code for connection and distribution)

Source: ESMAP analysis.
kW = kilowatts.

Mandatory grid-compatible standards

In this option, mini grids must comply with safety standards and technical standards that allow them to connect to the main grid in the future. Equipment or construction standards may also be regulated if subsidies are provided. Regulators may require mini grids to be grid compatible when they are built or require technical upgrades when the main grid arrives. The latter option may be better adapted for small systems that would not be viable if stringent technical standards were applied from the beginning or in countries where implementation of the main grid extension plan is uncertain (USAID 2017). Sri Lanka is one of the few countries that have developed specific technical standards for the interconnection of mini grids to the main grid. The country has successfully developed interconnection standards and procedures for hydropower mini grids, in which the mini grid must carry out a load-flow study and install safety relay equipment before interconnecting with the main grid.

Main grid standards

In this option, mini grids must comply with main grid technical standards. In Cambodia, mini grids must follow the 2004 Electric Power Technical Standards and the 2007 Specific Requirements of Electric Power Technical Standards, which also apply to the main grid. The regulator advises on how to build the mini grid system so that it can integrate with the main grid in the future (Tenenbaum, Greacen, and Vaghela 2018). In Bangladesh mini grids must comply with main grid standards in rural areas, which are lower than grid standards in urban areas.

Decision tree for regulating technical standards

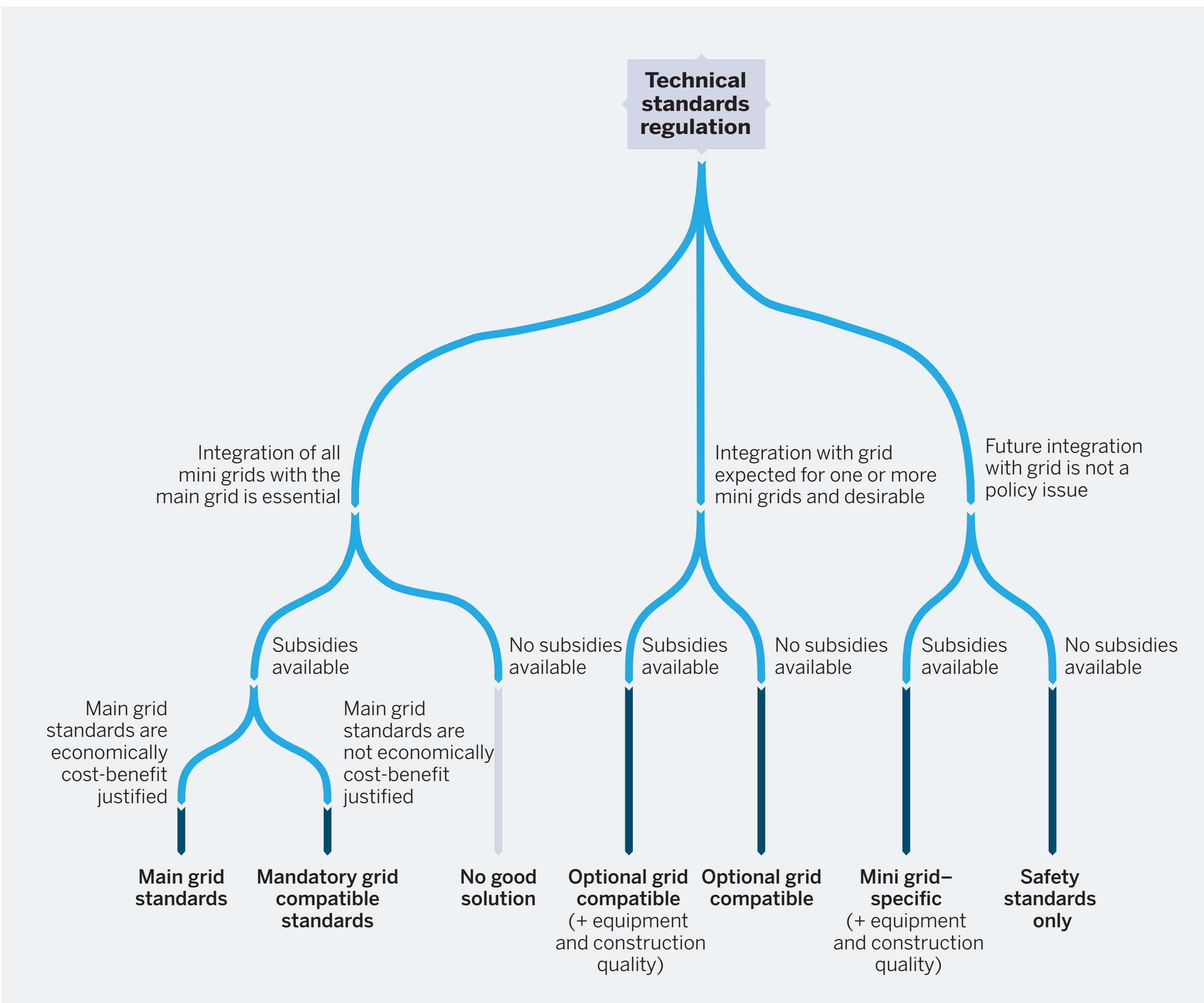
Figure 9.6 presents the decision tree for regulating technical standards.

One of the primary considerations for deciding how to regulate mini grid technical standards is what will happen when the main grid arrives in the service area of a mini grid.

Where future integration of mini grids into the main grid is not essential, regulators may opt for safety standards regulation only, or mini grid–specific standards with equipment and construction requirements if subsidies are provided or if the government wants to facilitate future interconnection of the mini grids.

Where future integration of mini grids into the main grid is expected at least for one or more mini grids, regulators may consider optional grid-compatible standards.

FIGURE 9.6 • Decision tree for regulating technical standards



Source: ESMAP analysis.

There are five options for regulating the technical standards of mini grids: (1) minimum safety standards only, (2) mini grid–specific standards, (3) optional main grid–compatible standards, (4) mandatory main grid–compatible standards, and (5) main grid standards. The choice among these options depends on the availability of subsidies (higher standards typically require subsidies) and what will happen when the main grid arrives in the service area of a mini grid (main grid–compatible standards are the minimum for enabling mini grids to interconnect with the main grid).

Where the integration into the main grid is an essential policy objective, and subsidies are available, regulators may consider two options: mandatory grid-compatible standards and main grid standards. The two options are likely to require subsidies to enable mini grids to cover the costs at these higher standards. Thus, if integration into the main grid is essential and no subsidies are available, there is no good option.

While it may seem clear in some cases that a mini grid will never be connected to the main grid—and hence requiring it to achieve main grid standards would add unnecessary costs—it is worth highlighting that grid-extension plans can and do change, often for political reasons. As a result, an area that was not planned for main grid extension in 10 years may suddenly find itself on the list of areas to receive a main grid connection in 5 years. Ultimately, because mini grids have a useful life of 15–20 years, it may be reasonable to assume that nearly every mini grid built today should be prepared for the arrival of the main grid. The next section identifies the options that should be made available to mini grid developers upon the arrival of the main grid.

REGULATING RELATIONSHIPS BETWEEN THE MAIN GRID AND MINI GRIDS

Regulating relationships between the main grid and mini grids can mitigate risks faced by investors while preserving the benefits of progressively expanding the main grid. Regulation for this purpose is warranted for two reasons.

First, it can reassure developers who worry they may lose their investment when the main grid extends to a community they serve because its risks the stranding of assets and expropriation. To provide certainty to investors, regulators should ensure (1) that options for the mini grid to integrate with the main grid (or, as an alternative, to exit from the business) are clear; (2) that the rules governing these options are not subject to regulatory or policy discretion; and (3) that formulas for determining compensation payments are unambiguous.

Mini grid regulations should explicitly state the options for what happens when the main grid arrives in the service area of a mini grid and should provide as much clarity as possible about how each option would be implemented.

Second, it is desirable that assets continue to be useful when the main grid arrives. If the distribution system is built to grid-compatible standards, it can be interconnected when the main grid arrives and continue to provide service. The mini grid's generator can provide power to the main grid or operate as a backup option.

Mini grids can integrate with the main grid or remain distinct from it. Options that provide for integration include becoming a small power distributor (SPD), a small power producer (SPP), both SPD and SPP, and asset buyout. Options where the mini grid remains distinct from the main grid include coexistence of the main grid and mini grid and asset abandonment. Table 9.7 describes these options and suggests the contexts in which they are suitable.

The following legal and regulatory requirements can help ensure that mini grid investors are protected when the main grid arrives.[6]

- In the event that the mini grid developer's exclusivity is protected by a legal contract with the government, a national utility, or another state-owned entity, the main grid arrival regulations should state clearly how the developer will be compensated for its loss of exclusivity.
- If mini grids are allowed to become SPDs, the retail tariff must include a distribution margin that enables the SPD to be commercially viable.
- If mini grids are allowed to become SPPs, SPPs should be given the legal right to sell power at a predetermined feed-in tariff, through a power purchase agreement.
- If mini grids have the option to sell all or part of their assets to the main grid operator, this asset buyout option should require an objective, fair, and predictable asset valuation method.

Small power distributor

A mini grid that converts to an SPD retains its distribution assets and connects them to the main grid. The generation assets are transferred to the utility, sold to a third party, moved to another location, abandoned, or decommissioned.[7] In theory, the generation assets may also be kept for backup power. The mini grid operator buys electricity wholesale from the utility and sells it to its retail customers.

TABLE 9.7 • Options for preserving value when the main grid arrives

Option	Description	Suitable where...	Examples
Small power distributor (SPD)	Mini grid retains its distribution assets (and becomes an SPD). Generation assets are transferred to the utility, retained as backup generation, sold to a third party, moved to another location, or decommissioned and abandoned. The SPD purchases electricity wholesale from the utility and sells it to its customers.	The distribution network is in good condition and grid compatible, and the generator is not competitive with generation on the main grid. There are enough retail customers for the SPD to operate profitably.	Cambodia (since 2001 mini grids are automatically converted to SPDs, and diesel generators must be decommissioned) Tanzania (SPD is one option for mini grids when the grid arrives)
Small power producer (SPP)	The mini grid's distribution network is transferred to the utility or abandoned. The SPP produces and sells power to the utility. Battery storage may be used to provide services.	The generator is competitive with generation on the main grid or can generate at a cost below the feed-in tariff. The utility is creditworthy.	Uttar Pradesh (isolated mini grids can convert to SPPs and sell power at a feed-in tariff determined at the state level; none had done so as of 2017) Tanzania (one option available to mini grids is to convert to an SPP) Bangladesh (mini grids must convert to SPPs)
Small power distributor plus small power producer	Mini grid retains its distribution and generation assets. Mini grid meets its customers' needs by buying from the main grid, running its generator, or both. Mini grid can sell its excess power to the main grid. Mini grid usually has the option of islanding (disconnecting from the main grid for technical or safety reasons).	Mini grid distribution network is in good condition and grid compatible, and generators are competitive with generation on main grid or can increase reliability of service. The utility is creditworthy.	Nigeria (mini grids have the option to convert to SPD plus SPP) Tanzania (mini grids have the option to convert to SPP plus SPD)
Asset buyout	The utility purchases all or some of the mini grid's assets and operates, decommissions, or abandons them.	Integration of mini grids by the utility is a core objective of the country's electrification strategy. Mini grid assets that would be sold (that is, the distribution infrastructure) are in good condition and grid compatible. The national or regional distribution company has the incentives and the money to purchase the mini grid's assets.[a]	Uttar Pradesh (mini grids have the option to sell their distribution assets to the utility, at a cost determined by the distribution company and the developer) Nigeria (mini grids have the right to sell some or all of their assets to the distribution company, at the depreciated value of the assets plus 12 months of revenue) Tanzania (mini grids have the option to sell their distribution assets to the connecting distribution utility at a price based on the distribution utility's avoided cost)
Coexistence of main grid and mini grid	Mini grid's distribution and generation assets are maintained. Main grid and mini grid are physically separate but operate in the same service area. Customers have the choice to remain with the mini grid or be connected to the main grid.	Main grid provides low-quality service or households cannot afford connection to the main grid. Distribution network is in good condition but not grid compatible (low-voltage DC networks). Mini grid offers a service/cost combination that suits some customers better than the main grid option.	Uttar Pradesh (mini grids are built alongside the main grid in some areas) Indonesia (mini grids coexist with the main grid in 50 communities)

TABLE 9.7, *continued*

Option	Description	Suitable where...	Examples
Asset abandonment	Mini grid's distribution assets, generation assets, or both are abandoned, decommissioned, or removed and used elsewhere.	The government wants to protect utility or distribution companies from competition. The distribution network is not grid compatible. Mini grid quality is below main grid standard, and it is not cost-effective to upgrade it. Generation assets cost more to run than the marginal cost of main grid generation and are not useful for backup.	Nigeria (mandatory for registered mini grids) Indonesia (150 of 200 mini grids that faced main grid arrival were abandoned) Sri Lanka (100 of 250 mini grids mini grids built were abandoned)

Source: ESMAP analysis.
DC = direct current.
a. In Tanzania, donors pay for 100 percent of the capital costs if TANESCO extends the main grid into previously unconnected villages. At present, donors do not provide TANESCO with any grant money to acquire the existing distribution assets of a mini grid in a village that has been served by a mini grid.

Small power producer

In the SPP model, the mini grid distribution network is transferred to the utility, abandoned, or decommissioned. The operator keeps the generator, along with any batteries, and sells the power generated to the utility. Depending on the technical design of the mini grid, the batteries can be used to provide services, such as shifting power from times it is less valuable to times it is more valuable.[8]

Small power distributor plus small power producer

In this model, the mini grid remains a mini grid, with the additional options of selling and buying power from the main grid. The mini grid thus becomes both an SPD and a SPP (also called a *grid-connected mini grid*). Both the distribution and generation assets are connected to the main grid. The mini grid operator retains the distribution grid and continues selling power to its customers. It also retains its generator and can meet its customers' needs by buying from the main grid, running its generator, or both. It can also sell excess power to the main grid. The mini grid also has the option of "islanding," where the configuration in which a portion of the grid becomes temporarily isolated from the main grid but remains powered by its own generator.

Asset buyout

In the asset buyout option, the utility purchases and operates the mini grid's assets. A variant includes a partial asset buyout, in which the utility buys out only the distribution assets. In this case, the generating assets may be abandoned, decommissioned, or used at another site if the technology allows it. The utility may be required to purchase the assets but not necessarily to operate them (in which case the utility abandons or decommissions them). In Nigeria, for example, regulation does not require the utility to operate the assets (NERC 2016).

Coexistence

In this option, the mini grid operator retains its distribution and generation assets. Customers have the option of remaining connected to the mini grids or switching to the main grid. The two grids remain physically separate. This option, while rare, exists in parts of India and Indonesia where the main grid provides unreliable power.

Asset abandonment

Where the distribution network and the generator are abandoned or decommissioned, the national or local utility treats the area like a greenfield site, building a new distribution system. The regulator can also require the mini grid operator to remove its distribution assets. The generation assets may be removed and used on another site if the technology allows it.

