COMMON GROUND

Sustainability, Inclusiveness, and Governance of Mini-Grids in Africa

Analysis and Case Studies

Edited by Lucy Baker, Subhes Bhattacharyya, Daniel Kerr, Temilade Sesan, and Elsie Onsongo



SUSTAINABILITY, INCLUSIVENESS, AND GOVERNANCE OF MINI-GRIDS IN AFRICA: ANALYSIS AND CASE STUDIES

Edited by

DR. DANIEL KERR,
DE MONTFORT UNIVERSITY, UK

DR. LUCY BAKER,
OPEN UNIVERSITY, UK

DR. TEMILADE SESAN,
UNIVERSITY OF IBADAN, NIGERIA

DR. ELSIE ONSONGO,
NUVONI CENTRE FOR INNOVATION RESEARCH, KENYA,

AND

PROF. SUBHES C. BHATTACHARYYA,
DE MONTFORT UNIVERSITY, UK

SUSTAINABILITY, INCLUSIVENESS, AND GOVERNANCE OF MINI-GRIDS IN AFRICA: ANALYSIS AND CASE STUDIES

Edited by

DR. DANIEL KERR,
DE MONTFORT UNIVERSITY, UK

DR. LUCY BAKER,
OPEN UNIVERSITY, UK

DR. TEMILADE SESAN,
UNIVERSITY OF IBADAN, NIGERIA

DR. ELSIE ONSONGO,
NUVONI CENTRE FOR INNOVATION RESEARCH, KENYA,

AND

PROF. SUBHES C. BHATTACHARYYA,
DE MONTFORT UNIVERSITY, UK

First published in 2026
as part of the Global Studies Book Imprint

Common Ground Research Networks
University of Illinois Research Park
2001 South First Dr, Suite 201 L
Champaign, IL 61820 USA

Copyright © Daniel Kerr, Lucy Baker, Temilade Sesan, Elsie Onsongo, and Subhes Bhattacharyya, 2026

All rights reserved. Apart from fair dealing for the purposes of study, research, criticism or review as permitted under the applicable copyright legislation, no part of this book may be reproduced by any process without written permission from the publisher.

Library of Congress Cataloging-in-Publication Data

Names: Kerr, Daniel (Research fellow) editor
Title: Sustainability, inclusiveness and governance of mini-grids in Africa : analysis and case studies / Edited by Dr. Daniel Kerr, De Montfort University, UK; Dr. Lucy Baker, Open University, UK; Dr. Temilade Sesan, University of Ibadan, Nigeria; Dr. Elsie Onsongo, Nuvoni Centre for Innovation Research, Kenya, and Prof. Subhes C. Bhattacharyya, De Montfort University, UK.
Description: Champaign, Illinois : Common Ground Research Networks, 2026. | Includes bibliographical references. | Summary: "Although access to clean energy has been recognised as a critical element for the sustainable development of societies, millions of people around the world, particularly in sub-Saharan Africa, lack access to electricity. Mini-grids have emerged as an electrification strategy for such population but various technical, economic, socio-political and governance issues militate against the sustainability of mini-grids. This book reports the results of a collaborative research that investigated the effectiveness of mini-grids as an electricity access option for delivering sustainable development of rural communities in Sub-Saharan Africa. Are mini-grids offering a reliable, secure supply to meet current and future needs? Are they offering affordable electricity and ensuring universal access? Are these ventures financially viable and attractive to investors? Are they contributing to local sustainable development agenda? What is the future of mini-grids and how can a large-scale roll out be planned to support the SDG 7 agenda? This book attempts to offer answers to these questions through a systematic analysis. The work has relied on extensive review of academic and practice-oriented literature and has combined existing secondary data with primary data collected through fieldwork. Through a combination of quantitative and qualitative analysis, the book shares novel insights and recommendations to shape the future of mini-grid development globally. The novel, evidence-based insights from the book would benefit a wide range of stakeholders in shaping and improving the mini-grid ecosystem"-- Provided by publisher.
Identifiers: LCCN 2026001753 (print) | LCCN 2026001754 (ebook) | ISBN 9781969318221 hardback | ISBN 9781969318238 paperback | ISBN 9781969318245 adobe pdf
Subjects: LCSH: Microgrids (Smart power grids)--Africa, Sub-Saharan | Electric power--Africa, Sub-Saharan | Sustainable engineering--Africa, Sub-Saharan | LCGFT: Case studies
Classification: LCC TK3106 .S87 2026 (print) | LCC TK3106 (ebook)
LC record available at https://lccn.loc.gov/2026001753
LC ebook record available at https://lccn.loc.gov/2026001754s

ISBN:978-1-969318-22-1 (HBK)
ISBN:978-1-969318-23-8 (PBK)
ISBN: 978-1-969318-24-5 (PDF)

Cover Design: Phillip Kalantis-Cope

Editors:

Dr. Daniel Kerr, Researcher, De Montfort University, UK
Dr. Lucy Baker, Senior Lecturer in Environmental Geography, The Open University, UK
Dr. Temilade Sesan, Lecturer and Researcher, University of Ibadan, Nigeria
Dr. Elsie Onsongo, Director, Nuvoni Centre for Innovation Research, Kenya
And
Professor Subhes C. Bhattacharyya,
Professor of Sustainable Energy Systems and Director, Institute for Sustainable Futures,
De Montfort University, UK
Email: Subhes.bhattacharyya@dmu.ac.uk

Acknowledgment

The research work reported in this book was funded by a Global Challenges Research Fund research grant (ES/T0006684/1 and ES/T0006684/2) from UKRI. The Global Challenges Research Fund (GCRF) is part of the UK's official development assistance (ODA) and addresses the UN Sustainable Development Goals.

The open-access publication fee of the book is also funded by the UKRI through its dedicated open-access funding.

Disclaimer

The views expressed in this book are those of the authors and do not necessarily represent the views of the institutions they are affiliated to or the funding agencies.

Citation

The suggested citation for this book is:

Kerr, D., Baker, L., Sesan, T., Onsongo, E., & Bhattacharyya, S. C. 2026. *Sustainability, inclusiveness, and governance of mini-grids in Africa*. Common Ground Research Network.

TABLE OF CONTENTS

List of figures *xxiii*
List of tables *xxvii*
Preface *xxxi*

Chapter 1: Introduction 1
Abstract 1
1.1 Introduction and Problem Statement 1
1.2 Research Gaps and Research Questions to Be Addressed 3
1.3 Activities Undertaken 7
1.4 Organization of the Book 8
References 9

Part 1: Insights from a Comprehensive Review of Literature **11**

Chapter 2: Technical Sustainability of Mini-Grids in Low-and Middle-Income Countries 13
Abstract 13
Acronyms 14
2.1 Introduction 15
2.2 Review Methodology 17
2.3 Definition and Features of Mini-Grids 24
2.3.1 Definition 24
2.3.2 Features 25
2.4 Design Considerations Affecting Technical Sustainability of Mini-Grids 27
2.4.1 Mini-Grid System Design 27