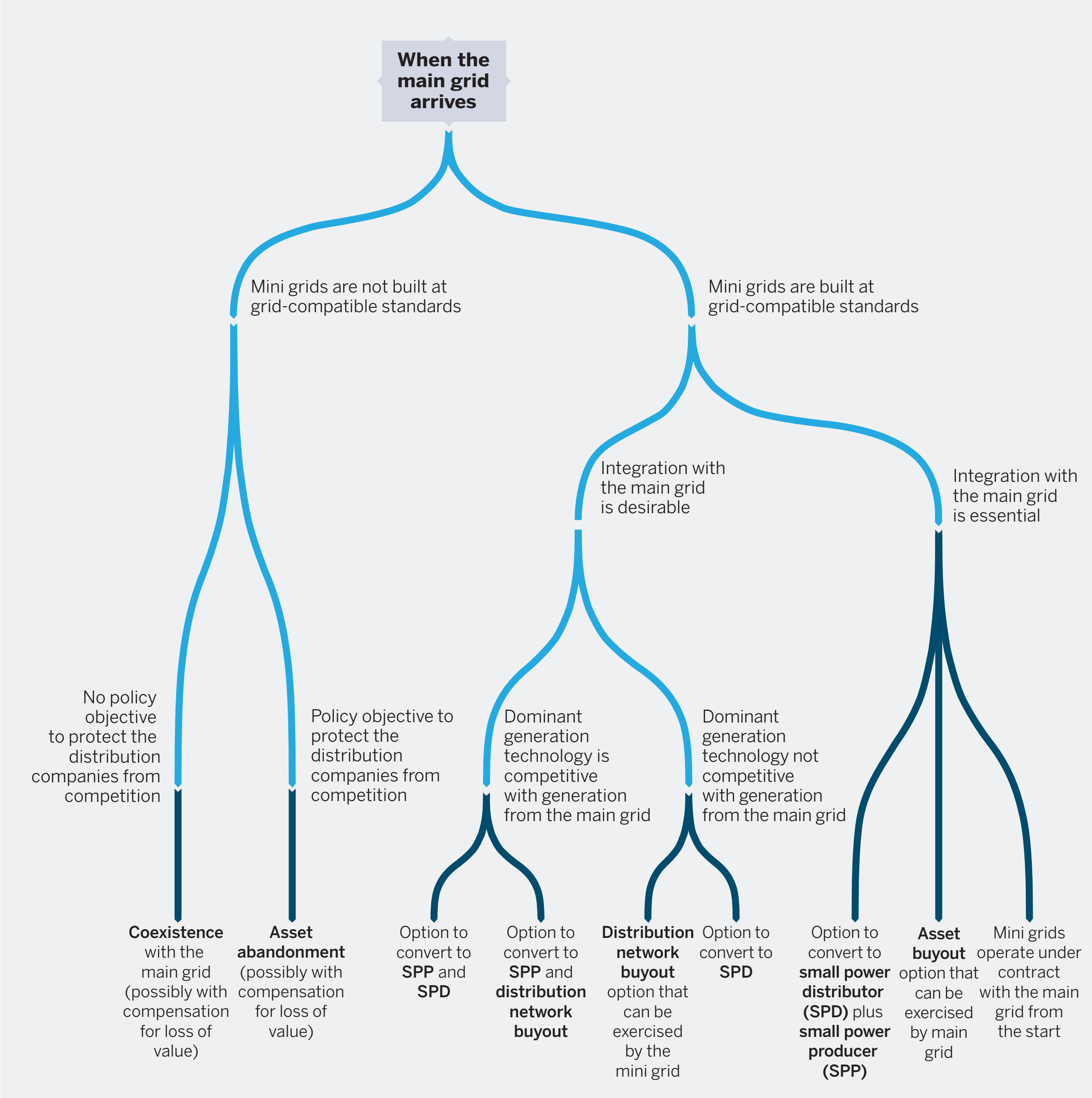
Decision tree for integration and exit options when the main grid arrives

Figure 9.7 presents the decision tree for integration and exist options for mini grids when the main grid arrives.

If mini grids are built to grid-compatible standards (and if it is essential or desirable for the country's electrification strategy to integrate mini grids into the main grid), the government may consider the SPP, SPD, SPP + SPD, and asset buyout options. If mini grids are not built at grid-compatible standards, the government may wish to allow mini grids to coexist with the main grid if it does not have a policy objective to protect distribution companies from competition; otherwise, it should require the mini grids to decommission their assets.

If mini grid generators are not competitive with generation on the main grid, the government may require mini grids

FIGURE 9.7 • Decision tree for integration and exit options



Source: ESMAP analysis.

to remove their generation assets and either allow them **convert to SPD** or give them the rights to **sell their distribution assets** to the main grid. If a mini grid's generation is eligible for feed-in tariffs or is competitive with generation from the main grid, the government may offer the possibility to the mini grid to convert to an SPP, with the option to continue operating as an SPD (**SPP + SPD option**).

For options that include asset buyout, the regulations should offer a credible compensation mechanism to the mini grid operators, who will want certainty that the utility can buy their assets and that the valuation will be fair. There are different ways to determine the appropriate compensation due the developer under the asset buyout option, but they generally fall into one of the following three categories:

Compensation based on assets: Under this approach, the value of the mini grid would be based on the value of its assets after accounting for depreciation and any grants the developer received for the assets. Apart from the usual physical assets, a mini grid may also have soft assets such as goodwill, which in the mini grid context might result from the community-engagement efforts of the mini grid developer. These tend to be difficult to valuate on the one hand, but on the other are important assets to the main grid operator: Entry into a service area with existing demand for high-quality electricity services and familiarity with for grid-based electricity. The compensation mechanism in the current Nigerian mini grid regulations is based on the "remaining depreciated value of assets" but also includes an additional payment equal to the revenue generated by the mini grid in the 12 months before the buyout.

Compensation based on cash flow: This method is forward looking and uses the discounted cash flow to calculate the present value of a business's future cash flows, including its terminal value. This method estimates future cash flows in terms of what a new business owner could achieve. It also recognizes the buyer's cost of capital. It is often difficult to produce reliable estimates of future cash flows because markets in which mini grids naturally operate are uncertain and unpredictable. The concession contract for mini grids in Haiti includes a compensation mechanism based on the greater of the book value of assets less any grants received toward their purchase, or the net present value of the expected profit (revenues minus costs) for the remainder of the concession, using a predefined discount rate.

Compensation based on utility's avoided cost: Under this approach, the developer is compensated an amount equal to the main grid operator's avoided cost of having to build grid infrastructure in the area served by the mini grid, after accounting for depreciation and any grants that the developer received for the assets. Consequently, a requirement for this approach is accurate data on the true, unsubsidized costs—typically per kilometer or per customer—of extending the main grid to rural areas. The mini grid regulations in Tanzania take this approach, stating that compensation is "based on the Rural Energy Agency's average capital cost for installing distribution equipment in rural areas measured on a cost per kilometer basis over a recent calendar or fiscal year minus depreciation" (Government of Tanzania 2019).

Under the first option, an independent third party can conduct a valuation of the mini grid's assets (splitting the valuation costs between both parties). But a major point of contention is likely to be which assets are to be sold to the main grid operator. In general, the main grid operator should be required to purchase the immovable distribution infrastructure assets if they are determined to be in good working order and built to the correct standards.

> Six options present themselves when the main grid arrives in a mini grid's service area: (1) allow the mini grid to operate as a small power distributor (SPD), (2) allow the mini grid to operate as a small power producer (SPP), (3) allow the mini grid to operate as an SPD and SPP, (4) allow the mini grid developer to sell its eligible assets to the utility, (5) allow the mini grid to coexist with the main grid, and (6) require the mini grid to decommission and remove its assets. The SPP, SPD, and SPP + SPD options require the mini grid to have been built at least to main grid–compatible standards. The asset buyout option requires a credible compensation mechanism.

In the first and third approaches, assets would only be eligible for compensation if they have been maintained to good working order and built to the appropriate technical standards.

The second option would be particularly applicable if the developer's exclusivity was granted contractually for a set period of time—for example, through a concession, license, or permit—and the main grid arrives before the expiration of the contract.

COMBINING REGULATORY ELEMENTS

Unpredictability and inconsistency are the two primary regulatory risks facing developers. To mitigate against these risks, this section proposes ways, first, to combine regulatory elements into effective packages so the regulations themselves are more consistent, and, second, to implement regulatory packages in a phased approach that increases predictability for the sector.

COMBINING REGULATORY ELEMENTS INTO EFFECTIVE PACKAGES

Regulations for mini grids are interrelated. For example, service standards can be regulated when tariffs are regulated, and mini grid assets can be protected when the main grid arrives, conditioning connection on compliance with technical standards, which in turn can be regulated when subsidies are provided.

The options for each element can be combined in many ways, only some of which yield effective packages. Table 9.8 summarizes packages that regulators can customize to fit their own conditions while ensuring that the results are consistent with the three core principles of regulatory systems: credibility, legitimacy, and transparency.[9]

TABLE 9.8 • Effective regulatory packages

Package	Description	Suitable where . . .	Examples
Laissez-faire	No regulation of entry, tariffs, service standards, or technical standards beyond those for safety. No provisions for when the main grid arrives. No subsidies provided.	The government wants to minimize barriers to investment to promote rapid electrification through private mini grids. Mini grids compete with other energy providers and traditional sources of power, like backup diesel generators. Government administrative and financial capacity are low. Government administrative and financial capacity are high or medium, but the scope for mini grids is not large or the government wants to allocate few regulatory resources to mini grids. Mini grids are community owned, making self-regulation sensible (Reiche, Tenenbaum, and Torres de Mästle 2006); the regulator could step in in case of political takeover.	Cambodia (de facto laissez-faire before 2001) Uttar Pradesh (voluntary laissez-faire)
Light regulation	Low-cost regulatory interventions that offer clear value while minimizing the risk of preventing mini grids on the edge of commercial viability from developing. Requires mini grids to register, agree with customers on tariffs, report service quality on specified service indicators, and follow safety standards. Provides optional grid-compatible standards, combined with provisions to convert to small power distributors (SPD), small power producer (SPP), or SPD + SPP; may provide model contracts for tariff setting.	The government wants to minimize barriers to investment while ensuring safety, knowing which mini grids are in business, and providing certainty to investors as to what happens when the grid arrives. Mini grid developers are in competition with other energy providers. Government administrative and financial capacities are low. Government administrative and financial capacities are medium or high, but the scope for mini grids is not large or the government wants to allocate few regulatory resources to mini grids.	Nigeria (for mini grids with less than 100kW of generation capacity) Tanzania (for mini grids with less than 100kW of generation capacity)
Central coordination and individualized tariff	Comprehensive approach to regulation and subsidies, based on a centrally coordinated approach where the government identifies areas suitable for electrification by mini grid, defines coverage targets, and proactively attracts operators to serve those areas. Requires mini grids to obtain a permit or license and to follow regulated service standards and grid-compatible standards Regulates tariffs. Provides options for when the main grid arrives. The government may provide information on where it is suitable for mini grids to operate and develop a package of regulation and subsidies that applies in such cases.	Central coordination is appropriate where there is a desire to rapidly expand service in the defined areas. Individualized tariff control is suitable where mini grids are no longer in competition with other sources of energy and have monopoly power.	Nigeria (centrally coordinated approach with least-subsidy tender planned) Madagascar (call for tenders) Bangladesh (information on where mini grid development is suitable and subsidy package)
Uniform tariff	Pursues a vision of geographic equity in electricity service. Requires that all mini grids obtain a permit or license, charge a uniform national tariff, and follow regulated service standards and grid-compatible standards. Provides energy subsidies and provisions for when the main grid arrives.	There is a uniform tariff policy. Expanding access rapidly is not a policy priority. There is a creditworthy subsidy provider, and/or cross-subsidies across a wide customer base are possible. The government can make a credible commitment that the subsidy will be provided over the long term. Administrative capacity is high.	Cambodia (grid-connected SPDs, as of 2017) Kenya (plans for mini grids to operate under contract to national utility and charge the national tariff)

Source: ESMAP analysis.
kW = kilowatt.

COMBINING REGULATORY ELEMENTS IN A PHASED APPROACH

The timing and extent of regulation are key to the development of mini grid sectors. Mini grid markets evolve as mini grids gain power in local energy markets as they mature. This maturing requires regulation to plan on adapting to new circumstances.

- In a nascent mini grid market, light regulation may be enough to achieve good service at the lowest possible tariffs. Mini grids face competition from traditional sources of energy when they start operating in regions where the main grid is unlikely to expand soon. This competition incentivizes mini grids to offer better service at lower tariffs, which reduces the need for regulation. When mini grids gain market power, heavier regulation may be required to ensure quality of service at the lowest possible tariffs. Without regulation, mini grids' position might allow them to excessively raise their tariffs. The challenge is to design a regulatory framework that promotes good service at the lowest cost-recovery tariffs throughout the stages of development of mini grid sectors. Such a regulatory framework needs to be predictable and flexible enough to evolve.

> The goal of a good regulatory framework for mini grids should be to promote good service at the lowest cost-recovery tariffs throughout the stages of development of a country's mini grid sector, taking into account subsidies and broader national electrification strategy. As a result, a regulatory framework for mini grids needs to be predictable yet flexible enough to evolve as the market evolves.

Defining different regulator phases for the short, medium, and long terms is one way to provide investors with regulatory predictability and certainty while allowing regulation to evolve. An example of a phased approach is shown in table 9.9.

Over two decades, Cambodia's regulation evolved from laissez-faire to a uniform national tariff for grid-connected SPDs (box 9.2). Regulation was introduced in the early 2000s and was applied progressively, evolving alongside the market. The proposed evolutionary framework approach would be different from Cambodia's experience, as the different phases of regulation would be defined from the start to provide certainty and predictability to investors. Cambodia's path from unregulated tariffs to uniform national tariffs is not the only path (for example, a country could go from unregulated to a price cap or an individualized cost-based tariff).

Thresholds to move from one phase to another should be established. The transition from the starting phase to the medium-term phase could be triggered by any of several criteria, including the number of years since the first mini grid was registered and initial market penetration. The transition from medium-term to long-term regulation could be triggered by the same criteria, but the levels would be higher (for example, 15 rather than 5 years since the first mini grid registration).

TABLE 9.9 • Three phases of evolutionary regulation

Area	Start	Threshold 1	Medium term	Threshold 2	Long term
Entry	Registration	Five years after first mini grid is registered Number of customers served reaches a certain level (for example, 40 percent of total identified in a national geospatial analysis) Average power consumption per customer reaches a certain level (for example, 40 percent of average main grid consumption)	Registration	Fifteen years after first mini grid is registered Number of customers served reaches a certain level (for example, 80 percent of total identified in a national geospatial analysis) Average power consumption per customer reaches a certain level (for example, 80 percent of average main grid consumption)	Permit/license
Tariff	Willing buyer–willing seller		Efficient new-entrant price cap		Individualized cost-based tariff
Service standards	Reporting		Differentiated regulated standards		Main grid-level standards
Technical standards	Safety standards Optional grid-compatible standards		Safety standards Optional grid-compatible standards		Safety standards Optional grid-compatible standards
Subsidies[a]	Implicit subsidies (for example, market or site information provided for free; land provided for free; favorable tax treatment) Capital subsidies		Capital and/or connection subsidies		Ideally not needed in the long term, but where needed, connection subsidies or, in the case of mandatory uniform tariffs, energy subsidies

Source: ESMAP analysis.
Note: The ability to transition from one regulatory package to another also depends on the administrative capacity of the regulator. Moving from left to right in the table requires an increase in the regulator's capacity.

a. See chapter 6 for a detailed discussion on subsidies.

Evolutionary regulation requires capacity at the outset to develop the credible, legitimate, and transparent system that will apply in the future. To attract investment under such a system, a government needs to credibly commit that it will abstain from intervening until the trigger is reached and will regulate as planned from then on. To provide such credibility, governments may consider using partial risk guarantees—a form of insurance that provides the private party with compensation for the failure of the regulator (or other government agency) to implement the regulation as written.

REGULATORY INNOVATIONS TO FURTHER INCENTIVIZE PRIVATE-SECTOR INVESTMENT IN MINI GRIDS

Even when regulatory frameworks for mini grids are well designed and implemented correctly and consistently, many investors will hesitate to commit millions of dollars of capital under a regulatory regime that rests solely on the discretion of independent regulators. What additional tools, then, are available to provide confidence to investors, while

BOX 9.2

FROM LAISSEZ-FAIRE TO COMPREHENSIVE REGULATION: CAMBODIA'S SUCCESSFUL ELECTRIFICATION WITH MINI GRIDS

In the 1990s, mini grids emerged in Cambodia under de facto laissez-faire conditions following the civil war and the Vietnamese occupation. By 2001 an estimated 150–300 diesel-fired mini grids provided power to 72,000–182,000 customers. These mini grids provided valuable services on a fully privately financed basis, with no regulation of entry, tariffs, service, or technical standards. They provided electricity to towns and villages that would not otherwise have been supplied. Although the charges of about $0.55/kWh were high by the standards of other countries, customers were pleased to get service even at these prices.

In 2001 the Cambodian government started to regulate the sector, taking a gradual approach. The Electricity Law passed in 2001 required all mini grids to obtain a license, charge tariffs approved by the Electricity Authority of Cambodia (EAC), and meet service and technical standards. The government used the following carrot-and-stick strategy to ensure compliance:

- Most mini grids came to the EAC to seek a license spontaneously, possibly because the license granted exclusive right over the service area.
- EAC advised mini grid operators on compliance with the standards and granted longer licenses to operators who showed improvements. It allowed tariffs to cover the investments required to upgrade licensee's distribution systems.
- In parallel, the Cambodian government distributed subsidies through the Rural Electrification Fund (REF), established in 2005 and financed by a $40 million loan from the World Bank. The REF implemented several programs, including a $45 per connection grant that ran from 2005 to 2012 and, starting in 2013, a zero-interest loan to pay for households' connection fees along with viability gap finance and funding for medium- and low-voltage lines.

Under these circumstances, mini grids expanded electricity access, lowered costs, and improved the quality of service. By 2016 at least 341 mini grids (including grid-connected mini grids [SPDs] that have up to 16,000 customers) were serving 1.3 million customers. Most mini grids interconnected with the main grid, which allowed them to decommission their expensive diesel generators and buy bulk power from the grid. In effect, they became SPDs. As a result, average tariffs fell to $0.24/kWh in 2016.

Regulation progressively tightened. Since March 2016, the government has been implementing a uniform national tariff program for grid-connected SPDs. Licensees buying bulk power from the national grid must charge a tariff converging toward the uniform national tariff (except in Phnom Penh and Takhmao, where Electricité du Cambodge [EDC] has a different tariff). This uniform tariff is below SPDs' cost-recovery tariff; the REF covers the difference with funds provided by EDC. This ongoing subsidy amounted to about $30 million in 2016. The EAC continues to calculate cost-recovery tariffs for individual SPDs, but the methodology has become more stringent, with SPDs' distribution margins decreasing from $0.16/kWh in 2011 to $0.05/kWh in 2016.

Source: World Bank 2017b.

also responding to unexpected events and developments? And how can this be achieved while assuring customers that their point of view is being considered and avoiding the risk of public backlash after being seen as offering too much protection to investors?

Two innovative regulatory mechanisms can address these questions:

- ***Regulation by contract,*** in which regulatory decisions are made subject to rules agreed to by both the developer and the government; and
- ***Arbitration-style appeal mechanisms,*** in which appeals against regulatory decisions are decided by a special tribunal constructed to balance the interests of the investor and the consumers.

These two mechanisms coexist alongside the different options discussed so far in this chapter. Regulation by contract usually includes provisions for market entry, tariffs, and service and technical standards, as well as an agreement as to the level of subsidy to be provided if provided by one of the contract signatories. Arbitration-style appeal mechanisms can coexist in any regulatory environment. Table 9.10 considers these mechanisms in turn.

REGULATION BY CONTRACT

Regulation by contract refers to a situation where the rules that govern tariffs (including mechanisms to adjust tariffs), services standards, and other conditions are embodied in a contract.[10] The rules and processes for adjusting terms and conditions are also embodied in the contract. Regulation by contract is often accomplished through rural electrification concessions, such as those in Madagascar, Mali, Senegal, and Uganda (World Bank 2015). Where contract law is respected, but regulators have not yet developed the track record needed to be credible to investors (or where formal regulatory agencies do not exist), regulation by contract may be a good option to boost investor confidence.

Contracts cannot be unilaterally changed, which can make regulation by contract more credible than independent discretionary regulation. Independent regulators often have broad discretion to change tariffs, or to change the rules and formulas by which tariffs are set. Under regulation by contract, these changes cannot be made unless both parties agree.[11] "From a legal perspective the concession is a contract between the government and the regulated company, the terms and conditions of which can only be altered by mutual consent" (Brown 2010). The essential point that differentiates regulation by contract from independent dis-

TABLE 9.10 • Two innovations in regulation that can further incentivize private-sector investment in mini grids

Option	Description	Suitable where . . .	Examples
Regulation by contract	Rules that govern tariffs, services standards, and other conditions are embodied in a contract between a public party (such as an REA, a municipality, or a local community) and the developer. The public party to the contract may be the central government, an REA or fund, a local government, or a customer collective.	Contract law is respected, and contracts can be enforced quickly and fairly. Regulators do not exist or do not have the track record needed to be credible to investors. There is a legal framework that enables contracts between government and private companies for the supply of public services. There is a centrally coordinated approach to mini grid development with competitive tenders. There is administrative capacity on both sides to negotiate the terms of the contract.	Nigeria (tripartite contract between developers, the local distribution company, and communities served, for grid-connected mini grids) Mali (rural electrification concessions) Madagascar (rural electrification concessions) Senegal (rural electrification concessions) Haiti (tripartite contract between developer, local government, and grant-giving government entity)
Arbitration-style appeal mechanism	Appeal: mechanism that enables investors to appeal a regulator's discretionary decisions to a neutral body. Arbitration: appeal model based on a balanced composition of the appellate body (each party chooses a member and the third is agreed upon by both parties).	Investors are concerned about the quality of regulatory decisions. The cost of arbitration is not disproportionate compared with the value of sums at stake. There is enough capacity on both sides to appoint arbitrators and manage the appeal process. Judicial or administrative appellate processes are inadequate.	Jamaica (Appeal Tribunal provided for in the license of the privately owned electricity utility)

Source: ESMAP analysis.
REA = rural electrification agency.

cretionary regulation is that under the first, public authorities cannot change the rules unilaterally.

A variant of regulation by contract occurs when one of the signatories is providing a subsidy. In Bangladesh, IDCOL, a government-owned financial institution, provides loans and grants to the mini grids in the country's mini grid program. The financing agreement with IDCOL controls the tariffs and sets the service and technical standards of the mini grids, providing a practical and flexible way to ensure that financing and regulatory parameters are aligned. It also avoids duplication by having a single agency responsible for both subsidy and regulation. This model does not yet, however, protect mini grids from independent discretionary regulation because, legally, they still require licenses from the Bangladesh Energy Regulatory Commission (BERC) and may be subject to BERC's regulatory control. Government policy is to remove mini grids from the licensing requirement, but this policy has not yet been made legally effective.

Tripartite contracts are another variant of regulation by contract. In Nigeria, grid-connected mini grids must sign a tripartite contract with the distribution company whose lines the mini grid is connected to, and the community it serves. The tripartite contract is designed to complement the formal mini grid regulations, and allows for the mini grid to act as if it were a delegate of the licensed distribution company, charged with improving service in an underserved area. The Nigerian Electric Regulatory Commission provided a template of a tripartite contract in Annex 11 of the 2016 mini grid regulations (NERC 2016). In Myanmar, a model tripartite contract between the developer, the government (Department of Rural Development), and the village electrification committee has also been developed. Since there is no national mini regulatory system in Myanmar, the tripartite contract is the de facto regulatory system for new mini grids (DRD 2017). Haiti developed a similar tripartite agreement between the developer, the local government, and the Ministry of Public Works, Transportation, and Communications, which provides a subsidy to the developer. In the absence of a formal mini grid regulatory framework, the template contract can both kickstart the nascent mini grid sector and lay the groundwork for a more formal framework based on how the sector evolves. The template contract was initially drafted with support from ESMAP in consultation with mini grid developers, municipal governments, and the grant-giving ministry through a series of workshops.

Contracts for mini grids could be bolstered by partial risk guarantees (PRGs) issued by the World Bank or other international finance organization (Tenenbaum, Greacen, and Vaghela 2018). The PRG would create an added incentive for the government or regulator to comply with the regulatory terms of the contract. A PRG is a form of insurance that the government entity signing the contract will adhere to the terms in the contract. If the government agency fails to do so, the PRG could compensate the private party. Within the broader electricity sector, PRGs have been used to support regulatory contracts that accompanied the successful privatizations of large electricity distribution enterprises in Uganda and Romania. The PRGs provided for financial compensation when the regulator failed to implement provisions of the contract, such as tariff-setting provisions. The PRG contributed to the success of these regulatory contracts.

One lesson learned from this experienced is that the transaction costs of establishing a PRG to back up a regulatory contract can be considerable. Therefore, PRGs are probably feasible only for larger groups of mini grids selected through a centralized competitive procurement, rather than for individual mini grids that come into existence through spontaneous initiatives.

ARBITRATION-STYLE APPEAL MECHANISM TO COMPLEMENT A LIGHT-HANDED REGULATORY APPROACH

An arbitration-style appeal mechanism enables investors to appeal a regulator's discretionary decisions to a neutral body that can overturn those decisions on grounds such as bias, failure to follow due process, or noncompliance with stated regulatory principles and rules.[12] "The appellate process, at a minimum, is largely designed to accomplish three things: assure that the regulator adheres to and does not exceed its legal authority and powers, to protect against arbitrary exercise of its powers, and to assure that all required legal processes were followed" (Brown 2010).

Of the three main types of appeal mechanisms—judicial or quasi-judicial, governmental, and arbitration—the arbitration model can be used where there is a desire to insulate regulatory decisions from politics and where there are concerns that the judiciary is ill-equipped (Brown 2010). The essence of the arbitration model is the balanced composition of the appellate body. Following standard principles for commercial arbitration, each party choses one member of an appeals panel. Those two members then agree on a third panel member, who becomes the chair of the appeals panel. There is usually a provision for a neutral party—presidents of the engineers' association or law society—to appoint the chair of the appeals panel, if the first two members cannot agree.

Once constituted, the appeals panel follows a process that is a similar to a court, but with more flexibility allowed—for example, in consideration of evidence and use of experts. The panel may be given a broad authority, including setting aside a regulatory decision and requiring the regulator to retake it after correcting flaws identified by the appeals panel, or substituting the appeals panel's own judgement for that of the regulator.

Jamaica has a well-developed system of independent regulation where decisions of the Office of Utilities Regulation with respect to regulation of the privately owned electricity utility may be appealed to a panel constituted on the arbitration model. Although Jamaica's electricity utility is much larger than a mini grid—with a peak demand of 600 megawatts—it provides a model that could be adapted to mini grids.[13] In Jamaica, this appeals mechanism was important in creating the investor confidence needed to attract millions of dollars of private finance for investment in electricity distribution and generation. The independent appeal tribunal in Jamaica is described in box 9.3.

Two regulatory innovations have emerged to further incentivize private-sector investment in mini grids: (1) regulation by contract, in which mini grid regulations are embodied in a legal contract; and (2) an arbitration-style appeal mechanism, in which an independent entity or tribunal can be asked to review a regulator's decisions, with the authority to overturn the regulator's decision.

INVESTORS' PERSPECTIVE ON MINI GRID REGULATIONS

Through conversations with private-sector investors and building on the International Finance Corporation's extensive experience investing in infrastructure projects around the world, we have identified four characteristics of mini grid regulations that investors perceive as barriers to investing in mini grids.

BOX 9.3
INDEPENDENT APPEAL TRIBUNAL IN JAMAICA

Jamaica has a well-developed system of independent regulation, where the regulator's decision with respect to regulation of the privately owned electricity utility may be appealed to a panel constituted on the arbitration model.

The regulator (Office of Utilities Regulation, OUR) has regulatory discretion with respect to regulation of the Jamaica Public Service Company (JPS), the privately owned national electricity utility. JPS's license, however, contains detailed rules that spell out how tariffs are to be set in a way that limits discretion and resembles a regulatory contract. The licensee, JPS, has the right to appeal a decision by OUR through a tribunal. The decision of the tribunal is binding for both parties (regulator and licensee).

This tribunal is similar to arbitration in the way that the members are appointed. Condition 32 of JPS's electricity supply license states as follows:

> If the Licensee is aggrieved by a decision of, or failure to act, by the Office, under this License, the licensee is allowed to appeal to the Appeal Tribunal (hereinafter called "the Tribunal")
>
> The Tribunal shall consist of three (3) members appointed by the Minister as follows:
>
> (a) one member shall be a former Judge of the Supreme Court or the Court of Appeal and shall be the Chairman of the Tribunal:
>
> (b) one member shall be appointed on the recommendation of the Licensee; and
>
> (c) one member shall be appointed on the recommendation of the Office.

Although the license mentions that the members of the Appeal Tribunal are "appointed by the Minister," in effect one is nominated by the utility, one by the regulator, and the deciding vote in case of disagreement rests with the third, who must be a retired high-ranking judge. In Jamaica, the judiciary has a good reputation for independence, which is partly why investors accepted this formulation.

This appeal mechanism was instrumental to the privatization of JPS, which needed guarantees that it would be able to charge reasonable tariffs. Ultimately, it helped create the investor confidence needed to attract millions of dollars of private finance for investment in electricity distribution and generation; according to JPS's annual reports, the utility has invested more than $500 million over the past 10 years.

Source: Jamaica Gazette 2016.

- ***Unclear or overly burdensome market entry processes**:* Unclear rules on licensing procedures and registration of assets is a major barrier to investment. In some countries, there is a lack of clarity on which licenses or permits are required, which entities issue them, and what the requirements and timing are for renewing them. This poses a significant risk from an investor's perspective. Furthermore, a government track record of complicated market-entry procedures or lack of capability that has led to multiyear delays in mini grid developers obtaining licenses or permits would send a signal to many investors that the market is not fit for private-sector investment.
- ***Politically motivated or opaque tariff regulations**:* If the tariff-setting process is politically motivated or opaque, it is difficult for the regulator to maintain support for tariffs that are economically viable for mini grid developers, and it is difficult for developers to design business plans if they do not know how their tariff will be evaluated. This bias or lack of clarity introduces uncertainty around tariffs that would dissuade investors from financing mini grids.
- ***Unclear rules or lack of protection for the developer if the main grid arrives**:* If the mini grid regulations do not give economically viable options to mini grid developers for what happens when the main grid arrives, investors are not likely to make long-term investments in mini grids. This risk is compounded if there is a lack of transparency on where and when the national grid will be extended, which makes it challenging for developers to identify potential project sites, and for investors to commit to investing in the sector.
- ***Lack of protection from government breach of contract**:* Legal contracts play an important role in regulations, not only in countries that opt for a regulation-by-contract approach, but also for regulatory regimes that have license agreements or other contractual arrangements between the government and the developer. If there is a need for the developer to enter into a contract with the government or the utility, a lack of protection for the developer if the government or utility defaults on its contractual obligations would be a red flag for potential investors.

The above four barriers are balanced by the following four "must haves" in a regulatory regime necessary to attract external investment into the mini grid sector:

- **Adequate capacity by the regulator to implement its regulations**: Investors require at least a minimum threshold (though this threshold is not well defined) of regulator capacity to be able to carry out its duties, such as review and approval of tariffs; issue licenses; and respond to complaints. Investors have also cited a "one-stop shop" for all relevant permits and approvals for all bureaucratic processes related to starting and operating a mini grid business as a "nice to have" (though not a "must have"), which makes the mini grid sector more attractive as an investment opportunity. Additional streamlining can be achieved by combining licenses and permits for generation, distribution, and electricity supply.
- ***Clear procedures for tariff review and approval**:* Simplified and transparent tariff review, approval, and revision processes, as well as clear benchmarks or calculations against which mini grid tariffs are reviewed, are "must have" elements of the tariff review and approval process for investors. An additional "nice to have" that investors have suggested is the availability of external assistance for the developer when it applies to the regulator for its tariff schedule approval.
- ***Clear main grid expansion plans, combined with viable options for the developer when the main grid arrives**:* The existence of grid expansion plans, ideally with clear explanations of how the plans were developed (for example, least-cost approach to electrification), combined with economically viable compensation or a continuity plan for when the main grid arrives, are "must haves" for investors. In addition, investors will be looking at whether the grid-arrival options, including a compensation mechanism, cover the developer over a long period.
- ***Compensation mechanism for government breach of contract**:* Any contract the developer enters into with the government or the utility should include a compensation mechanism if the government or utility defaults on its contractual obligations.