2.4.2 Procurement and Installation 30
2.4.3 Nontechnical Aspects 32
2.5 Influence of Operations and Maintenance on the Technical Sustainability of Mini-Grids 33
2.5.1 Availability 33
2.5.2 Reliability 34
2.5.3 Power Quality 36
2.5.4 Adequacy 36
2.5.5 Maintenance 37
2.5.6 Other Considerations and Challenges 38
2.6 Assessment of Technical Sustainability of Mini-Grids 39
2.6.1 Approaches and Frameworks 39
2.6.2 Indicators for Technical Sustainability 42
2.7 Discussions and Framework for Technical Sustainability 47
2.7.1 Reflection on Literature Review 47
2.8 Framework for Technical Sustainability 50
2.9 Summary and Future Perspectives 51
References 53

Chapter 3: Understanding Business Models and Access to Finance for Mini-Grid Development in Sub-Saharan Africa 61
Abstract 61
Keywords 62
Acronyms 62
3.1 Introduction 63
3.2 Literature Review Methodology 66
3.3 Unpacking Mini-Grid Business Models 68
3.3.1 Ownership and Management Models 69
3.3.1.1 Public Utility Model 71
3.3.1.2 Private Model 71
3.3.1.3 Hybrid Model 72
3.3.1.4 Community Model 74

3.3.2 Consumer-Focused Models 75
3.3.2.1 Households and Small Businesses Approach 75
3.3.2.2 Anchor Business Consumer—A-B-C Model 76
3.3.3 Cost Recovery Models 77
3.3.3.1 For-Profit Model 77
3.3.3.2 Partially Subsidized Model 78
3.3.3.3 Fully Subsidized Model 78
3.3.4 Bundling Models 79
3.3.4.1 Clustering and Operational Bundling 79
3.3.4.2 Portfolio Diversification and Financial Bundling 80
3.4 Access to Finance: Actors, Institutions, and Processes 81
3.4.1 Sources of Finance: From Public and Private 82
3.4.2 Type of Finance 84
3.4.2.1 Debt 84
3.4.2.2 Equity 85
3.4.2.3 Subsidies 86
3.4.2.4 Results-Based Financing 87
3.5 Exploring Key Risks and Challenges 88
3.5.1 External Risk for Mini-Grids 88
3.5.1.1 Regulation and Market Access 88
3.5.1.2 Demand Uncertainty and Poor Forecasting 92
3.5.1.3 Political and Macroeconomic Risks 92
3.5.2 Internal Challenges for Mini-Grids 94
3.5.2.1 Customer Credit and Nonpayment Risk 94
3.5.2.2 Governance Risk 95
3.5.2.3 Labor Challenges 95
3.5.2.4 Community Engagement Challenge 96
3.6 Conclusion 97
References 99

Chapter 4: Of Monopolies and Mini-Grids: Case Studies from Kenya, Tanzania, Nigeria, and Senegal 107
Abstract 107

Acronyms 108
4.1 Introduction 110
4.2 Governing Electricity: Of Monopolies, Mini-Grids, and Beyond 113
4.3 Mini-Grids in Context: Between Energy Access and Productive Use 116
4.4 Country Case Studies 120
4.4.1 Kenya 123
4.4.2 Tanzania 126
4.4.3 Nigeria 129
4.4.4 Senegal 133
4.5 Conclusion 137
References 140

Chapter 5: Are Mini-Grids Socially Inclusive? A Literature Review 149
Abstract 149
5.1 Introduction 150
5.2 Inclusive Innovation: An Analytical Framework 151
5.3 Mini-grids as Inclusive Innovation 154
5.4 Methodology 155
5.5 Characteristics of Selected Articles 157
5.6 Findings 161
5.6.1 Defining Social Inclusivity 161
5.6.2 Inclusion of Intention: The Case for Mini-Grids 162
5.6.3 Inclusion of Consumption and Impact 163
5.6.4 Inclusion of Process: Social Inclusion in Mini-Grid Development Processes 171
5.6.5 Feasibility, Site Acquisition, Approval 171
5.6.6 Financing 173
5.6.7 Engineering, Procurement, and Construction 176
5.6.8 Operation and Maintenance 177
5.7 Inclusion of Structure 179

5.8 Post-Structural Inclusion 181
5.9 The Dark Side of mini-grids: Exclusions and Environmental Effects 181
5.10 Discussion and Conclusion 184
References 188

Part 2: Fieldwork Reports 199
Chapter 6: Kenya Fieldwork Report 201
Abstract 201
6.1 Introduction and Background 201
6.2 Methodology 202
6.2.1 Research Design 202
6.2.2 Research Area 202
6.2.3 Data Collection 203
6.2.3.1 Data Collection Plan 203
6.2.3.2 Questionnaire 203
6.2.3.3 Lessons Learned During Questionnaire Development 205
6.2.3.4. Recommendations 206
6.2.3.5 Interview Guides 207
6.2.3.6 Planning for the Key Informant Interviews 207
6.2.3.7 Planning for FGD, How They Were Conducted, and Outcomes in General, Lessons 207
6.2.3.8 Recommendation regarding FDGs 208
6.3 Field Visits 208
6.3.1 Planning for field visits 208
6.3.2 Actual Fieldwork 209
6.4 Observations/Findings 214
6.4.1 Kajiado County 214
6.4.1.1 Oloika Mini-Grid 214
6.4.1.2 Olkiramatian Mini-Grid 216

6.4.2 County Energy Department of Kajiado County 217
6.4.3 Siaya County 218
6.4.3.1 Ndeda Island Mini-Grid 218
6.4.3.2 County Energy Department of Siaya County 219
6.4.4 Homa Bay County 221
6.4.4.1 Mfangano Island 221
6.4.4.2 Ringiti Island 223
6.4.5 Kisii County 224
6.4.5.1 Powerhive 224
6.4.5.2 Powerhive 249 226
6.4.5.3 Gionseri B 227
6.4.5.4 Baranne Mini-Grid 228
6.4.5.5 County Energy Department of Kisii County 229
6.4.6 Busia County 230
6.4.6.1 KUDURA Power East Africa 230
6.4.6.2 Sidonge Mini-Grid 232
6.4.6.3 Dirakho Mini-Grid 233
6.4.6.4 County Energy Department of Busia County 233
6.4.7 Turkana County 234
6.4.7.1 Longech Mini-Grid 234
6.4.7.2 Lolupe Mini-Grid 235
6.4.7.3 Nadwat 236
6.4.8 Kalobeyei Settlement 237
6.4.9 County Energy Department of Turkana County 238
6.4.10 Murang'a County 239
6.4.10.1 Magiro Hydro Mini-Grid 239
6.5 Crosscutting Findings 241
6.5.1 Governance 241
6.5.1.1 Energy Use 242
6.5.2 Cost of Connection and Use 242
6.5.3 Technical Sustainability 243
6.6 Lessons Learned & Limitations 243
6.6.1 Planning 243

6.6.2 Actual Fieldwork 244
6.7 Concluding remarks 245

Chapter 7: Nigeria Fieldwork Report 247
Abstract 247
Acronyms 247
7.1 Introduction and Background 248
7.2 Methodology 249
7.2.1 Research Design 249
7.2.2 Research Area 249
7.2.3 Data Collection Plan 249
7.2.4 Questionnaire Development and Data Collection 251
7.2.5 Planning and Implementation of Key Informant Interviews 252
7.2.6 Planning and Implementation of FGDs 254
7.3 Observations and Findings 254
7.3.1 Mini-Grid Site Visitation and Community Engagement 255
7.3.1.1 Rije Community Mini-Grid 255
7.3.1.2 Adebayo Community Mini-Grid 257
7.3.2 Ozuzu Community Mini-Grid 262
7.3.3 Akpabom Community Mini-Grid 265
7.3.4 Eka Awoke Community Mini-Grid 268
7.3.5 Torankawa Mini-Grid 271
7.3.6 Dakiti Community Mini-Grid 274
7.3.7 Mbela Lagaje Mini-Grid 277
7.3.8 Nigeria Electricity Supply Company, Jos 280
7.3.9 Gbamu Gbamu Mini-Grid 284
7.4 Key Informant Interviews 288
7.4.1 The Energy Commission of Nigeria 288
7.4.2 Renewable and Rural Policies Department (Ministry of Power) 289
7.4.3 Heinrich Böll Stiftung (HBS) 289