CONCLUSION AND RESOURCES

In this chapter, we have presented the different ways that regulators in many countries have dealt with five key regulatory decisions. We suggested ways to combine different approaches into coherent regulatory packages, taking into account how a mini grid sector might evolve over time. We also presented two innovative regulatory mechanisms that can further incentivize private-sector investment in mini grids. Finally, we presented an investor's perspective that highlights the main barriers for mini grid regulations and also the "must haves" to attract private-sector investment.

No single approach to regulating mini grids works best in all settings. But when developing regulations for the first time, changing regulations, and implementing them, the overarching approach should be light-handed. This would entail the following four principles (Tenenbaum and others 2014):

- Minimize the amount of information required by the regulator

> The overarching approach to regulating mini grids should be light-handed, which entails (1) minimizing the amount of information required by the regulator, (2) limiting the number of separate regulatory processes and decisions, (3) standardizing documents and forms, and (4) acknowledging and using related decisions made by other government or community bodies.

- Limit the number of separate regulatory processes and decisions
- Standardize documents and forms
- Acknowledge and use related decisions made by other government or community bodies.

Working together, regulators and policy makers must select the regulatory options that are appropriate for their specific needs and that can attract private-sector investment in mini grids to ensure timely and low-cost access to electricity.

The following resources provide helpful guidance for developing mini grid regulations:

- *Mini Grids and Arrival of the Main Grid-Lessons from Cambodia, Sri Lanka, and Indonesia* (Tenenbaum, Greacen, and Vaghela 2018) is a comparative analysis of regulatory, commercial, and technical characteristics of mini grids before and after the main grid arrived in villages previously served by isolated community-owned and privately owned mini grids. This report also highlights recent technical, commercial, and regulatory developments affecting mini grids in different countries.
- *Practical Guide to the Regulatory Treatment of Minigrids* (USAID 2017) provides guidance for creating an enabling regulatory framework for mini grid development on the issues of mini grid policy and planning, retail service regulation, and technical standards. While this report mostly focuses on regulatory decisions once policy decisions have been made, it offers guidance on policy decisions and how regulators can play a role in these decisions. It also recommended steps for policy makers and regulators once decisions have been made.
- *Policies and Regulations for Private Sector Renewable Energy Mini-grids* (IRENA 2018) gives practical advice on policy and regulation design, covering licensing, tariffs, arrival of the main grid, and access to finance for different technologies and levels of service, based on a wealth of examples from Africa, South America, and Southeast Asia.
- *From the Bottom Up: How Small Power Producers and Mini-Grids Can Deliver Electrification and Renewable Energy in Africa* (Tenenbaum and others 2014) is a guide focusing on regulatory and policy decisions that African electricity regulators and policy makers must make to create a sustainable decentralized track to electrification.
- "Electrification and Regulation: Principles and a Model Law" (Reiche, Tenenbaum, and Torres de Mästle 2006) defines regulation, sets out general principles to apply, and offers a typology of electricity supply models and a model electrification law.

ACKNOWLEDGMENTS FOR THE SIX-COUNTRY CASE STUDIES THAT INFORMED THIS CHAPTER

The authors would like to thank the peer reviewers, Emily Chessin and Jakob Schmidt-Reindhal, for their useful recommendations, and all of the stakeholders interviewed to prepare the six case studies on which this chapter draws.

BANGLADESH

ESMAP wishes to thank Monowar Islam, of the Bangladesh Energy Regulatory Commission, and Md. Enamul Karim Pavel and Ms. Farazana Rahman, of the Infrastructure Development Company Limited (IDCOL), who shared their knowledge and contributed insights into Bangladesh's mini grid framework and experience. ESMAP is also grateful to Chris Purcell of Catalyst Off Grid Advisors for his important contributions; Mahfuzur Rahman, of IDCOL, for organizing the team's visit to mini grid sites; Fuad Sakib, of IDCOL, for showing the team the sites; and the SuperStar Group, SolarGao, and Solar Electro Bangladesh Ltd., for providing insights on their experience in developing mini grid projects in Bangladesh.

CAMBODIA

ESMAP thanks H.E. Dr. Ty Norin, Badri Rekhani, Teng Sokhomal, and H.E. Yim Viseth of the Electricity Authority of Cambodia, who shared their knowledge and insights on Cambodia's mini grid framework and experience. ESMAP also benefitted greatly from substantive inputs from senior officials and managers in government agencies and organizations whom they met during their field trip, including Dr. Loeung Keosela, of the Rural Electrification Fund Department of Electricité du Cambodge, and H.E. Victor Zona, of the Ministry of Mines and Energy. The case study was enriched by reviews and contributions from experts in the power sector in Cambodia, including Rin Seyha, Un Roeurn, and Sophal. ESMAP is also grateful to mini grid operators

Keo Nguon and Chaek Sean for organizing the team's visit to mini grid sites and providing insights on their experience in developing projects in Cambodia.

UTTAR PRADESH (INDIA)

ESMAP thanks Vikas Chandra Agarwal, S.K. Agarwal, and Sanjay Srivastava of the Uttar Pradesh Electricity Regulatory Commission, and Shruti Deorah, of the Central Electricity Regulatory Commission, who shared their knowledge and insights on Uttar Pradesh's mini grid framework and experience. ESMAP benefitted greatly from substantive inputs from senior officials and managers in government agencies and organizations met during the field trip, including Disha Banerjee, of the Smart Power for Rural Development/Rockefeller Foundation; Deepak Gupta and Saloni Sachdeva, of the Shakti Foundation; and Sangeeta Singh, of the Uttar Pradesh New & Renewable Energy Development Agency. The case study was enriched by reviews from experts in the power sector in Uttar Pradesh, including Debajit Palit, of the Energy and Resources Institute; and contributions from mini grid developers, including Ketan Bhatt, Rohit Chandra, Sarraju Narasinga Rao, and Anil Raj of OMC Power; Nikhil Jaisinghani and Sandeep Pandey, of Mera Gao Power; and Pramod Singh, of Tata Power. ESMAP is grateful to OMC Power for organizing the team's visit to mini grid sites and providing insights on its experience in developing mini grids projects in Uttar Pradesh.

KENYA

ESMAP thanks Silas Chebo, Leah Jara, Caroline Kimathi, Patrick Kungu, and Eng. Joseph Oketch, of the Energy Regulatory Commission; Eng. Isaac Kiva, of the Ministry of Energy; and Eng. Ephantus Kanweru and Francis Mutua, of the Rural Electrification Agency, who shared their knowledge and insights on Kenya's mini grid framework and experience. The case study was enriched by reviews and contributions from experts in the power sector in Kenya, including David Mwangi and Benard Muok. ESMAP is grateful to mini grid developer Stephen Nakholi, of RVE.Sol, for organizing the team's visit and showing its members mini grids in Sidonge, and to David Hirsh, of Powerhive, for providing insights on his experience in developing mini grid projects in Kenya.

NIGERIA

ESMAP thanks Dr. Musiliu O. Oseni and Dr. Abdussalam Yusuf, of the Nigerian Electricity Regulatory Commission, who shared their knowledge and insights on Nigeria's mini grid framework and experience. ESMAP benefitted greatly from substantive inputs from senior officials and managers in government agencies and organizations met during the field trip, particularly Damilola Ogunbiyi and Lolade Abiola, of the Rural Electrification Agency; and Dr. Sanusi Ohiare, of the Rural Electrification Fund. The case study was enriched by reviews and contributions from developers and experts in the power sector in Nigeria, including Bolade Soremekun, of Rubitec Solar; and Dolapo Kukoyi, of Details Commercial Solicitors. ESMAP is grateful to mini grid developers Ifeanyi Orajaka, of GVE Projects, and Okenwa Anayo Nas, of Nayo Tropical Technology, for organizing the team's visit to mini grid sites and providing insights on their experience in developing mini grids projects in Nigeria.

TANZANIA

ESMAP thanks Eng. Godwin Samwel and Eng. Massawe, of the Energy and Water Utilities Regulatory Authority (EWURA); Advera F. Mwijage, of the Rural Energy Agency; and Patrice Tshaklara, of the Tanzania Electric Supply Company Limited (TANESCO), who shared their knowledge and insights on Tanzania's mini grid framework and experience. The case study was enriched by reviews and contributions from experts in the power sector in Tanzania, including Anastas Mbwala. ESMAP is grateful to mini grid developers Joanis Holzigel, of Rafiki Power, and Prosper Magali, of Ensol, for organizing the team's visit to mini grid sites, and to Khalfan Hussein, of Rafiki Power, and Alicia Rutajumbukilwa, of Ensol, for showing the team the mini grids in Changombe and Mpale, respectively, and providing insights on their experience in developing mini grids projects in Tanzania.

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NOTES

1. The most frequently used statistical definition of an outlier is any data point that lies outside a range defined by 1.5 times the "inter-quartile range" (IQR), or the difference between the 1st and 3rd quartiles.
2. Collecting payment on a regular basis is often a challenge in the early stages of mini grid operations, after the initial enthusiasm has settled in the community. This is mainly due to two reasons: (1) consumers are not used to regular expenses of this kind, and (2) the cost per kWh is a parameter that is not easily compared with the cost of traditional energy services, but it may be easily compared with the kWh tariff of the main grid. Information from email exchange with mini grid expert from INENSUS (mini grid developer), June 2018.
3. The methodology would be to (1) create a stylized efficient mini grid by estimating the financial and technical parameters, including generation capacity, planned outage rate, capacity factor, heat rate (for thermal plants), plant life, construction period, total capital cost (generation and distribution), fixed and variable operating and maintenance cost, and the weighted average cost of capital; and (2) set the tariff following the approach for an individualized cost-based tariff limit.
4. The line rent is set at Tk 120–300 ($1.46–$3.60) a month, depending on the type of consumer (IDCOL 2015).
5. In Sierra Leone the tariff is one of the criteria in the multiattribute process, but it remains to be seen whether the tariff approved by the regulator will be set at the winning bid tariff. The bid product will depend on the business model in the public-private partnership arrangement (it may be an engineering, procurement, and construction contract, as in Kenya, or a build-own-operate contract (as in Nigeria) (Tenenbaum, Greacen, and Vaghela 2018).
6. A recent ESMAP technical report presents case studies for three Asian countries (Cambodia, Indonesia, and Sri Lanka) of what happened to existing community-owned and privately owned mini grids when the main grid arrived at their villages (Tenenbaum, Greacen, and Vaghela 2018).

7. *Abandonment* means that the assets are left in place as is. *Decommissioning* means the assets are entirely or partly dismantled and no longer functional.
8. Battery technology at mini grid scale costs about $0.25 to $0.40/kWh, which may not be cheaper for the utility than running peaking plants (Lazard 2018).
9. According to Brown, Stern, and Tenenbaum (2006), regulatory systems are credible when investors "have confidence that [it] will honor its commitments," legitimate when consumers are "convinced that [it] will protect them from the exercise of monopoly power," and transparent when "investors and consumers 'know the terms of the deal.'"
10. Concessions usually include such terms and conditions as the price paid for the concession, pricing methodology, provisions on when and how tariffs might be changed, monopoly or nonmonopoly status, service expectations, degree of regulatory discretion to which the company is subject, definition of territory to be served, length of concession, capital investment expectations, potential liabilities and other risk exposures, and a host of other requirements (Brown 2010).
11. Rules in a contract might specify how the tariff could adjust over time, but the base tariff or the formulas by which the tariff is set would not be changed unilaterally.
12. This section draws on regulatory theory and examples in the electricity sector. No examples in the mini grid sector have been found, given the relatively nascent state of mini grid regulation.
13. No examples of a fully developed arbitration-style appeal mechanism were found in the mini grid sector, although arbitration clauses are relatively common in power purchase agreements (for example, in Tanzania's standardized power purchase agreement) and other contracts between a developer and the government (for example, in Haiti's concession agreement).

CHAPTER 10

CUTTING RED TAPE FOR A DYNAMIC BUSINESS ENVIRONMENT

CHAPTER OVERVIEW

This chapter presents four mechanisms that can help develop an enabling business environment for mini grids: (1) reducing red tape through standardized agreements and processes; (2) using technology platforms to connect developers with investors and suppliers in large-scale mini grid tenders; (3) eliminating duplication of government oversight by delegating authority to a single entity (or a formal regulator); and (4) setting up e-government services to reduce the overhead cost of business registration, land and building permits, and environmental approvals. All four mechanisms can be deployed in parallel, and each has the potential to make it significantly easier, and less risky, to do business as a mini grid.

WHY AN ENABLING ENVIRONMENT MATTERS

Private-sector players—both investors and developers—operate within business-enabling environments that give them confidence to invest. They will be putting their money into assets with 10- to 20-year lives and will earn a return on their investment only if the business of selling electricity is profitable. However, in our conversations with investors and developers, a common theme emerges: "We're not willing to commit millions of dollars of capital to mini grids in countries where it's just too difficult to set up and run a mini grid business."

Mini grid developers must navigate multiple layers of bureaucracy as they build, own, and operate their mini grids. From an investment standpoint, each additional approval, review, permit, license, or other bureaucratic process constitutes a risk to the business. Sometimes more than 20 clearances are needed before a company can start operating a business. Simplified and standardized approaches to overseeing mini grid businesses would help reduce risk—and overhead costs—for developers. The end result would be more mini grids providing more access to affordable electricity for large groups of people who would otherwise wait years for a main grid connection. This is particularly important in countries with high electricity-access deficits.

> Mini grid developers often must navigate a complex and murky path of permits, regulations, and contracts as they build and operate their mini grids. Sometimes more than 20 clearances are needed before a company can start operating a business. From an investment standpoint, each additional approval, review, permit, license, or other bureaucratic process constitutes a risk—and therefore a cost—to the business.

This chapter offers four ways to increase the ease with which mini grid developers can set up and operate their businesses.

- Reduce red tape through standardized agreements and processes.
- Use technology platforms to connect developers with investors and suppliers and to stage large-scale tenders to reduce inefficiencies in the market.

- Eliminate overlaps in government oversight by delegating authority to a single entity, whether or not that entity is a formal regulator.
- Set up e-government services to reduce overhead associated with business registration, land and building permits, and environmental approvals.

All four mechanisms can be deployed in parallel, and each has the potential to make it significantly easier, and less risky, to do business as a mini grid.

The four strategies presented in this chapter do not address all of the bureaucratic processes that mini grid developers must navigate, many of which are described in earlier chapters. However, the options presented here can be implemented in the near term using existing resources and institutional structures. They would complement most other initiatives described earlier, including those aimed at reducing the risks of corruption and expropriation.

Each of the four strategies presented in this chapter requires a certain amount of government capacity to implement. We address this issue throughout the chapter and refer readers to chapter 7, which covers training and skills building.

CHARACTERISTICS OF DOING BUSINESS AS A MINI GRID

Mini grids operating in low-income countries have several unique characteristics that affect how they interact with, and are affected by, the business environment.

LONG-LIVED SUNK ASSETS

As in other infrastructure sectors, most of the investment in a mini grid business—particularly when powered by renewable sources of energy—goes into assets with high upfront capital costs, long lifetimes, and typically no alternative uses. That is, most mini grid businesses have high sunk costs.

The importance of sunk costs becomes clear when comparing mini grids' capital assets with assets that are mobile, such as those of a bus operator. Buses can be sold at full market value to bus companies in another jurisdiction if the business environment suddenly became unfavorable. This is not the case for a mini grid operator. While some assets—such as containerized battery systems or solar photovoltaic (PV) modules—can be moved and sold, others, such as the distribution grid or a mini hydropower plant, cannot. The only way an investor can recover its investment in sunk assets, and earn a return, is by earning revenue over the asset's life (except in special cases when the main grid arrives, as discussed in chapter 9). For this reason, investors require that the rules governing their business be stable and predictable.

UNPREDICTABILITY AND THE NEED FOR FLEXIBILITY

Unpredictable changes in demand, technological innovation, and other factors will have significant effects on the profitability of mini grids over their lifetime. For example, demand for electricity grows as consumers gain access to it. When existing customers start to consume more energy, the average generation cost per kilowatt-hour (kWh) will go down. If the tariff stays at the same level, the mini grid will earn returns above its cost of capital.

The costs of many mini grid components are also decreasing over time (see chapter 1). New battery technologies will bring down the cost of supplying power at night. Other factors—such as exchange rate depreciations, unfavorable changes to the tax code, or extreme weather events that damage systems and require expensive rebuilds—push costs in the opposite direction.

If policies, taxes, and rules and regulations for doing business kept pace automatically with exogenous factors like those mentioned above, investors could have complete certainty about how their investment would be affected. In practice, an unknowable number of factors may change over time, and political and regulatory decisions can neither keep pace with nor account for all of them. Thus, at least some of the current rules and policies that define the business environment will lag behind the actual conditions experienced by businesses. In other words, no contract is ever complete. This phenomenon has been called *the contractual incompleteness problem.* Parties can write a solid contract now, but it cannot possibly account for every eventuality (Brown and others 2006, 114). As a result, developers need a business environment that is conducive to operating flexibly, so that they can adapt—taking advantage of changes that drive down their cost of electricity and absorbing shocks in a way that does not put them out of business.

THE POLITICAL NATURE OF ELECTRICITY

In many countries where large portions of the population do not have access to electricity, electricity is a political tool. Those seeking to win favor from the public will promise to provide or reduce the price of electricity (Bakovic, Tenenbaum, and Woolf 2002, 12–14). If reducing the price of electricity led to shortages of electricity, the problem would self-correct: no one votes for power cuts. However, because most of the costs of a mini grid are sunk, mini grids can continue to operate (for a while), even at tariffs far below their average cost of service. Cutting tariffs is a tempting target for politicians. Investors in the mini grids would lose their investment, but the political calculus is that investors' votes are few compared with the many votes of electricity consumers.

This path is particularly tempting in communities that willingly agreed to a tariff before they had electricity and move quickly from being delighted just to have electricity to a phase of being pleased to have electricity but complaining about its cost. In the village of Bisanti, in Nigeria, after receiving electricity for the first time, inhabitants proudly told visitors about how they were the only place in Nigeria to have had uninterrupted power supply for two years and how pleased they were to have electricity. All customers interviewed quickly moved on to explain that the cost of power was too high and that a way had to be found to bring the costs down.[1]

There are enough episodes of political pressure creating unfavorable business environments for mini grid companies in low-income countries that investors are wary of this risk.

- In Cambodia the regulator has been tightening the calculation of full-cost-recovery tariffs, reducing distribution margins for grid-connected small power distributors (Tenenbaum, Greacen, and Vaghela 2018).
- In Nigeria all mini grids built and planned prior to 2017 were "registered" (which allows for unregulated tariffs), and no investor opted for a "permit" (which comes with regulation of tariffs and service standards, as well as protection of assets when the grid arrives). This pattern suggests that investors were waiting to see whether the business environment—and in particular, the additional regulation that comes with receiving a permit—would allow them to earn the returns they need.[2] One Nigerian mini grid operator commented that political risks were the biggest threat. He has invested in containerized generation and battery storage units in part so that he can remove these units if political factors affect the viability of his business.[3]
- In Tanzania several investors interviewed expressed reluctance about investing because of concerns about how the regulation would be enforced or fears that rules might change after they invested. One developer expressed concerns about the lack of clarity on how the Energy and Water Utilities Regulatory Authority would enforce tariff regulation. Others expressed concerns about how the authority might use its discretionary power to approve the conversion to a small power producer (SPP) or small power distributor, or how it would compensate assets once the main grid arrived. One mini grid developer indicated that it was holding off from investing in a project because of a proposal made by the regulator to remove the existing stipulation that feed-in tariffs would not be changed retroactively. This proposal was not implemented, but the example illustrates that investors are reluctant to invest wherever they fear that the rules could be changed after they have sunk their investment.[4]

Some elements of the business environment—notably a strong legal system that includes competent, independent judicial oversight or review—can mitigate these political risks (Brown 2012). In countries that lack effective rule of law and judicial protections for investors, other mechanisms are needed. These need to be credible and to give investors confidence that commitments will be honored and that they will be dealt with fairly.

> Mini grids operating in low-income countries have several unique characteristics that underpin how they interact with, and are affected by, the business environment. To start with, most of the investment in a mini grid business—particularly when it is powered by renewable sources of energy—goes into assets with high upfront capital costs and long lifespans. Changes in demand, technological innovation, policies, taxes, and rules and regulations are often unpredictable. Finally, electricity is a political tool, so political expediency risks compromising economic viability. These factors make it even more important that mini grid developers operate in an environment that is conducive to starting and operating a business.

FOUR COMPLEMENTARY OPTIONS TO MAKE IT EASIER FOR MINI GRID DEVELOPERS TO DO BUSINESS

This section presents four complementary options that can make it more attractive for investors and developers to do business. They emerged from in-depth case studies of mini grids in Bangladesh, Cambodia, Kenya, Nigeria, Tanzania, and Uttar Pradesh, as well as from World Bank experience in other countries, including Haiti, Mali, Myanmar, and Nigeria. The options are not mutually exclusive and may be complementary.

The four options are summarized in table 10.1 before being described in separate sections of the text.

TABLE 10.1 • Options for making it easier for mini grid developers to do business

Option	Description	Advantages	Disadvantages	Suitable where . . . [a]	Examples
Reduce red tape through standardized, preapproved templates and contracts.	Standardized power purchase agreements (PPAs) govern what happens when the mini grid connects to the main grid and sells electricity to the main utility company. A standardized asset transfer template is used when the mini grid sells its assets to the main utility company or a distribution network operator. A standardized social and environmental management system makes it easier for developers to track and manage their social and environmental impacts.	Standardized PPAs and standardized asset transfer templates reduce risk for developers by increasing their negotiating power with the main utility or other purchasing entity. Standardized social and environmental management systems reduce costs for developers compared with creating their own environmental and social management system. They also reduce costs for the regulatory or oversight authority, which would otherwise have to monitor compliance.	Standardized documents and processes are not tailored to the unique needs and characteristics of individual projects or deals. This risk can be mitigated by allowing the parties to the agreement—or the developer for its environmental and social management system—to make changes to the standardized template, though these changes would require review and approval by the appropriate authority.	Standardized PPAs and asset transfer agreements can be enforced as contracts. The utility is able to pay on time for the electricity that it purchases from the mini grid under standardized PPAs. The purchasing entity is able to pay on time for the assets it agrees to buy. Formal requirements to monitor the environmental and social aspects of mini grid projects are in place or are being developed.	Nigeria: A standardized environmental and social management process is being developed. Tanzania: A standardized PPA cap is in place for mini grids and small power producers. ESMAP developed a standardized asset transfer agreement for the regulator in Tanzania.
Use technology platforms to connect developers with investors and suppliers and to run large-scale mini grid tenders.	A technology platform receives data from developers about their mini grid projects, standardizes the data, and makes it available to investors and suppliers. The goal is to help investors finance mini grid portfolios and to help developers secure financing and attractive deals from component suppliers. The platform can also be used for large-scale tenders of mini grid projects and portfolios where the standardized presentation of developers' projects facilitates bid review.	Dramatically streamlines the process for connecting investors with developers. Reduces the time and resources required to run a large-scale tender for mini grids. Levels the playing field by enabling all mini grid projects to be evaluated by potential investors across the same metrics. Serves as a useful tool to share market intelligence in a controlled way. Standardizes applications for mini grid tenders, facilitating transparent comparison of applications (reducing opportunities for corruption). Makes it easier for the government to manage large amounts of data.	Relies on a single platform, which may create a bottleneck in the market if there are technical problems with the platform and if the platform is the only way developers can legally bid for mini grid sites. May pose privacy concerns for some developers and investors. May crowd out small-scale developers or community-led mini grid projects by catering more to larger-scale developers with greater technical and administrative capacity.	A large cohort of developers exists possessing the capacity to provide data on their projects as required by the platform. Large-scale tenders are being planned for dozens or hundreds of mini grids. Financial investors are seeking to invest in portfolios of mini grids.	Nigeria: The Odyssey platform is being used for the tender of 250 mini grids. Economic Community of West African States (ECOWAS): The Odyssey platform was used for a renewable energy mini grid tender.

Option	Description	Advantages	Disadvantages	Suitable where . . . [a]	Examples
Eliminate duplication of government oversight by delegating authority to a single entity when no formal regulator for mini grids exists.	In the absence of a formal regulator, the national government delegates oversight of mini grids to a single government entity that knows the context well (typically a rural electrification agency, local government, or government agency providing financial support for rural development activities).	Gives investors confidence that only one government entity will have primary oversight authority over their business. Enforcement of regulation may be easier in the case of delegation to local governments. Complex interfaces between agencies can be avoided if the subsidizing agency also acts as the regulator.	Some local governments may lack financial and human resources to design and enforce a regulation, and different jurisdictions may have different rules, making it more difficult for developers to build in multiple jurisdictions. Delegating authority to a grant-giving agency may result in conflicts of interest.	No formal regulatory agency is tasked with overseeing mini grids. A legal framework explicitly grants authority to local governments or to a specific government entity.	Nigeria, Haiti, and Myanmar: Community agreements. Bangladesh: Grant-making government entity has authority. Mali: Rural electrification agency has authority.
Set up e-government services to reduce overhead costs.	These initiatives provide businesses (and citizens) with a way to interact online with government agencies online to perform bureaucratic tasks such as business registration, land and building permits, and environmental approvals. Ideally this would be done through a one-stop shop specific to mini grids.	The main advantage for developers is that it speeds up many processes that would normally take days or weeks to accomplish in person. It can also increase transparency, as electronic records can be accessed by the relevant stakeholders as needed.	E-government initiatives require security and data protection on both ends (government and citizen or business), and these may not yet be possible in some countries. E-government initiatives can also "disenfranchise" small businesses and households that do not have reliable access to the internet.	Governments have adequate data protection and online security available to protect sensitive data.	Nigeria: "National e-Government Strategies" Kenya: "e-Citizen" India: "e-Governance Infrastructure" Ghana: Recently launched "Forum on e-Governance"

Source: ESMAP analysis.

a. "Suitable where..." does not mean that wherever this condition is fulfilled, the option should be picked. Rather, it means that under these conditions, this option may be well suited, while under other conditions, another option may be better suited. ESMAP = Energy Sector Management Assistance Program.

The Energy Sector Management Assistance Program (ESMAP) has identified four complementary options to make it easier for mini grid developers to do business: (1) reducing red tape through standardized pre-approved templates; (2) using technology platforms to connect developers with investors and suppliers and to run large-scale mini grid tenders; (3) eliminating duplication of government oversight by delegating authority to a single entity if no formal regulator for mini grids exists; and (4) setting up e-government services to reduce overhead associated with business registration, land and building permits, and environmental approvals.

REDUCING RED TAPE THROUGH STANDARDIZED, PREAPPROVED TEMPLATES

Mini grid developers often must navigate a complex and murky path of permits, regulations, and contracts as they build and operate their mini grids. Chapter 9 discusses the mini grid–specific permits and approvals that developers must typically obtain. In addition, developers usually other must wade through other types of red tape (table 10.2).

These approvals may be costly and take time to obtain, making the business environment less conducive to private-sector investment. Box 10.1 provides some brief examples.[5]

Three standardized templates could significantly reduce the cost—in time and money—as well as the risk that developers incur as they build and operate their mini grids.

TABLE 10.2 • General types of bureaucratic processes that mini grid developers navigate

Type of bureaucratic process	Examples
Right to operate a business	Registering as a business Obtaining construction or building permits Registering as a tax-paying entity
Land and natural resource rights	Registering the property Proving ownership or usage rights to land Securing approval of the right to use a specified amount of water or other natural resource
Environmental approvals	Undergoing environmental review at the level specified by the national environmental agency Undergoing review and approval by the river or irrigation authority Obtaining statements from the relevant government agency that the project is not in a protected area.

Source: Tenenbaum and others 2014, 84.

BOX 10.1

THE EFFECT ON INVESTMENT OF PERMITS OUTSIDE THE ELECTRICITY SECTOR

Many countries require mini grid operators to obtain various permits.

In Nigeria, all mini grids must comply with environmental legislation. Developers must obtain an Environmental and Social Impact Assessment Certificate from the Federal Ministry of Environment. According to Nayo Tropical Technology, which was building a mini grid in September 2017, obtaining this clearance could take two years. The ministry and the Rural Electrification Agency are currently developing a more streamlined process.

In Tanzania, Rift Valley Energy was the first operator (other than TANESCO, the national utility) to obtain a license. In addition to the actual electricity license, the operator had to obtain 27 permits, licenses, or agreements from various government bodies.

In Zimbabwe, mini grids must get clearance from the Environmental Management Agency and the Zimbabwe National Water Authority. The two agencies required fees to evaluate the impact of the project. Combined, those fees could represent 6.5 percent of total project costs. One of the agencies recently lowered its fees.

Sources: IRENA 2016; World Bank 2017a, 2017b.

- Standardized power purchase agreements (PPAs) that detail what happens when the mini grid connects to the main grid and the mini grid sells electricity to the main company. This would correspond to the "SPP" and "SPP plus SPD" options discussed in chapter 9.
- A standardized asset transfer template that describes what happens when the mini grid sells its assets to the main utility or a distribution network operator. This would correspond to the "buyout" option discussed in chapter 9.
- A standardized social and environmental management framework to make it easier for developers to track and manage their social and environmental impacts.

The templates touch on three areas developers frequently mention as being difficult, time consuming, and risky. In the absence of standardized PPAs, developers are left with very high levels of uncertainty and risk if they want to connect to the main grid and sell electricity to the main utility, because mini grid developers hold very little bargaining power against the main utility when negotiating on the price of electricity and the conditions of its sale. Similarly, a lack of bargaining power makes selling assets to the main utility or a distribution network operator risky for the developer because it will have difficulty negotiating a fair price. In the absence of a standardized environmental and social management framework, developers are often left with cumbersome, and sometimes conflicting, reporting requirements and operating rules that they must follow.

The three templates help create an enabling business environment that makes it easier not only to *start* a business but also to *operate* one. The first two templates simplify developers' interaction with the main grid if and when it arrives in the mini grid's service area, a topic discussed further in chapter 9. Developers can also present these templates to their investors to show that their investments will not be lost if the main grid arrives. The third template makes it easier to navigate the environmental and social clearances that developers need when starting and operating their mini grids.

Standardized power purchase agreements

In addition to making it easier and less risky for mini grid developers to sell their electricity to the main grid, standardized PPAs can reduce the administrative capacity required by the regulator and eliminate the need for a regulatory review of each negotiated PPA (Tenenbaum and others 2014). Standardized PPAs typically contain clauses on a variety of terms and conditions related to the price and sale of electricity, the obligations of the utility and the developer, and safety and technical requirements, among others. Table 10.3 contrasts key clauses from two good examples of PPAs, a PPA with a 1.5-megawatt rice husk gasification facility in Cambodia with the standardized PPA in Tanzania.

A well-drafted standard PPA is not enough in itself to protect investors. There must be a requirement in the law for the main grid to sign the PPA. The standard PPA contains protections on top of the existing legal framework (against late payment, for example) that are critical to investors. However, the contract is binding only once it is signed by both parties. Regulation or law should specify that the utility must enter the standard PPA when it connects to an isolated mini grid that is converting to an SPP.

In Tanzania the Electricity Rules require the main grid to enter the standard PPA in cases where the isolated mini grid is allowed to become an SPP (EWURA 2017). In Cambodia there is no standard PPA and no obligation in the law for the main grid to connect to the SPP and enter into a PPA.