7.4.4 The World Bank 290
7.4.5 Renewable Energy Association of Nigeria (REAN) 291
7.4.6 Havenhill Synergy Limited 292
7.4.7 Community Research and Development Center (CREDC) 293
7.4.8 Rubitec Nigeria Limited 294
7.4.9 GVE Projects 295
7.4.10 Nayo Tropical Technologies Limited 295
7.4.11 Gen Sustainability Solutions Limited 296
7.4.12 Rural Electrification Fund 297
7.4.13 Nigeria Electricity Regulatory Commission 298
7.4.14 Abuja Electricity Distribution Company (AEDC) 298
7.4.15 Benin Electricity Distribution Company (BEDC) 299
7.4.16 Ibadan Electricity Distribution Company (IBEDC) 299
7.5 Cross-Cutting Findings 300
7.5.1 Energy Access and Use 300
7.5.2 Tariffs and Affordability 301
7.5.3 User Perception of Mini-Grids 303
7.6 Lessons Learned and Limitations 303
7.7 Concluding remarks 304
Reference 304

Chapter 8: Tanzania Fieldwork Report 305
Abstract 305
Acronyms 305
8.1 Introduction 307
8.2 Approach Followed for the Fieldwork 310
8.3 Mini-Grid Case Studies from Tanzania 310
RUVUMA REGION 311
8.3.1 Tulila Mini-Hydro-Based Mini-Grid 311
8.3.1.1 Plant Development 311
8.3.1.2 Governance 311

8.3.1.3 Sustainability 312
Financial Sustainability 312
Technical Sustainability 312
Affordability 313
Business Model 313
8.3.1.4 Inclusivity 313
8.3.1.5 Challenges and Lesson Learned 314
8.3.2 Chipole Mini-Hydro-Based Mini-Grid 314
8.3.2.1 Plant Development 314
8.3.2.2 Governance 315
8.3.2.3 Sustainability 315
Financial Sustainability 315
Technical Sustainability 316
Affordability 316
Business Model 316
8.3.2.4 Inclusivity 317
NJOMBE REGION 318
8.3.3 TANWAT Biomass-Fired Mini-Grid 318
8.3.3.1 Plant Development 318
8.3.3.2 Governance 319
8.3.3.3 Sustainability 319
Financial Sustainability 319
Technical Sustainability 319
Affordability 320
Business Model 320
8.3.3.4 Inclusivity 320
IRINGA REGION 321
8.3.4 A Case Study on Mwenga Hydro- and Wind-Integrated Mini-Grid in Tanzania 321
8.3.4.1 Background 321
8.3.4.2 Plants Development 321
8.3.4.3 Governance 323

8.3.4.4 Sustainability 323
Financial Sustainability 323
Technical Sustainability 325
Affordability 327
Business Model 327
8.3.4.5 Inclusivity 328
8.3.4.6 Customer Aspects 328
Households 328
Productive Uses 328
DODOMA REGION 329
8.3.5 Leganga Solar Mini-Grid 329
8.3.5.1 Plant Development 329
8.3.5.2 Governance 330
8.3.5.3 Sustainability 330
Financial Sustainability 330
Technical Sustainability 331
Affordability 331
Business Model 332
8.3.5.4 Inclusivity 332
8.3.6 Ngutoto Solar Mini-Grid 333
8.3.6.1 Plant Development 333
8.3.6.2 Governance 333
8.3.6.3 Sustainability 334
Financial Sustainability 334
Technical Sustainability 334
Affordability 334
Business Model 334
8.3.6.4 Inclusivity 335
MOROGORO REGION 335
8.3.7 Songambele/Kitaita Solar–Diesel Hybrid Mini-Grid 335
8.3.7.1 Plant Development 335
8.3.7.2 Governance 336
8.3.7.3 Sustainability 336

Financial Sustainability 336
Technical Sustainability 336
Affordability 336
Business Model 337
8.3.7.4 Inclusivity 337
8.3.8 Leshata Solar–Diesel Hybrid Mini-Grid 338
8.3.8.1 Plant Development 338
8.3.8.2 Governance 338
8.3.8.3 Sustainability 339
Financial Sustainability 339
Technical Sustainability 339
Affordability 339
Business Model 339
8.3.8.4 Inclusivity 340
8.3.9 Mvuha Solar PV–Diesel Hybrid Mini-Grid 340
8.3.9.1 Plant Development 340
8.3.9.2 Governance 341
8.3.9.3 Sustainability 341
Financial Sustainability 341
Technical Sustainability 342
Affordability 342
Business Model 342
8.3.9.4 Inclusivity 342
8.3.10 Biro Gasifier Mini-Grid 343
8.3.10.1 Plant Development 343
8.3.10.2 Governance 344
8.3.10.3 Sustainability 344
Financial Sustainability 344
Technical Sustainability 344
Affordability 345
Business Model 345
8.3.10.4 Inclusivity 346
PWANI REGION 347

8.3.11 Kibindu Gasifier–Solar Hybrid Mini-Grid 347
8.3.11.1 Plant Development 347
8.3.11.2 Governance 347
8.3.11.3 Sustainability 347
Financial Sustainability 347
Technical Sustainability 348
Affordability 348
Business Model 349
8.3.11.4 Inclusivity 349
KILIMANJARO REGION 350
8.3.12 TPC Biomass-Fired Mini-Grid 350
8.3.12.1 Plant Development 350
8.3.12.2 Governance 351
8.3.12.3 Sustainability 351
Financial Sustainability 351
Technical Sustainability 351
Affordability 352
Business Model 352
8.3.12.4 Inclusivity 352
8.3.13 Mjimwema Multifunctional Platform Straight Vegetable Oil/Diesel Mini-Grid 353
8.3.13.1 Plant Development 353
8.3.13.2 Governance 354
8.3.13.3 Sustainability 354
Financial Sustainability 354
Technical Sustainability 355
Affordability 355
Business Model 355
8.3.13.4 Inclusivity 355
8.3.14 Kikuletwa Mini-Hydro-Based Mini-Grid 356
8.3.14.1 Plant Development 356
8.3.14.2 Governance 357

8.3.14.3 Sustainability 358
Financial Sustainability 358
Technical Sustainability 358
Affordability 359
Business Model 359
8.3.14.4 Inclusivity 359
KIGOMA REGION 360
8.3.15 Kigoma Diesel-Based Mini-Grid 360
8.3.15.1 Plant Development 360
8.3.15.2 Governance 360
8.3.15.3 Sustainability 361
Financial Sustainability 361
Technical Sustainability 361
Affordability 361
Business Model 362
8.3.15.4 Inclusivity 362
8.3.16 Kigoma Solar PV–Based Mini-Grid 362
8.3.16.1 Plant Development 362
8.3.16.2 Governance 363
8.3.16.3 Sustainability 363
Financial Sustainability 363
Technical Sustainability 363
Affordability 364
Business Model 364
8.3.16.4 Inclusivity 365
TANGA REGION 365
8.3.17 Mpale Solar–Diesel Hybrid Mini-Grid 365
8.3.17.1 Plant Development 365
8.3.17.2 Governance 366
8.3.17.3 Sustainability 366
Financial Sustainability 366
Technical Sustainability 366