Standardized asset transfer agreements

We have not yet encountered a standardized asset transfer agreement in the mini grid sector. ESMAP has created such an agreement for the regulator in Tanzania, but it has not yet been used in practice. However, asset sale agreements

TABLE 10.3 • Key provisions of power purchase agreements in Cambodia and Tanzania

Provision	Cambodia	Tanzania
Obligation to connect	Under the power purchase agreement (PPA), the buyer must make the connection to the small power producer (SPP), with the latter bearing the interconnection costs.	Under the PPA, the buyer must make the connection to the SPP, and the SPP bears the interconnection costs.
Obligation to buy the SPP's output	A "must-take" clause covers 40 percent of the generation capacity, with an option to buy up to 80 percent of the capacity. The SPP must produce no less than the must-take amount.	The PPA states the contract to be a take or pay contract, and the seller's facility to be a must-take facility.a However, because risk of the main grid not being able to receive the SPP's power is largely allocated to the SPP, this PPA is not a take-or-pay contract in accordance with the usual terminology. Grid risk is largely allocated to the SPP through the exclusions to the buyer's obligation to purchase the buyer's entitlement. PPA Article 2(h) states that the buyer may "interrupt, reduce or cease to purchase and accept delivery of all or a portion of the buyer's Entitlement to the extent necessary under Good Utility Practice in order to install equipment, make repairs, replacements, investigations or inspections of the buyer's electric system." PPA Article 2(h) provides that the buyer may "curtail or interrupt" taking power from the SPP "whenever the buyer's system or the systems with which it is directly interconnected experience an Emergency, or whenever it is necessary to aid in the restoration of service on the buyer's system or on the systems with which it is directly or indirectly interconnected." This clause omits the language above related to ceasing to purchase; accordingly it is unclear whether the buyer is still required to pay for buyer's entitlement not taken in such circumstances. As financiers and potential SPPs are likely to perceive grid risk as substantial, the allocation of risk stated above may make it difficult or impossible for SPPs to obtain finance.
Pricing	The regulator preapproved this tariff. The tariff is denominated in dollars and is constant in nominal terms.	The price of the energy sold is defined by regulation. PPAs signed after August 2015 are denominated in dollars and indexed on the U.S. Producer Price Index. This arrangement places the currency exchange risk on the offtaker, which is often a requirement to enable project finance in foreign currency. (In PPAs signed before August 2015, prices were denominated in local currency and indexed to local inflation.)

TABLE 10.3, *continued*

Provision	Cambodia	Tanzania
Enforcement of payment	Late payment attracts default interest at a rate of 20 percent a year. If payment is two months late, a right to withhold supply arises. This contract feature gives the supplier leverage and protection in case of nonpayment; without this provision, the seller would still have to supply following the other provisions in the PPA, even if it is not being paid.	Late payment attracts default interest at the prime rate (announced by the Bank of Tanzania), compounded monthly. Eventual nonpayment gives rights to the SPP to terminate the contract as an event of default (which may be triggered if the buyer does not meet its obligations under the PPA).
Dispute resolution mechanism	Disputes are to be resolved through mutual discussion during a 30-day period. If the discussion fails, domestic courts resolve the dispute.	After a 60-day informal dispute resolution period, either party can appeal to the regulator to resolve the dispute. The SPP could also seek international arbitration to resolve it, in which case then has 20 days to do so. The SPP must reimburse the buyer's travel expenses in case of arbitration. No arbitral rule is specified, and the parties must agree on the location of the arbitration.
Risk sharing	The SPP bears transmission and distribution risks, commercial and market risks, and security-of-supply risks.	The SPP bears transmission and distribution risk (the buyer can claim *force majeure* on its system). The buyer bears some government risk (in case of failure to achieve the commercial operation date for the seller, caused by failure of the government to grant necessary permits).
Changes in law [b]	The PPA does not contain a provision covering changes in law.	The PPA does not contain a provision covering changes in law.
Force majeure	*Force majeure* is defined as events that cannot be managed by the buyer or seller that prevent them from meeting their obligations, including war, riots, demonstration, flooding, and earthquakes.	*Force majeure* is defined as events outside the reasonable control of the parties and not resulting from any of the parties' failure or negligence, including acts of God, fires, floods, epidemics, earthquakes, civil disturbances, insurrections, strikes, and war.
Lender step-in rights	The PPA does not mention lender step-in rights.	The PPA contemplates lender step-in rights. If the buyer is to claim an event of default against the seller, it needs to notify lenders and give them "reasonable time, access, and opportunity" to resolve the default, and cooperate with them to this end. Article 3(c)2 appears to provide both parties with mutual rights to step in to resolve events of default attributable to the other party. This would provide the SPP with the ability to step in and cure events of default on the buyer's grid, so long as the SPP satisfies the requirement that it "has the skills and means to carry out the work necessary" (PPA, Article 3(c)2), which is very unusual.
Termination	A party can terminate the agreement if the other party breaches its obligations and does not remedy the breach within 30 days following written notification. In case of serious breach, the delay is 15 days.	The PPA defines conditions of default. There is an immediate right to terminate the contract upon the occurrence of an event of default, although several events of default also have default and rectification periods specified within them (PPA Article 3(c)1). Conditions for default include failure to complete the project on time, bankruptcy, failure to meet the obligations in the agreement and remedy within 60 days after written notice, failure to make undisputed payment within 90 days, and reorganization of the buyer preventing it from performing its obligations.

Sources: EWURA 2014, 2015.

a. A take-or-pay contract typically specifies an amount of electricity that the offtaker must purchase from the generator. If the contracted amount of kilowatt-hours is not used by the offtaker, the offtaker is still responsible for paying for it. Must-take typically applies to "nonfirm generators" (intermittent renewables) and means that the offtaker must buy whatever amount of electricity is generated by the generator.

b. Changes in law would mean negotiation of the SPP, which may be very burdensome for the regulator and would defeat the purpose of having a standardized PPA (Tenenbaum and others 2014).

are common in other sectors. A standardized asset transfer template for mini grids would be intended primarily for agreements between privately owned mini grids and the main utility or distribution network operator. Before applying a standardized template to a specific deal between two parties or incorporating it into a broader regulatory framework, care should be taken to ensure that the template adheres to existing laws, rules, and regulations and is appropriate for the local context.

In general, a standardized asset template would cover the following topics:

- *Eligibility*. This section establishes that the mini grid's assets are eligible to be transferred to the utility/distribution network operator and that the mini grid owner is eligible for compensation under the regulations governing what happens when the main grid arrives. Assets are typically eligible for sale if they were built to grid-compatible standards and have been maintained well. Typically, only distribution infrastructure—lines, poles, transformers, and meters (if compatible with the utility's billing system)—would be considered for the sale. Movable assets like generators, batteries, and solar panels are typically not sold to the utility but can be repurposed by the developer. Developers are typically eligible if they have registered with, or have received a license or permit from, the regulator and are operating as a legal business within the laws of the country.
- *Bill of assets for sale*. This section identifies and lists the assets that are to be transferred. It should include as much information as possible about the assets, including when they were purchased, when they were installed, and whether they have had any major repairs. The purchasing entity typically has the right to a third-party evaluation of the quality and quantity of the assets and mutually agrees with the developer which assets are to be sold.
- *Compensation mechanism*. This section states how the developer is to be compensated for its assets. Several approaches are possible, such as those outlined in chapter 9. The most common types are (1) compensating the developer for the fair market value of its assets after accounting for depreciation and any grants that the developer received, plus some amount of recent annual revenues (this is the approach in Nigeria); and (2) compensating the developer based on the utility's avoided cost of having to build comparable infrastructure to connect the mini grid's customers, after accounting for depreciation and any grants that the developer has received (this is the approach in Tanzania). The developer and the purchasing entity can mutually agree on the use of a third party to assist with the valuation of the assets. It is too early to evaluate the effectiveness of these different approaches.
- *Notification to relevant entities*. This section identifies the entities that each party to the agreement must notify. These typically include the regulator, the developer's investors and/or board, and the utility's or distribution company's investors and/or board.
- *Signatures*. This section contains the signatures of the parties to the agreement, which are typically accompanied by the signature of one or two witnesses.
- *Annexes* are often used to attach additional information, such as detailed inventories of the assets, accounting information on grants received, or the developer's expenditures on the assets up for sale. It can be particularly useful to provide a worksheet describing how to calculate the compensation due to a mini grid owner for its assets. Another important annex is the certificate of deposit in an escrow account or a bank guarantee letter from the purchasing entity's bank, stating that funds are available and have been set aside exclusively for the purchase of the assets.

A standardized asset transfer template that was developed for Tanzania is available on the companion website to this handbook: www.esmap.org/mini_grids_for_half_a_billion_people.

Standardized social and environmental management frameworks

One of the most intensive clearance processes that developers can face is a review of the mini grid's environmental and social impacts. With these clearances often comes ongoing monitoring of environmental and social safeguards. Streamlining and clarifying the environmental and social management process can reduce risk and overhead costs, making it easier for mini grids to do business.

An example of how to streamline this typically resource- and time-intensive process for both the developer and the government oversight entity comes from Nigeria. The Federal Ministry of Environment is responsible for monitoring mini grid projects, including final reviews of all environmental and social impact assessment reports. The Rural Electrification Agency (REA) developed a standardized Environmental and Social Management System (ESMS) that has been approved by the Ministry of Environment. The system is designed to manage potential environmental and social risks while simplifying the clearances that developers must obtain.

The ESMS is effectively a standardized process for both developers and the REA. Before the standardized ESMS,

FIGURE 10.1 • Nigeria's Environmental and Social Management System for minimum-subsidy tenders for mini grid development

Process steps	E&S Tasks and responsibilities
SITE SELECTION	
Create list of potential sites Conduct site surveys Select project sites based on site survey results	• Include E&S information questions in site surveys • Analyze and verify survey information • Apply E&S Exclusion Criteria for Mini Grid and Power Generation Sites • Estimate land requirement for each site based on expected generation capacity • Prepare tender documents, including E&S requirements
TENDERING PROCESS	
Prepare for competitive tendering process – Lot package – Advertising – Developer information and capacity building – Online platform	• Include E&S information from demand surveys in lot package • Include E&S criteria for developers as part of overall criteria for appraisal and selection of bids (ESMS + clean track record with no environmental or labor fines) • E&S aspect in bid workshop for developers • Grievance Redress Mechanism
Submit bidding package	• Prepare and submit required documents (ESMS as part of business plan) to REA for review and verification • Confirm clean E&S track record
Review and select winning bidder developers	• Review bids to ensure all E&S criteria are met • Liaise with developers if improvement to ESMS is needed (until REA is satisfied that a robust system exists)
Sign agreement	Grant agreement b/w REA and developer includes E&S clause
CONSTRUCTION AND OPERATION	
Prepare for construction	• Conduct E&S screening • Classify sites into E&S risk category (I, II) • Inform REA of outcomes of screening (consolidated report), including if sites fall under E&S exclusion criteria for mini grid and power generation sites • Prepare ESIA, ESMP, RAP/LRP, as applicable • Obtain E&S permits required by law • Conduct stakeholder engagement • Submit relevant documents to REA
Review and verify preparation documents	• Verify developers' information (sample checks for adequacy of the ESIAs, ESMPs, stakeholder engagement process, RAPs/LRPs) *Testing and commissioning can provide a good platform for verification*
Construction and operation	• Conduct construction & maintain good compliance • Maintain a grievance mechanism to address community concerns • Inform REA of incidents or accidents • E&S reporting as part of progress report to REA
Monitor construction and operation	• Monitor E&S performance throughout project • Maintain an REA-level grievance mechanism to address any project-related feedback

Source: Rural Electrification Agency of Nigeria.

Note: Gold shading indicates steps for the REA; blue shading indicates steps for mini grid developers.

E&S = environmental and social; ESIA = Environmental and Social Impact Assessment; ESMP = Environmental and Social Management Plan; ESMS = Environmental and Social Management System; RAP/LRP = Resettlement Action Plan / Livelihood Restoration Plan; REA = Rural Electrification Agency.

FIGURE 10.2 • Nigeria's Environmental and Social Management System for performance-based grants for mini grid development

Process steps	E&S Tasks and responsibilities
PROPOSAL-ACCEPTANCE INTO THE PROGRAM	
Program announcement	• Publish site's selection / eligibility criteria, including E&S exclusion criteria for mini grid and power generation sites • Publish E&S qualification criteria for developers (ESMS + clean track record with no environmental fines or labor fines) • Maintain REA-level grievance mechanism
Prepare and submit proposal package	• Prepare and submit required documents (ESMS as part of business plan) to REA for review and verification • Confirm clean E&S track record
Review and approve developers	• Review proposal package to ensure all E&S criteria are met • Liaise with developers if improvements to ESMS are needed (until REA is satisfied that a robust system exists)
Sign agreement	Agreement between REA and developer to include E&S clause
DESIGN VERIFICATION FOR SITE	
Prepare sites E&S documents	• Conduct E&S screening • Classify sites into E&S risk category (I, II) • Inform REA of outcomes of screening (consolidated report), including if sites fall under E&S exclusion criteria for Mini Grid and Power Generation Sites • Prepare ESIA, ESMP, RAP/LRP, as applicable • Obtain E&S permits required by law • Conduct stakeholder engagement • Submit relevant documents to REA
Review and verify preparation documents	• Verify developer's information (desk review of ESIAs, RAPs, sample site visits) during design verification with aim to minimize E&S impacts
CONSTRUCTION & OPERATION	
Construction and operation	• Conduct construction & maintain good compliance • Maintain a grievance mechanism to address community concerns • Inform REA of incidents or accidents • E&S reporting as part of progress report to REA
Monitor construction and operation	• Monitor E&S performance throughout project • Maintain an REA-level grievance mechanism to address any project-related feedback

Source: Rural Electrification Agency of Nigeria.

Note: Gold shading indicates steps for the REA; blue shading indicates steps for mini grid developers.

E&S = environmental and social; ESIA = Environmental and Social Impact Assessment; ESMP = Environmental and Social Management Plan; ESMS = Environmental and Social Management System; RAP/LRP = Resettlement Action Plan / Livelihood Restoration Plan; REA = Rural Electrification Agency.

each developer had to devise its own environmental and social management framework and have it approved by the Ministry of Environment. Ensuring that it was adhering to the policies and rules related to environmental and social management was often time consuming and onerous for the mini grid business. The purpose of the ESMS is to set out a ministry-approved standardized process for how developers and the REA can jointly ensure that the mini grid meets its environmental and social requirements. Because it is preapproved by the Ministry of Environment, the ESMS significantly reduces the number of additional clearances that the developer must obtain by increasing the role of self-evaluation and implementing light-handed administration by the REA. Figures 10.1 and 10.2 depict the process. Because the standardized ESMS is a recent innovation, we do not yet have results for how well it works in practice.

In the minimum-subsidy tender approach to mini grid development (figure 10.1), developers are expected to submit their environmental and social safeguard strategy, including a verifiable clean bill of environmental and social compliance over a period of at least three years. These requirements coincide with the developer's responsibilities to conduct requisite site screening and risk categorization, secure required environmental permits from the Ministry of Environment, and prepare applicable site-specific safeguards for clearance with the REA. The responsibilities of the developer go beyond the tendering process to include the construction and operation phase, keeping up-to-date records of environmental and social incidents, and submitting progress reports on environmental and social compliance to the REA.

In the performance-based grant approach to mini grid development (figure 10.2), in which developers receive performance-based grants based on the number of mini grid connections at sites that they identify and develop themselves, developers are expected to conduct all necessary environmental and social screening of their proposed site. While an independent third party is expected to monitor environmental and social compliance, all developers must prepare a strategy for battery disposal as part of their environmental and social responsibilities in line with the Ministry of Environment's guidelines.

Summary of advantages, disadvantages, suitability, and requirements for success of standardized templates

Standardized templates have several advantages compared with project- or deal-specific agreements, although they have some important disadvantages as well. They are not suitable everywhere and have several critical requirements for success.

Advantages. Standardized PPAs and asset transfer agreements reduce costs—in time and money—for both parties to the agreement. Standardized environmental and social management systems reduce the costs to the developer compared with having to create its own systems; they also reduce the costs to the regulatory or oversight authority that would monitor compliance, because all developers would be using the same template.