Affordability 367
Business Model 368
8.3.17.4 Inclusivity 368
8.4 Concluding Remarks 369

Part 3: Mini-Grid Sustainability, Inclusiveness, and Governance Analysis 371

Chapter 9: Mini-Grid Performance Analysis Using Data Envelopment Analysis 373
Abstract 373
Acronyms 373
9.1 Introduction to Productive Efficiency Measurement 374
9.2 Literature Review of DEA Applications to Renewable Energy Systems 377
9.3 Estimation Approaches for the Best-Practice Frontiers 379
9.4 Illustrative Case Applications 380
9.4.1 Data Selection for the Application 381
9.4.2 Results from the CCR Analysis 382
9.4.3 Results from the BCC Analysis 385
9.4.4 Scale Efficiency of Mini-Grids 387
9.5 DEA and Mini-Grid Performance Benchmarking: Discussion 388
9.5.1 CCR, BCC, and Scale Efficiency Discussion 388
9.5.2 Geographic Differences in Mini-Grid Performance 392
9.5.3 Ownership Models and Mini-Grid Performance 393
9.6 Conclusions 394
References 395
Annex 9.1: Mini-grid data extracted from the meta-analysis dataset. 398

Chapter 10: Mini-Grid Sustainability Framework and Its Application to Selected Mini-Grids in Kenya 403
Acronyms 403
Abstract 403

10.1 Introduction 404
10.2 Framework Design 405
10.3 Application to the Mini-Grids Visited in Kenya 412
10.5 Conclusions 418
References 419
Annex 10.1: *Details of Sustainability* Scores 421

Chapter 11: Harnessing Mini-Grid Regulation and Investment for Rural Electrification in Nigeria: Challenges and Prospects 423
Acronyms 423
Abstract 423
11.1 Introduction 424
11.2 Mini-Grids in the Context of Electricity Sector Governance 427
11.3 Methods 431
11.4 The Intersection of Mini-Grid Regulation and Market Development in Nigeria 432
11.4.1 The Growth of the Mini-Grid Market in Nigeria Predates Regulation and Associated Development Finance, but It Has Subsequently Been Shaped by These Factors 433
11.4.2 The Advent of Regulation and Investment Has Helped to Accelerate the Activities of Market Actors, but Winners and Losers Have Emerged in the Process 437
11.4.3 The Premise of Electrifying Last-Mile Communities Through Improved Regulation and Investment for Mini-Grid Expansion Is Not Aligned with Institutional and Financial Realities 441
11.5 Conclusions and Policy Implications 444
Acknowledgments 446
References 446

Chapter 12: Regulatory Framework and Tariff Aspects of Electricity Mini-Grids in Tanzania 455
Abstract 455
Acronyms/Abbreviations 456
12.1 Background 458
12.1.1 Objectives, Research Questions, and Paper Organization 458
12.1.2 Country Context 459
12.1.3 Evolution of Regulatory Framework 461
12.1.3.1 First-Generation SPP Framework 462
12.1.3.2 Second-Generation SPP Framework 463
12.1.3.3 Third-Generation SPP Framework 463
12.2 Methodology 464
12.3 Overview Concept on Mini-Grid Regulatory Framework Rules and Tariff Aspect 468
12.3.1 The Regulatory Framework 469
12.3.1.1 Institutional Arrangements of the Sector 470
12.3.2 Acts, Regulations, and Rules Relevant to Mini-Grids 473
12.3.3 Tariff Structures for Mini-Grids in Tanzania 476
12.3.4 Tariff-Setting 477
12.3.5 Gaps in the Existing Literature 478
12.3.6 Comparative Analysis 479
12.4 Evidence from Field Findings 479
12.4.1 Regulatory Framework–Related Aspects 480
12.4.1.1 Approval Processes 480
12.4.1.2 Grid Compatibility 482
12.4.1.3 Grid Interconnection 483
12.4.1.4 Technical Standards 485
12.4.2 Tariff-Related Aspects 485
12.4.2.1 Tariff-Setting 486
12.4.2.2 Tariff Levels Within and Across Mini-Grid Locations 489

12.4.2.3 Mini-Grid Versus National Grid Tariff Comparison 492
End-use Customer Aspects 494
12.4.2.4 Cost Recovery 496
12.5 Conclusions and Recommendations 497
12.5.1 Concluding Remarks 497
12.5.2 Recommendations for Further Research 499
References 500
Appendices 504

Chapter 13: Household Agency in Sustainability Transitions: A Case Study of Mini-Grids in Kenya 509
Acronyms 509
Abstract 509
13.1 Introduction 510
13.2 Literature Review 513
13.2.1 Mini-Grids and Energy Transitions 513
13.2.1.1 Household Agency 514
13.2.2 Energy Justice and Household Agency in Mini-Grids 517
13.3 Research Methodology 520
13.3.1 Coding Scheme 520
13.3.2 Analysis Using Atlas.ti 520
13.4 Analysis of Results 524
13.4.1 Household Agency Toward Connection to the Mini-Grid 525
13.4.2 Household Agency After Connection to the Mini-Grid 530
13.4.2.1 Challenges Faced by Households 531
13.4.2.2 Adoption to Technology 534
13.4.2.3 Behavior Modification 535
13.4.2.4 Household Innovation 536

13.5 Discussion 536
References 537

Chapter 14: Concluding Remarks 543
14.1 Introduction 543
14.2 Evidence Base 543
14.3 Lessons from Country Cases 545
14.4 Areas for Future Work 547
14.4.1 Theme 1: Productive Uses of Energy for Mini-Grids and Enhancing the Mini-Grid Value Chain 547
14.4.2 Theme 2: Inclusivity and Leaving No One Behind: Approaches for the Bottom-of-the-Pyramid Users 548
14.4.3 Theme 3: Beyond Mini-Grids: Micro-scale Systems or Regional Integration 548
14.4.4 Theme 4: Resilient, Equitable, and Affordable Energy Systems for All 549
References 550

LIST OF FIGURES

Figure 1.1: Trend of Electricity Access Improvements Around the World 2
Figure 1.2: Research Questions and Sub-Questions 6
Figure 2.1: Multi-tier Framework for Energy Access Measurement 41
Figure 2.2: Technical Sustainability Framework Used by Katre and Tozzi (2018) 42
Figure 2.3: Technical Indicators Used by Ilskog (2008) 43
Figure 2.4: Indicators Used for Technical Sustainability in the Composite Sustainability Index proposed by Rahmann et al. (2016) 46
Figure 2.5: Elements of Mini-Grid Technical Sustainability 49
Figure 2.6: Technical Sustainability Framework 51
Figure 3.1: Mini-Grids by Type of Technology in Tanzania, Kenya, 66
Figure 3.2: Phases of Access to Finance 82
Figure 5.1: The Ladder of Inclusive Innovation (LII) Depicting Different Levels (or gradations) of Inclusion 153
Figure 5.2: Three-Stage Systematic Literature Review 155
Figure 5.3: Methodology Adapted from Rosca et al. (2018). 156
Figure 5.4: Literature Shortlisting Process 157
Figure 5.5: Year-Wise Distribution of Papers Published from 2008 to 2021 158
Figure 5.6: Articles by Country of Study 158
Figure 5.7: Article Types and Empirical Approach Used 159
Figure 5.8: Year of Publications Overall Publications vs Publications with the Exclusion Criteria 159

Figure 5.9: Document Type and Country Focus 160
Figure 5.10: Authorship and Affiliation 161
Figure 6.1: Map of Kenya Indicating Counties Visited for Fieldwork 202
Figure 6.1: Oloika Mini-Grid 215
Figure 6.2: Olkiramatian Mini-Grid 216
Figure 6.3: Hybrid Mini -Grid at Ndeda Island 218
Figure 6.4: Institutions Served by the Mini-Grid: Left to Right; Health Facility and Public Primary School 219
Figure 6.5: Mini-Grid at Ringiti Island 223
Figure 6.6: Shores of Lake Victoria at Ringiti Island 223
Figure 6.7: Organic Solid Waste Collected from Kisii Municipal Market 226
Figure 6.8: BSF in the Drier 227
Figure 6.9: Solar Mini-Grid at Gionseri B, Kisii County 227
Figure 6.10: Community Library Powered by Kudura Mini-Grid at Sidonge 232
Figure 6.11: Longech Mini-Grid, Turkana County 235
Figure 6.12: Participants at a Focus Group Discussion in Lolupe, Turkana County 235
Figure 6.13: Gold Processing Using Mini-Grid Electricity in Nadwat, Turkana County 237
Figure 6.14: Magiro Hydro Mini-Grid, Murang'a County 239
Figure 7.1: Mini-Grid Sites Visited 249
Figure 7.2: (a and b): Rije Community Biogas Mini-Grid and Community 256
Figure 7.3: Adebayo Community Mini-Grid 258
Figure 7.4: Focus Group Discussion with Community Members at Adebayo 259
Figure 7.5: A Carpenter Who Uses Power from the Mini-Grid 261
Figure 7.6: Poles Waiting to be Energized 262
Figure 7.7: Ozuzu Community Mini-Grid Plant 263
Figure 7.8: Filling Station Powered by Energy from the

Mini-Grid in Ozuzu Community 265
Figure 7.9: Akpabom Community Mini-Grid 266
Figure 7.10: Akpabom Mini-Grid Battery Bank 267
Figure 7.11: Eka Awoke Mini-Grid System 268
Figure 7.12: Some Electrical Appliances Offered by the Mini-Grid Developer and Operator 270
Figure 7.13: Focus Group Discussion in Torankawa Community 273
Figure 7.14: Dakiti Community Mini-Grid 275
Figure 7.15: Sample Electricity Meter at Dakiti Community 277
Figure 7.16: Mbela Lagaje Mini-Grid Site 278
Figure 7.17: Mbela Lagaje Mini-Grid Lines 279
Figure 7.18: Mbela Lagaje Mini-Grid Lines 280
Figure 7.19: Gbamu Gbamu Mini-Grid Site 285
Figure 8.1: Visited Site Regions 308
Figure 8.2: The Chipole Hydro Power Dam After It Was Washed by Floods 317
Figure 8.3: Mwenga Mini-Grid Wind Turbines with Transmission Lines 322
Figure 8.4: Containerized Leganga Solar PV Mini-Grid 331
Figure 9.1: Measurement of Productive Efficiency 375
Figure 9.2: Scatter Plot of Output-Oriented CCR Efficiency 383
Figure 9.3: Scatter Plot of Input-Oriented BCC Efficiency 385
Figure 9.4: Scatter Plot of Output-Oriented BCC Efficiency 386
Figure 9.5: Scatter Plot of Input-Oriented Scale Efficiency 387
Figure 9.6: Scatter Plot of Output-Oriented Scale Efficiency 388
Figure 10.1: Framework for Mini-Grid Sustainability Assessment 406
Figure 10.2: Technical Sustainability Scores 414
Figure 10.3: Economic Sustainability Scores 415
Figure 10.4: Social Sustainability Scores 415
Figure 10.5: Institutional Sustainability Scores 416
Figure 10.6: Environmental Sustainability Scores 416
Figure 10.7: Total Sustainability Scores 417
Figure 11.1: Growth in Power Output from Operational Mini-Grids

in Nigeria, 2001–2022 433
Figure 11.2: Coverage Area of Electricity Distribution Companies in Nigeria 439
Figure 13.1: Network Presentation of Household Challenges on Atlas.ti 22 531

LIST OF TABLES

Table 2.1: Scope of the Review and Inclusion Criteria 18
Table 2.2: Sources of Literature Used in the Survey 20
Table 2.3: Codes for the Thematic Analysis of the Technical Dimension of Mini-Grid Sustainability 20
Table 2.4: Indicators and Attributes Used in the Multi-tier Framework 44
Table 2.5: Scoring Methodology 52
Table 3.1: Scope of the Review 67
Table 3.2: Literature Review Coding 68
Table 3.3: Number of Mini-Grids by Ownership Model 70
Table 3.4: Contractual Options for Hybrid Models 73
Table 3.5: Types of Subsidies 87
Table 3.6: Summary of Risks and Challenges for Mini-Grids 89
Table 3.7: Doing Business Ranking 2020 93
Table 4.1: Multi-Tier Energy Access Framework 118
Table 4.2: Comparative Statistics Kenya, Tanzania, Nigeria, and Senegal (2024) 120
Table 4.3: Institutions and Processes of Electricity Governance and Regulation (2022) 121
Table 6.1: Matrix of Targeted Mini-Grids in Each Country 204
Table 6.2: Itinerary of Mini-Grid Sites Visited During the Study 209
Table 6.3: Characteristics of Mini-Grids Visited 211
Table 6.4: Number of Interviews or FGD Conducted per Mini-Grid 212
Table 6.5: Types of Productive Users, Institutions, and Community Leaders Interviewed at Mini-Grid 213
Table 6.6: FGDs Conducted 214
Table 7.1: Mini-Grid Location and Composition 250
Table 7.2: Key Informant Interviews 251

Table 7.3: Schedule of Mini-Grid Communities/Sites Visitation 253
Table 8.1: Selected Mini-Grids by Technology and Ownership Model 308
Table 8.2: Mini-Grid Location, Technology, Energy Source, Capacity, Operating Status, and Type of Operating Network 309
Table 8.3: Energy Charge Tariff 2012 to February 2022 for Mwenga and TANESCO 324
Table 8.4: Connection Charges for Mwenga Customers 326
Table 9.1: Variables Used in the Analysis of Duran and Sahinyazan (2021a) 382
Table 9.2: Peer Groups and Plant Distribution 384
Table 9.3: Full DEA Results 389
Annex 9.1: Mini-Grid Data Extracted from the Meta-Analysis Dataset 398
Table 10.1: Description of the Framework Components and Measures 407
Table 10.2: Summary of Sustainability Evaluation of Mini-Grids in Kenya (for Selected Cases) 413
Annex 10.1: *Details of Sustainability* Scores 421
Table 12.1: Summary of Mini-Grids and Distributed Types, Numbers, Capacities, and Number of Connections 461
Table 12.2: List of Mini-Grids Visited, Locations, Types, Capacities, Connection Status, and Operating Status 465
Table 12.3: National Policies 475
Table 12.4: Codes for the Thematic Analysis of Regulatory Framework–Related Aspects 480
Table 12.5: Steps for Mini-Grid Development Clearances 481
Table 12.6: Codes for the Thematic Analysis of Tariff-Related Aspects 486
Table 12.7: Tariffs for Main Grid Connection Under the First-Generation SPP Framework (Avoided Cost) 486