Standardized PPAs and asset transfer agreements reduce the risk to developers by increasing their negotiating power with the main utility or other purchasing entity. Standardized environmental and social management systems reduce developers' risk by ensuring that they know exactly how their performance across specific environmental and social indicators will be monitored.

Disadvantages. Standardized agreements and systems are not tailored to the unique needs and characteristics of individual projects or deals. This risk can be mitigated by allowing the parties to the agreement, or the developer in the case of an environmental and social management system, to make changes to the standardized template, which would require review and approval by the appropriate authority.

Where suitable. The three standardized templates are well suited in markets with a large number of mini grids with relatively similar characteristics and where large tenders for dozens or hundreds of mini grids are being prepared.

Requirements for success. The most important requirement for successfully rolling out standardized PPAs and asset transfer agreements is the enforceability of contracts. These documents are intended as legally enforceable contracts; their ability to reduce the risk for developers is contingent on the developer being able to count on the legal system should any adverse circumstance invoke one or more clauses of the agreement. Contract enforcement requires substantial government capacity and could be an area where targeted capacity building is required.

A specific requirement for the success of standardized PPAs is the ability of the utility to consistently pay on time for the electricity that it purchases from the mini grid. Where the buyer is commercially insolvent, long payment delays are likely.

A specific requirement for the success of a standardized asset transfer template is the ability of the purchasing entity to pay on time for the assets it agrees to purchase.

For standardized environmental and social management systems, the most important requirement ensuring that the system is preapproved by the relevant government agencies that would oversee the environmental and social aspects of mini grids.

Three standardized templates have the potential to significantly reduce the costs of bureaucracy: (1) standardized power purchase agreements governing sales of mini grid electricity to the main grid; (2) standardized asset transfer agreements for governing sales of mini grids' eligible assets to the main utility; and (3) a standardized environmental and social management system that is applied when mini grid developers must obtain environmental approvals. The first two templates help mini grid developers negotiate with the national utility on more even and transparent terms. The third simplifies the process for obtaining approval of the developer's environmental and social management system. The first two templates should be used only in countries where contracts are enforceable. The third should be used only after it has been approved by the government agencies responsible for the environmental and social aspects of mini grids.

USING TECHNOLOGY PLATFORMS TO CONNECT DEVELOPERS WITH INVESTORS AND SUPPLIERS AND TO CONDUCT LARGE-SCALE MINI GRID TENDERS

Creating an enabling business environment for mini grids goes beyond reducing red tape. It also entails removing market inefficiencies and increasing market intelligence. One way to do this is to use a technology platform to connect developers with financial investors and component suppliers and to run large-scale tenders for mini grids at the regional or national scale.

The leading example of such a platform is Odyssey Energy Solutions,[6] which has developed a web-based platform that streamlines the process of building investable portfolios of mini grids. The platform helps developers analyze site data, forecast demand, design their systems, model tariffs, and produce pro forma financial statements and analytics. Developers can share these data on the website with financiers and suppliers to secure investment and seek attractive procurement deals. The World Bank's experience with Odyssey in Nigeria is described in box 10.2.

One important reason to consider using a technology platform like Odyssey in the rollout of national mini grid programs is that it significantly increases the market efficiencies of several key processes. First, it creates a single hub connecting developers and financiers, thus making deal sourcing and deal making easier and less costly for both financiers and developers—in essence, reducing the transaction costs of deals. Second, use of a technology platform provides governments and donors with an efficient way to review mini grid projects, because each project is presented in a standardized way. In this way, it increases market intelligence and makes government procurement more transparent, thus reducing the risks of corruption and expropriation. Third, a technology platform can also make procurement of mini grid components easier for developers by providing a hub to connect developers and technology suppliers.

BOX 10.2

WORLD BANK EXPERIENCE WITH ODYSSEY ENERGY SOLUTIONS IN NIGERIA

The World Bank selected Odyssey as its technology platform to run a large-scale tender for mini grids for the Nigeria electrification project. The project involves a $150 million investment in mini grids, of which $70 million was allocated to mini grid procurement using a top-down approach.

Nigeria's Rural Electrification Agency conducted extensive geospatial and socioeconomic analysis on an initial list of 8,000 potential mini grid sites to identify 250 that have good potential to support commercially viable mini grids. In effect, the REA performed the due diligence that has typically been performed by developers in other countries. Data for these sites is made available on the Odyssey platform, and developers are preparing bids by entering their project data into the platform.

The process generates standardized bids for the REA and the World Bank to review, with successful bids eligible to receive an upfront capital cost subsidy. It is expected that the tender will extend access to 110,000 new mini grid customers. More information on how the Odyssey platform is used in Nigeria appears in chapter 2 of this handbook.

Source: ESMAP analysis.

Technology platforms like Odyssey that can present mini grid data in a standardized format also facilitate large-scale tenders for mini grids at the regional or national scale. The fact that all projects are presented the same way streamlines and expedites the review of developers' bids. In addition, built-in analytics in the platform help developers check their financial and technical models for errors and inconsistencies, increasing the likelihood that the technical and financial specifications of bids selected for the tender will be met during project implementation.

Advantages. Using a technology platform like Odyssey can streamline the process for connecting developers with investors and component suppliers. In this way, it helps create an enabling business environment not only for developers but also for technology vendors and financial investors. Technology platforms can also significantly reduce the time and resources required to run a large-scale tender by creating efficiencies for both developers and bid reviewers. Platforms can level the playing field by enabling investors to evaluate mini grid projects across the same metrics, through a standardized presentation of project data.

Disadvantages. Reliance on a single platform can create a bottleneck in the market if technical problems with the platform cause major disruptions to the market or tender process. Use of an online platform may also pose privacy concerns for some developers, who may not feel comfortable giving their project-level data to a third-party website. Using a technology platform like Odyssey as the go-to hub for investment and procurement deals may also crowd out small-scale developers and community-led mini grid projects by catering to larger-scale developers with greater technical and administrative capacities.

Suitability. A technology platform like Odyssey is suitable when there is a large cohort of developers with the capacity to provide data for their projects covering all metrics required by the platform. It is also applicable in countries that are planning large-scale tenders for dozens or hundreds of mini grids, particularly when geospatial data are available for the sites on which developers are bidding. This technology platform–enabled strategy is especially suitable in markets where financial investors are seeking commercial investments in portfolios of mini grids.

Requirements for success. To be successful, a technology platform like Odyssey requires active participation from both buyers and suppliers in the markets the platform intends to facilitate—namely, the procurement market for mini grid components, the investment market for portfolios of mini grids, and the market for mini grids created by government and donor tenders. In addition, while governments may be familiar with conducting tenders, they may not be familiar with using a digital platform like Odyssey for that purpose. As a result, capacity building targeted at the use of these types of platforms will likely be required.

> The use of technology platforms to connect developers with investors and suppliers and to conduct large-scale mini grid tenders has the potential to improve market efficiencies in three ways: (1) by reducing the transaction costs financiers face when investing in mini grids; (2) by increasing market intelligence and making government procurement more transparent, thus reducing risks of corruption and expropriation; and (3) by simplifying procurement of mini grid components easier for developers by connecting developers with potential suppliers. To be successful, the platform needs active participation from developers, investors, suppliers, and the government.

ELIMINATING DUPLICATION OF GOVERNMENT OVERSIGHT BY DELEGATING AUTHORITY TO A SINGLE ENTITY

In many countries, in the absence of a formal regulator tasked with overseeing mini grids, developers face double or triple layers of government oversight—from rural electrification authorities to local governments to agencies providing subsidies, among others. Each additional layer of oversight compounds the risk and cost of the mini grid business, raises the likelihood that rules and regulations for developers will change, and increases the chances that those rules and regulations will be inconsistent or conflicting.

One way to reduce multiple layers of oversight (again, when there is no formal regulator) is to delegate primary oversight authority for mini grid–specific activities to a single government entity. This does not mean that that entity will wield the exclusive authority over mini grids. For example, a government agency with a legal mandate to protect the environment could not legally cede its authority to another government entity. What it does means is that only one authority will be responsible for decisions that would normally fall to a formal regulator: decisions related to market entry (permits, registration, licensing), tariffs, service standards, technical standards, and what to do when the main grid arrives.

These decision areas mirror those discussed at length in chapter 9, but they are discussed again here for two reasons. First, a lack of clarity on *who* holds authority for these decisions when there is no formal regulator represents a significant risk to mini grid businesses. The underlying assumption of this chapter is that a regulator or other government entity has already been tasked with making regulatory decisions about mini grids. Second, multiple government entities having authority over these decisions represents a constraint on the ease with which mini grid developers can do business.

The two most common candidates for overseeing mini grid activities in the absence of a formal regulator are the local government and the agency that provides grants or subsidies to mini grid developers (Tenenbaum and others 2014).

Local government. If a village hosting a new mini grid has an effective local government, it can regulate the mini grid, typically through a contract signed with the developer. This is a variant of a "community agreement" that takes advantage of an existing local government body to represent the community. Such a local governance framework should be consistent with the local government's legal authority.[7] One important drawback of delegating authority to local governments is that developers that want to build mini grids in several different jurisdictions would need to adhere to each local government's set of rules and guidelines. For this reason, delegating oversight of mini grids to local governments is not likely to be compatible with a portfolio approach to development.

Grant-making agency. Where mini grids are contracted or subsidized by rural electrification agencies (REAs) or other grant-making agencies, complex interfaces between agencies can be avoided if the subsidizing agency also acts as the regulator. REAs that provide subsidies often perform reviews of mini grid business plans, which is similar to a traditional cost-of-service review that a regulator would undertake (Tenenbaum and others 2014).

In Bangladesh, for example, the Infrastructure Development Company Limited (IDCOL), the grant-making agency, is the de facto regulator. In Mali, AMADER (Agency for the Development of Domestic Energy and Rural Electrification), the grant-making agency, is legally responsible for traditional regulatory responsibilities (Tenenbaum and others 2014). This technique—delegating regulatory functions to the agency that distributes subsidies—can also be found in industrialized countries. In the United States, the New York State Development Authority has provided subsidies to private providers of community solar projects in return for control over the prices that the developers will charge to low- and moderate-income customers.

However, delegating regulatory power to financing agencies may create conflicts of interest and may not be suitable where those agencies lack adequate capacities or skills. In Bangladesh, some developers view IDCOL's double role as a conflict of interest. As a financing institution, it has its own financial interests, and some developers do not perceive it as an independent party balancing the interests of developers and customers, as a traditional regulator would.[8] In addition, grant-making agencies have competencies in financial analysis but may not be trained for cost-of-service calculations or other technical decisions that factor into mini grid regulations.

An important task for the government entity assigned to oversee mini grid activities is to anticipate what will happen when the main grid arrives in the mini grid's service area. Discharging this task requires the grant-making agency or local government to ensure that its technical specifications for mini grids are compatible with eventual interconnection with the main grid, and to stipulate clear terms for transferring oversight authority to the entity that regulates the main grid (Tenenbaum and others 2014).

Table 10.4 provides a summary of the local government and REA options, with advantages, disadvantages, and examples.

Suitability. Delegating oversight of mini grids to local government or a public grant-making agency is well suited for countries where no regulatory agency is tasked with overseeing mini grids or where no formal regulations specific to mini grids are in place. This strategy may also be suitable when used in conjunction with a centrally coordinated approach to mini grid development, where the grant-making entity uses competitive tenders to select operators for concession areas (USAID 2017).

Requirements for success. Two conditions must be met if governments wish to successfully delegate oversight of mini grids to a single entity in the absence of a formal regulator. The most important requirement is that the legal delegation of authority be clear and specific. In Haiti, for example, a 2006 decree legally delegates to municipal governments the authority to oversee the production, distribution, and sale of electricity within their jurisdictions (Government of Haiti 2006). Second, the entity to which authority has been delegated should specify which laws and regulations will take precedence over its own authority.

TABLE 10.4 • Advantages and disadvantages of two options for mini grid oversight

Option	Advantages	Disadvantages	Examples
Local government	Local government is more accessible to developers and customers than a national entity would be. Enforcement of regulation may be facilitated by the physical presence of the regulator in the community.	Some local governments may lack financial and human resources to design and enforce a regulation. Different jurisdictions might have different rules, which makes it significantly more difficult for developers to build in multiple jurisdictions.	Community agreements used in Haiti, Nigeria, and Myanmar
Rural electrification agency or grant-making body	Complex interfaces between agencies can be avoided if the subsidizing agency also acts as regulator.	May lead to conflict of interests. May not be appropriate if the grant-making agency does not possess adequate skills.	Bangladesh Mali

Source: USAID 2017, 46–48.

In countries where no formal regulator is tasked with overseeing mini grids developers often face double or triple layers of government oversight. To reduce the layers of bureaucracy, governments can formally delegate oversight authority to a single entity. The two most common options are local governments or the public agency that provides grants or subsidies to mini grid developers (for example, a rural electrification agency). For either of these options to be successful, there must be a clear legal delegation of authority to the entity, and the entity must explicitly state which laws and regulations will take precedence over its own authority.

In parallel, the oversight entity must have sufficient capacity to oversee the mini grid sector effectively and credibly. In most cases, this entity will require significant support during the early stages of its role.

SETTING UP E-GOVERNMENT SERVICES TO REDUCE OVERHEAD

As access to the internet expands rapidly in developing countries—including through mobile data networks—countries are beginning to establish "e-government" initiatives. These initiatives provide businesses (and citizens) with a way to interact with government agencies online to accomplish tasks such as business registration, land and building permits, and environmental approvals.

Several recent examples of e-government initiatives include those in India, Kenya, and Nigeria. Across these and other initiatives, the objective is to increase the use of internet-based services to streamline and make more transparent both internal government operations and the ways that citizens and businesses interact with the government.

In some cases, e-government initiatives will have separate sets of services for individuals and businesses. The e-government web portal in Kenya offers one such example. Under the "e-Business" section of the website,[9] companies can apply for, pay for, and receive PDF copies of their business licenses. Under the "e-Citizen" section,[10] individuals can apply and pay for a variety of government services.

Most e-government websites require users to create an account to access online services. This typically includes providing certain personal information. Because this will be stored online—usually on servers that are owned by the government or by a company contracted by the government—the long-term success and reputation of e-government initiatives depend significantly on the quality of data protection. Protection includes high-level encryption of the e-government website (for example, using the "https" protocol instead of the "http" protocol) and robust data management practices for government employees who interact with information submitted by businesses and citizens.

As more and more commerce is conducted online, demand from citizens and businesses for e-government services will almost certainly increase. Meeting demand will require collaboration between the government and companies, and between the government and its citizens, to identify the types of services that can be offered online. One example of the collaborative process of establishing an e-government initiative is the "Forum on e-Governance" that the Ghanaian government recently launched.

Actually building out the e-government capabilities typically requires a partnership between the government and the private sector. In Nigeria, a public–private partnership was established to develop the online infrastructure—both the back end of the website that government employees would use, and the front end that citizens and businesses would use.

Advantages. The main advantage of an e-government initiative for businesses is that it speeds up many processes that would normally take days or weeks to conduct in person. It can also increase transparency, as electronic records can be accessed by stakeholders as needed.

Disadvantages. The main disadvantage is that e-government initiatives require security and data protection on both ends (government and citizen or business), and these may not yet be possible in some countries. E-government initiatives can also disenfranchise small businesses and households that do not have reliable access to the internet.

Suitability. E-government initiatives are suitable where governments have adequate data protection and online security available to protect sensitive data, and where there is demand from citizens and businesses to be able to interact with the government via the internet.

Requirements for success. To be successful, an e-government initiative requires a participatory approach to identifying the types of services that citizens and businesses would like to have available via the internet. It also typically requires a public–private approach to building out the back- and front-end capabilities of the e-government website and related suite of services, since most government agencies will not have the technical capabilities to develop the platform in-house. Finally, a successful initiative requires robust data protection—not just within the website, but also with respect to the government employees who interact with the sensitive information that citizens and businesses submit online.