Table 12.8: Tariffs for Mini-Grid Before and After Grid Connection Under First-Generation SPP Framework (Avoided Cost) 487
Table 12.9: Tariffs for SPPs Selling Electricity to the Grid Based on Specific Technology Under Second Generation (w.e.f. June 21, 2019) 487
Appendix 12.A: TANESCO End-Use Customer Tariff—April 1, 2016 to 2024 504
Single-Phase Charges 505
Appendix 12.B: Trend of SPP Feed-in Tariff (2009–2020) Sold to TANESCO 506
Table 1: End-Use Customer Energy Charge Tariff from 2012 to January 2022, and February 2022 to Date 508
Table 2: End-Use Customer Connection Charges 2012 to Date 508
Table 13.1: Assessment of Parameters 521
Table 13.2: Household Demographics 523
Table 13.3: Interviews Conducted 524

PREFACE

This edited book presents original research outcomes undertaken through a funded research project—Sustainability, Inclusiveness, and Governance of Mini-Grids in Africa (SIGMA)—supported through the Global Challenge Research Fund of the UKRI (ES/T006684/1 and ES/T006684/2) undertaken between March 2020 and March 2024. The study's original plan was significantly affected by the COVID-19 pandemic and the subsequent reduction in UK international development funding from late 2020. The original three-year project plan had to be revised to deal with the restrictions imposed by the above challenges. Through strong determination, perseverance, and dedication, the project team has managed to overcome the challenges and produced interesting research that has been disseminated through project dissemination events organized in the UK and in project participating countries. The academic outputs were initially presented as working papers, and, subsequently, several outputs were converted into journal papers. This edited book provides a complete collection of important outputs that we believe would be of interest to the wider audience working in the area of mini-grids in general and in Africa in particular.

We would like to thank all the contributors to this volume for their continued support and hard work. They have made extraordinary efforts to produce the outputs despite funding challenges and the restrictions imposed by the pandemic. The fieldwork had to be carried out in difficult conditions, and we are particularly thankful to our researchers who were involved in the process. We also thank all our stakeholders who participated in our case studies, consultation events, dissemination workshops, and online events and offered valuable insights. Without their support and inputs, the project would not be possible.

This open-access publication has been made possible by the generous funding from the UKRI. We are very grateful to them for this support. We also thank our respective research offices and our families for their support, understanding, and patience.

We alone are responsible for any errors, omissions, and commissions. We would appreciate any feedback on this volume, which could be shared with any of the editors by email.

Daniel Kerr, Lucy Baker, Temilade Sesan, Elsie Onsongo, and Subhes C. Bhattacharyya

CHAPTER 1

Introduction

Daniel Kerr,[1] Lucy Baker,[2] Temilade Sesan,[3] Elsie Onsongo[4] and Subhes C. Bhattacharyya[1]

[1]Institute for Sustainable Futures, De Montfort University, Leicester, UK
[2]Geography and Environment Studies, The Open University, Milton Keynes, UK
[3]Center for Petroleum, Energy Economics and Law, University of Ibadan, Ibadan, Nigeria
[4]Nuvoni Centre for Innovation Research, Nairobi, Kenya

Abstract

This chapter introduces the background and context of the book. It indicates the research questions and highlights the knowledge gap the study intends to fill. The research activities undertaken to answer the research issues are presented and the organization of the book is indicated at the end of the chapter.

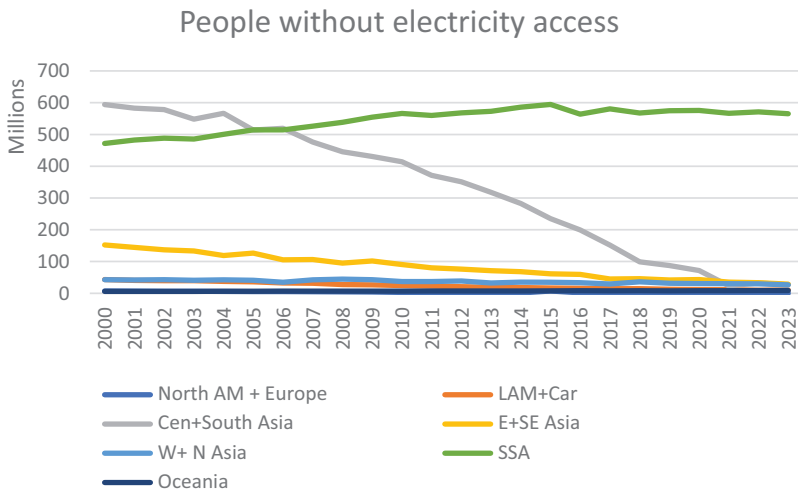
Keywords: Mini-grids, Africa, sustainability, inclusiveness, governance, research gaps, energy access, SDG 7

1.1 Introduction and Problem Statement

By 2023, approximately 666 million people (8.2% of the world's population) lacked access to electricity globally, of which 85% were in sub-Saharan Africa (SSA) (IEA et al., 2025). While the rest of the regions have seen significant improvements in electricity access (see Fig. 1.1), SSA has seen an increase in the continent's population without access to electricity compared to that at the start of the twenty-first century (from 518 million in 2000 to 565 million in 2023) (IEA et al., 2025).

Tackling this energy access gap requires nothing less than a socio-technological transformation in which decentralized and off-grid renewable electricity generation will play a key role in displacing the overreliance on unsustainable and low-quality energy sources (Ockwell & Byrne, 2016, p. 5). More specifically, and as the focus of this research, mini-grids have been identified as a key technology for the realization of the Sustainable Energy for All Initiative

Figure 1.1: Trend of Electricity Access Improvements Around the World



Source: IEA et al. (2025).

Legend: North AM + Europe – North America and Europe; LAM + Car – Latin America and the Caribbean; Cen + South Asia – Central Asia and South Asia; E + SE Asia – East Asia and South-East Asia; W + N Asia – Western Asia and Northern Asia; SSA – Sub-Saharan Asia.

(SE4All) and the Sustainable Development Goals, not least SDG 7, one of whose targets (Target 7.1) is to reach universal energy access by 2030 (IEA et al., 2025). The term mini-grid (sometimes referred to as micro-grid) refers to a low-voltage distribution network of electricity with embedded small-scale electricity generation capacity. The network can operate in isolation from the national transmission and distribution network, but can also connect to it should the network expand. Mini-grids are being built, owned, operated, and managed by different entities, e.g., the private sector, NGOs, local communities, and public sector agencies (Knuckles, 2016), and they cater to various needs at multiple scales, from basic services such as lighting and mobile phone charging to productive and institutional electricity needs for schools, clinics and businesses. These systems, particularly those combining solar photovoltaic (PV) and battery storage, are seen as a game changer and the least-cost option for rapid, cost-effective, pro-poor, high-quality universal electrification in SSA and elsewhere. Due to their flexibility and modularity, mini-grids have also been put forward as a way to bypass failing large-scale, capital-intensive utilities in many low- and middle-income countries (LMICs)

by reaching informal settlements in urban areas or remote rural populations directly, where the cost of connection to the centralized national grid is prohibitive. Consequently, it has been argued that mini-grids are "emerging as a third alternative to rural electrification, coming between the option of large-scale grid extension and pico-scale stand-alone solutions like solar home systems or solar lanterns" (Pedersen, 2016).