E-government initiatives can significantly reduce the overhead costs of interacting with the government to apply for permits, licenses, and approvals. To be successful, the initiative requires a participatory approach to identifying which services should be offered online, a public–private partnership approach to building out the e-government website and associated services, and robust data protection measures both online and for government employees handling sensitive information.

INVESTORS' PERSPECTIVES ON THE FOUR OPTIONS PRESENTED ABOVE

Through conversations with private-sector investors, and building on the International Finance Corporation's extensive experience investing in infrastructure projects around the world, we have identified characteristics of each of the four options discussed in this chapter that investors perceive as either barriers or "must haves" when considering a mini grid investment.

On reducing red tape through standardized preapproved templates

- *Barrier:* The template documents are not adaptable to different mini grid business models and are not updated as new regulations or policies come into effect.
- *Must have:* The preapproved templates must protect the investment from government delay, expropriation, or changes to the law.

On using technology platforms to connect developers with investors and suppliers and run large-scale mini grid tenders

- *Barrier:* The government lacks sufficient capacity to use the technology platform effectively.
- *Must have:* The technology platform must integrate both technical and financial aspects of mini grid projects at the level of each mini grid and at the portfolio level.

On eliminating duplication of government oversight by delegating authority to a single entity

- *Barrier*: The governmental body to whom oversight authority has been delegated does not have the adequate capacity to design and enforce rules and policies that govern the mini grid sector.
- *Must have*: The authority to which oversight is delegated must have a good record of fair, transparent, and effective governance.

On setting up e-government services to reduce overhead costs

- *Barrier*: The underlying institutional framework behind the e-government service is complicated, ineffective, and opaque. Online technologies will not solve structural institutional issues.
- *Must have*: Sufficient institutional capacity—and coordination—are necessary to run the back end of e-government services.

Beyond the four options described in this chapter, investors have also pointed to three factors in a country's enabling environment that they assess when considering investment opportunities. These factors, along with the characteristics that investors perceive as barriers and "nice to haves" (as opposed to "must haves") follow.

Qualified local personnel

- *Barrier:* The supply of qualified local personnel (for example, project managers and engineers) is insufficient to manage and operate mini grids and to close tenders and complete the technical design phase of mini grid projects.
- *Nice to have:* Labor legislation carve-outs should allow the importation of essential workers to build and maintain mini grid projects in the face of shortages of skilled local labor. Regional licensing standards for operations and management should ensure adequate labor quality and minimize developers' labor search costs. Training programs should exist for operators, with associated labor exchanges and a centralized labor pool.

Chapter 7 provides an in-depth discussion on training and skills development for the mini grid sector.

Transaction costs

- *Barriers*: Costs to import and deliver materials to the mini grid site are high because of tariffs and customs duties. Poorly managed procurement processes are overly burdensome for developers.
- *Nice to have*: Tariffs and custom duties are reduced for major components needed to construct mini grids. Bidding processes have clear criteria that value operational experience and quality. Development partners help to finance feasibility studies, develop portfolio-based bid packages, and provide transaction advisors.

Financial infrastructure

- *Barrier*: Telecom coverage and mobile finance sectors have limited access to remote areas of the country, limiting the viability of data transfer and mobile payment platforms. Microfinance options for potential productive-use customers are lacking.

- *Nice to have*: Mobile banking services reach a large portion of the population, including in nonurban areas. Microfinance institutions are willing to lend—or have experience lending—to micro- and small enterprises for the purchase of income-generating machines and appliances.

CONCLUSION

Mini grids are businesses and therefore navigate the complex world of permits, licenses, approvals, and clearances. Bureaucratic processes generally include permits and processes related to setting up and operating a business, acquiring land rights, and receiving approval for the environmental and social impacts that the project may have.

From an investment standpoint, these bureaucratic processes constitute risks to the business; from the developer's perspective, they also increase the cost of doing business. Therefore, simplifying and streamlining the environment in which developers do business can make the mini grid market more attractive to the private sector. A more appealing market means more mini grids providing more access to affordable electricity to more people.

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NOTES

1. Field interviews conducted by Castalia in Bisanti, Nigeria, August 2017.
2. However, the framework is very recent (adopted in 2017), and market reaction may change in time.
3. Field interviews conducted by Castalia with developers (2017)
4. Field interviews conudcted by Castalia with developers (2017) and email exchange with developers (2018).
5. Tenenbaum and others 2014 (87, 104-14) discuss regulatory processes and nonelectricity approvals and provide recommendations on designing a good regulatory review and approval system in a way that minimizes barriers to investment. USAID 2017 (73-–76, 103–6) suggests different options for designing the regulatory process and environmental review for mini grids, including adapting environmental reviews to size.
6. See https://www.odysseyenergysolutions.com/.
7. Formal community agreements are used in Nigeria, Myanmar, and Haiti. These agreements are a form of regulation by contract. Chapter 9 provides a detailed discussion on regulation by contract.
8. Email exchange with a mini grid developer, 2017.

CHAPTER 11

CALL TO ACTION

CHAPTER OVERVIEW

In this final chapter, we present a call to action for key mini grid stakeholders, from policy makers and regulators to developers to investors and suppliers. The goal is to help build 210,000 mini grids to connect half a billion people by 2030. We also highlight some topics for future research.

Concrete actions that various stakeholder groups can undertake in the near term to help connect half a billion people to mini grids by 2030 are described below.

POLICY MAKERS

Policy makers can leverage the latest geospatial analysis technology to develop high-quality national electrification plans to guide investment in mini grids, main grid extension, and solar home systems. They can develop legislation that supports the electrification plan with a clear institutional framework. They can ensure that existing legislation—for example on renewable energy, rural development, and foreign trade and import duties—is conducive to large-scale deployment of mini grids powered by renewable energy.

REGULATORS

Regulators can adopt a light-handed approach and provide clear guidance in the five key areas discussed in chapter 9: market entry, retail tariffs, service standards, technical standards, and arrival of the main grid. Regulators can ensure that the process of developing or changing regulations is transparent and involves extensive public consultation. Regulators can adopt a light-handed approach that (1) minimizes the amount of information required of developers, (2) limits the number of separate regulatory processes and decisions, (3) standardizes documents and forms, and (4) integrates related decisions made by other government or community bodies. In addition, regulators can collaborate with regulatory agencies from other countries to develop harmonized technical specifications. Doing so will expand the total market for developers and their suppliers by making it easier to do business in multiple countries.

DEVELOPMENT PARTNERS

Development partners can coordinate the design and funding of strategic interventions to crowd in public and private investment. For the mini grid sector to scale up rapidly over the next decade, investment from all sources will need to increase dramatically. Coordinated funding from donors will be essential to de-risk—and therefore catalyze—early large-scale investment in mini grids in countries marked by large deficits in access to energy. In parallel, development partners will need to support the development, diffusion, and uptake of actionable knowledge throughout the sector.

INDUSTRY ASSOCIATIONS

Industry associations should hold members and stakeholders to account by developing and tracking progress toward key performance indicators (KPIs) that are linked directly to enlarging the mini grid sector. In the overview to this handbook, we presented a set of KPIs that are relevant for mini grid developers; similar KPIs can be developed for other associations of stakeholders, such as solar photovoltaic manufacturers and appliance manufacturers. To track progress toward their KPIs, industry associations should collect data from their members on a regular basis and make appropriate data available to the public in a clear and transparent way.

MINI GRID DEVELOPERS

Developers should work individually and collectively toward two KPIs that will help the industry grow at scale: (1) increasing the pace of deployment through a portfolio approach to mini grid development, and (2) providing service of superior quality. With support from development partners and other stakeholders to crowd in finance and establish enabling business environments in key access-deficit countries, the cost of mini grid electricity could fall to $0.25/kilowatt-hour (kWh) by 2025 and $0.20/kWh by 2030. To facilitate collective action, mini grid developers can join an industry association and support other initiatives that promote continued professionalization of the industry.

INVESTORS

Investors should strive to develop financing vehicles to channel investment—debt, equity, risk-sharing instruments, and convertible notes—from large and small investors into portfolios of mini grids. The only way to reach the scale of investment needed to connect 490 million people to mini grids by 2030 is to enable current investors to invest more and to attract new investors. Existing financial flows are typically the result of one-off deals. What the sector needs are new types of financing vehicles, developed for investors by investors, that remain actively managed and sustainably funded.

SUPPLIERS

Suppliers are urged to take a longer view of the mini grid industry than what quarterly reporting might suggest. That means preparing now—when the market is nascent—for 2025, when the market will be expanding rapidly at scale. To demonstrate their commitment to a long-term view, suppliers can consider two types of discounts to mini grid developers. First, suppliers could allow developers to receive bulk-order discounts for all orders made within a certain timeframe—say, two years. Second, suppliers could offer significant discounts for prepaid orders of components to be shipped at a date in the future—say, two years from the order date.

RESEARCHERS

Both qualitative and quantitative research is needed to address the knowledge gaps identified earlier in this chapter and to identify statistically significant causal relationships that can inform investment decisions. When carrying out research, it is important to ensure that people in low-income countries are actively engaged in the knowledge development process, with a particular focus on engaging female scholars, students, and research subjects.

TOPICS FOR FUTURE RESEARCH

In the course of assembling this handbook, we have identified the following avenues for future research.

COLLECTING DATA ON INSTALLED AND PLANNED MINI GRIDS

In the overview and chapter 1, we present data and analysis from extensive surveys of mini grids around the world. However, the data sets that underpin these chapters can be improved. The global database of installed and planned mini grids discussed in the overview does not include data from several countries that are likely to see large numbers of mini grids—for example, Brazil and several countries in North Africa and the Middle East. In addition, there are likely to be a large number of small diesel-only mini grids scattered around the world that do not appear in our data set. The data set for chapter 1 contains detailed information for more than 400 mini grids, but statistical analyses will be even more robust and generalizable if they are conducted on a larger number of mini grids from a wider set of countries.

Future data collection efforts should focus on countries not well covered in the databases discussed in the overview and in chapter 1, and on diesel-only and renewable-only mini grids. Establishing teams of researchers focused on particular countries or regions would be a good way to improve data collection. In addition, regular surveys—for example every two years—will help improve trend analyses on the global mini grid market and mini grid costs. Demand for mini grid services from different types of customers, ideally over time, is another key data gap to fill.

COMBINING MINI GRIDS, SOLAR HOME SYSTEMS, AND MAIN GRID EXTENSIONS INTO AN INTEGRATED ELECTRIFICATION STRATEGY AT THE LOCAL LEVEL

In chapter 2, we focused on geospatial analysis and other tools to help countries and developers prepare portfolios of mini grids. As we highlight in that chapter, as well as in the overview, mini grids are one of the three main strategies for increasing electricity access, alongside solar home systems and extending the main grid. Electrification planning that incorporates all three strategies tends to delineate geographic areas where each strategy is the least-cost solution. However, a topic that has received less attention is how best to combine two or all three of these technologies in a single area. For example, while a mini grid may be the best solution for a town that is densely populated but far from the main grid, it may not be economically viable for the mini grid to connect every customer in that town. In situations like this, combining mini grids and solar home systems in the same geographic area is a solution worth considering.

A 4,000-person town in Togo serves as a cutting-edge example of how mini grids can be combined with solar home systems. A partnership between Bboxx, General Electric, and Togo's Ministry of Energy has deployed a solar-diesel–hybrid mini grid and solar home systems to serve every household, school, and shop in the town—and to provide streetlights (Ross 2019). Notably, Bboxx, as the developer, uses its proprietary digital technology to remotely monitor not only the mini grid but also the solar home systems and streetlights, thus bringing the management control of different electrification solutions under one metaphorical roof.

Some examples of places where combined electrification strategies may make sense are described below.

- ***Mini grids and main grid extensions.*** Urban and peri-urban areas underserved by the main grid, or where the main grid is unreliable.
- ***Mini grids and solar home systems.*** Towns far from the main grid with dense population centers and households far from the town center.
- ***Solar home systems and main grid extension.*** Very low-income urban and peri-urban areas where some households cannot afford a connection to the main grid or lack a permanent housing structure.
- ***Mini grids, solar home systems, and main grid extension:*** Urban or peri-urban areas that are underserved by the main grid and where some households cannot afford a connection to the main grid or mini grid or lack a permanent housing structure.

BUSINESS TACTICS AND STRATEGIES FOR MINI GRID DEVELOPERS

In chapter 5, we zoom in on the private-sector entities that participate in the mini grid value chain; in chapter 6 we discuss how to channel financing to private-sector mini grids. A related topic not covered in those chapters is business techniques and strategies that private-sector developers can use to raise money for their business and to operate the mini grid.

As we note in chapter 6, if mini grid developers are going to attract investment, they will need to develop a viable business plan. What makes a good business plan? In parallel, developers may need to design a "pitch deck"—a short presentation to show investors as a way to attract their investment. What does that entail, and how should developers pitch their businesses to investors? Answers to these and other questions about how to own and operate a mini grid business in key energy access-deficit countries could be the focus of future research, in partnership with business scholars who have studied these topics in other contexts.

In addition, while much has been written about mini grid business models, we do not address this topic directly anywhere in the report. The term *business model* is often used loosely and interchangeably with ownership structure (as in ACP-EU Energy Facility 2012) or profit-making status (as in Schnitzer and others 2014). The framework in table 11.1 from academic research on business models (Knuckles 2016; Baden-Fuller and Haefliger 2013), can provide the basis for a more structured discussion of mini grid business models in future research.

A more structured discussion of mini grid business models is useful for at least three reasons. First, it can offer insight into how mini grid sectors are evolving over time. The first-, second-, and third-generation mini grids that we describe in this handbook display significantly different business models. Second, it can identify areas where developers and suppliers can innovate. For example, recent innovations in monetization include pay-as-you-go metering paid using mobile money. Third, it can help regulators and policy makers develop enabling environments that accommodate a variety of business models and permit innovation in the business model over time. Specifying options for what business models are available to mini grid developers when the main grid arrives is just one example of this.

POLICIES AND BUSINESS ENVIRONMENT FACTORS THAT AFFECT MINI GRIDS

Chapters 9 and 10 discuss the regulatory and general business environments within which mini grids must operate. By focusing on regulations, chapter 9 does not enter into a detailed discussion of policies that affect mini grids. However, various policies have a direct impact on mini grid businesses, from national electrification and rural development plans to policies that restrict or encourage trade and others that protect the environment, workers' rights, and gender equality. While it is beyond the scope of this book, an assessment of how different policies affect mini grids would constitute an important contribution to the sector. In chapter 10, we did not address the full set of bureau-

TABLE 11.1 • Analytical framework to guide future research on mini grid business models

Business model dimension	Example topics
Customer	Grid-connected versus stand-alone: When is the utility a viable customer? Anchor-Business-Community model: What makes a good "B" or "A" customer? Productive users of electricity: What are effective ways to target local businesses?
Value proposition	Affordability and willingness to pay: How do developers find the right price point? Tier of service and quality of service: What levels of service do customers want? Appliances and productive use: How much value do these add, and for whom?
Value chain	Who designs, builds, owns, operates, and maintains the mini grid? Is the industry moving toward specialization or vertical integration? How can the supply chain for components be made more efficient?
Monetization	Tariff level and structure: What works best, when, and why? Connection charges: How can these be made affordable for customers? Cross-subsidization: When do cross subsidies work and why? Financing: Should developers finance connection charges and appliances in-house or go through third parties?

Source: Adapted from Knuckles (2016).

cratic processes that affect the ease with which mini grid developers do business. Land rights, business permitting, taxes and import duties, and corruption are just some of the important business environment topics that future research on mini grids should consider. The World Bank's Doing Business initiative could serve as an excellent resource and partner for this work.

Connecting 490 million people to mini grids by 2030 is a monumental task that will require unprecedented levels of investment, innovation, and commitment from developers, investors, development partners, governments, and other stakeholders. We hope that the ideas presented in this book can serve as motivation and guidance for decision makers all along the mini grid value chain.

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