Although the number of mini-grids has crossed 21,000 installations, providing electricity to 48 million people (Mini-grid Partnership, 2024), the mini-grid "explosion" has not materialized despite the rapidly falling costs of solar PV since 2010 (Bagley et al., 2018). International organizations and Development finance institutions are actively promoting mini-grids through various initiatives such as UNDP-led Africa Minigrids Program and AfDB's Sustainable Energy Fund for Africa (Agutu et al., 2022). Progress has been patchy between and within countries, across rural areas and informal urban settlements, and between high-and low-income communities (Ockwell et al., 2018). Among the barriers to scaling up mini-grids in Africa are the lack of mini-grid-specific regulatory framework, unproven business models, demand uncertainty, limited access to finance, lack of capacity (Oyman, 2017), high investment costs, and grid integration issues (Cyril et al., 2024). Further, the evidence base to verify the assumption of renewable mini-grids as sustainable, inclusive technological solutions remains limited.

With this in mind, this study (hereafter the SIGMA project) seeks to provide an applied and analytical approach to uncover the complex dynamics behind the challenges of installing sustainable and inclusive decentralized electricity systems. With comparative case studies from Senegal, Nigeria, Tanzania, and Kenya, our key objectives in undertaking this research are to: (a) **develop an evidence base for the performance of mini-grids in the case study countries**; (b) **undertake an analysis of existing business models and policy frameworks** in each case; and (c) **take forward analytical concepts of the political economy of decentralized electricity systems** to understand the political drivers behind differences in the speed of adoption of mini-grids in different countries.

1.2 Research Gaps and Research Questions to Be Addressed

This study responds to a number of highly significant research gaps under three interrelated themes: Sustainability, Inclusiveness, and Governance as follows:

Sustainability: The evidence base on the extent to which existing mini-grid systems are delivering economic, social, and environmental benefits and contributing to sustainable development is poor. The developmental benefits have been presumed and not demonstrated (e.g., Pueyo & DeMartino, 2018), and there has been limited research into their long-term performance and effectiveness. First, there is a need for a more in-depth understanding of the socio-technical sustainability of mini-grids, taking contextual factors into account and the configuration of and interactions among elements in the system, not only technical and economic, but also social and political. Further research is needed to understand how mini-grids get socially embedded in different SSA regions, specifically their alignment with socio-cultural expectations, dilemmas around managing demand versus system capacity, and how local communities experiment to address challenges of technical performance (Ulsrud et al., 2011). On the economic front, there is a research gap on how revenue generating and not for profit business models can deliver financially and technically sustainable mini-grids (Pedersen, 2016). Further, there is a need to link different business model configurations with different mini-grid outcomes such as profitability and scale (Knuckles, 2016). Similarly, a comparative analysis of financing and revenue-generation mechanisms that takes into account new technologies and innovative financing schemes emerging in SSA is lacking. There is a research gap on how various different business models can deliver financially and technically sustainable mini-grids (Pedersen, 2016).

Inclusiveness: Beyond the technical and financial emphasis mentioned above, there has been limited significance placed on the importance of a socially just, sustainable, and inclusive energy provision (Ockwell et al., 2018). Furthermore, assumptions are often made that low-income and socio-economically and politically marginalized communities will automatically benefit from decentralized electricity interventions. But what are the local socio-economic conditions into which these new technological systems are being introduced? Who reaps the benefits from the mini-grid value chain? It is evident that mini-grids are struggle to balance economic sustainability and affordability, which further disenfranchises low-income households (Moner-Girona et al., 2016). What opportunities exist to mitigate the cost-of-access and affordability constraints?

The dynamics of social inclusion and exclusion related to mini-grids remain a pertinent developmental challenge. For instance, multi-lateral and bi-lateral development institutions such as the UK's Foreign, Commonwealth Development Office" [nb DfID was merged with FCO in about 2020] and the World Bank favor a private-sector-led off-grid electrification, but a cost-reflective

tariff that would make the private sector financially viable can create a tariff divide between the wealthier urban population and the poorer rural communities, with subsequent opposition to these systems. We therefore set out to understand to understand how electrification through mini-grids can be embedded within development programs, and as a consequence, which livelihood opportunities can or should be included in different types or scales of mini-grids (Bhattacharyya & Palit, 2016). Further, there is a need to critically analyze the extent and terms of inclusion in the process of design and planning for mini-grids in SSA against their effectiveness, and the role of local knowledge systems (Ulsrud et al., 2011). Given that productive and domestic uses of energy are gendered (Pueyo and Maestre, 2019), the dynamics around the participation and empowerment of women, of youth, low-income communities and other marginalized groups in mini-grid electrification systems are germane to realizing a just energy transition, and thus, worth investigating.

Governance: While various reasons have been attributed to the lack of investment in mini-grids, the implementation of an appropriate governance framework and an effective regulatory structure stands out as a key challenge. Further factors that have been identified include unproven and inappropriate business models often due to unreliable data or the lack of information, demand uncertainty, limited access to finance, and lack of human and technical capacity (Banerjee et al., 2016; Manetsgruber et al., 2015; Oyman, 2017). As argued in the Green Mini-Grid Africa Strategy (AfDB, 2017), "the lack of available finance is often cited as the main barrier to the sector's growth, but the reluctance of financiers is often due to one key constraint—the lack of public policies and regulations required to enable private sector investment" (p. 4). The process of improving financing mechanisms for prospective mini-grid developers could benefit from targeted policy intervention (Yadoo & Cruickshank, 2012). Further evidence is needed to understand which ownership structures ae more viable, and how these structures evolve over time due to contextual changes such as shifts in regulatory guidelines.

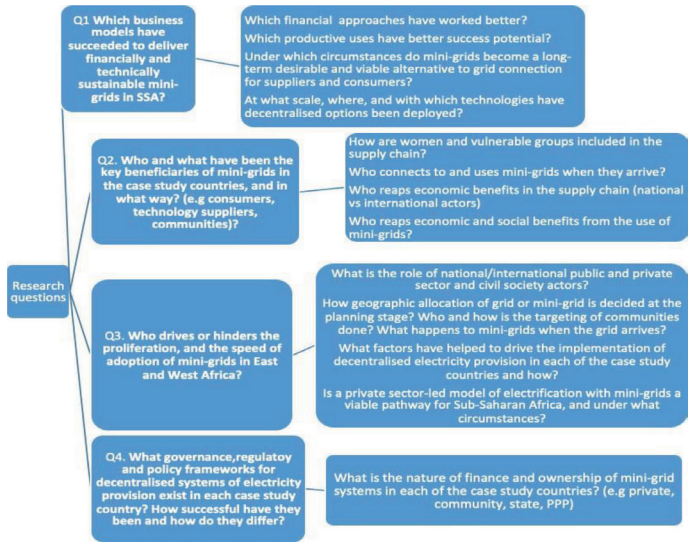
In parallel, political resistance to small and decentralized installations by incumbent players, such as state-owned utilities, has posed a further challenge. This project will therefore undertake a systematic comparative analysis of electricity governance in each case study country and how it has accounted for decentralized systems. This will also include things like tariff-setting, cost-recovery power purchase agreement, and government-backed guarantees. Given that scholarship on decentralized electricity is largely dominated by engineering and economics, existing studies have tended to privilege the technical and financial barriers to decentralized electricity access and have given limited regard to the significance of the social,

economic, political, and cultural realities, which often determine the success or failure of the technical and financial factors (Ockwell et al., 2018). While there have been attempts to address some of these issues, there is a scarcity of longitudinal studies. With no systematic framework for evaluation, it has thus far been impossible to develop program-level synergies and appropriate planning processes in order to accelerate the electrification process. In addition, comparative studies of mini-grids in SSA are scarce (Moner-Girona et al., 2018). This study therefore reframed the way in which challenges have been approached thus far, and, in so doing, generates a deeper interdisciplinary body of empirical evidence from the case study countries in order to understand the multi-dimensional and context-specific challenges that exist, and the ways in which these may be overcome or mitigated.

Based on the above discussion, we have identified four main research questions and a set of sub-questions (see Fig. 1.2).

(1) Which business models have succeeded in delivering financially and technically viable mini-grids in SSA?
(2) Who and what have been the key beneficiaries of mini-grids in the case study countries, and in what ways?
(3) Who drives or hinders the proliferation and speed of adoption of mini-grids in East and West Africa? (
(4) What governance, regulatory, and policy frameworks for decentralized systems of electricity provision exist in each case study country, how successful have they been, and how do they differ?

Figure 1.2: Research Questions and Sub-Questions



We addressed these questions as part of a Global Challenges Research Fund project which began in early 2020 and was led by de Montfort University and its continuation (ES/T006684/2) at the University of Surrey. The work involved analyzing sustainability, inclusiveness, and governance issues related to mini-grids in Africa through an evaluation of projects in four countries, namely Nigeria, Senegal, Tanzania, and Kenya.

1.3 Activities Undertaken

The SIGMA project has produced a wide range of activities to meet our research objectives:

- Literature Review—A wide-ranging review of literature on the project themes of sustainability, inclusiveness, and governance for each country context.
- Frameworks for Mini-Grid Performance and Sustainability Analysis—SIGMA researchers have produced both an indicator-based framework for mini-grid sustainability analysis and an analytical framework using data envelopment analysis for mini-grid performance.
- Fieldwork—Partners in Kenya, Nigeria, Tanzania, and Senegal have undertaken extensive fieldwork activities, including visits to a variety of mini-grid sites and stakeholder and key informant interviews with governments, regulators, and mini-grid developers.

- Country Case Studies—SIGMA researchers have summarized country-level outcomes in our series of fieldwork reports and working papers.
- Collaboration, Networking, and Capacity-Building—SIGMA partners undertook a number of in-country networking and capacity-building events, facilitating South–South and North–South knowledge exchange and building networks of practitioners, governments, private sector, and third-sector actors in the mini-grid space.
- Dissemination—In addition to our working paper series, SIGMA researchers have been published in *Energy Policy* and *Energy for Sustainable Development*, as well as presenting at the Gender and Inclusion Summit 2022, COP27 and COP28, and the 4th International Conference on Solar Technologies & Hybrid Mini Grids to Improve Energy Access. In addition, we have run events with the Nigerian Rural Electrification Agency, collaborated on reports with PeopleSun, and run our own webinar series and high-level policy dialogue sessions.

A final dissemination event was organized in hybrid mode on 16 February 2024. The hybrid event was held at the Holiday Inn hotel in Guildford (Surrey) and was attended by around fifty participants (in person and online). The agenda for the event included formal presentations by the project team in the morning session, followed by invited guest presentations in the post-lunch session. SIGMA Principal Investigator Professor Subhes Bhattacharyya from the University of Surrey gave an overview of the project, and representatives from each of the country teams—Nigeria, Senegal, Tanzania, and Kenya—presented results. Team representatives then discussed key cross-cutting issues in a high-level panel, and guest speakers presented on the role of energy democracy and politics in African country energy transitions and the technical, economic, and social aspects of solar mini-grid infrastructures. The conference attendees, including those joining online, were engaged in three thematic discussions: productive uses, inclusivity and leaving no one behind, and beyond mini-grids. A sample of key outputs and a set of ten posters were displayed physically during the event.

1.4 Organization of the Book

This book presents the main outputs of the SIGMA study and is organized in three parts: the first part presents a state-of-the-art review of the literature, Part 2 presents the fieldwork details from Kenya, Nigeria, and Tanzania, while Part 3 presents case studies and analyses. The first part contains four chapters covering technical sustainability (Chapter 2), business models and access to finance (Chapter 3), governance issues (Chapter 4), and social inclusiveness (Chapter 5). In Part 2, Chapters 6 to 8 present the details of the fieldwork undertaken in Kenya, Nigeria, and Tanzania. Part 3 contains five chapters—mini-grid sustainability analysis using the data envelopment approach (Chapter 9), sustainability analysis framework (Chapter 10), mini-grids in electricity governance (Chapter 11), regulatory framework in Tanzania (Chapter 12), and household innovation and agency in energy transition (Chapter 13). Finally, concluding remarks are presented.

References

African Development Bank. (2017). *Green Mini-grids Africa Strategy*. https://au.int/sites/default/files/documents/32183-doc-green_mini-grid_gmg_africa_strategy-e.pdf

Agutu, C., Egli, F., Steffen, B., & Schmidt, T. S. (2022). *De-risking off-grid electrification finance and fostering standalone system deployment policies are key to achieving SDG7*. Climate Compatible Growth Programme COP27 Policy Brief Series (Version 1). https://hdl.handle.net/2134/33252

Bagley, C., Brown, E., Campbell, B., Cloke, J., Cameron, S., Collings, S., Gunning, R., Kabell, H., McDonnell, J., Seng To, L., & Turner, B. (2018). *Mapping the UK research and innovation landscape: Energy & Development*. Low Carbon Energy for Development Network. https://www.lcedn.com/sites/default/files/files/UK%20Energy%20and%20Dev%20research%20landscape%20review_Final_April%202018.pdf

Banerjee, S. G., Moreno, A., Sinton, J., Primiani, T., & Seong, J. (2016). *Regulatory indicators for sustainable energy: A global scorecard for policy makers*. The World Bank.

Bhattacharyya, S. C., & Palit, D. (2016). Mini-grid based off-grid electrification to enhance electricity access in developing countries: What policies may be required? *Energy Policy*, *94*, 166–178.

Cyril, A. O., Ujah, C. O., Ekwueme, B. N., & Asadu, C. O. (2024). Photovoltaic mini-grid incorporation: The panacea for electricity crisis in sub-Saharan Africa. *Unconventional Resources*, *4*, 100079. https://doi.org/10.1016/j.uncres.2024.100079

IEA, IRENA, UNSD, World Bank and WHO. (2025). *Tracking SDG7: The Energy Progress Report, 2025*. World Bank. https://www.iea.org/reports/tracking-sdg7-the-energy-progress-report-2025

Knuckles, J. (2016). Business models for mini-grid electricity in base of the pyramid markets. *Energy for Sustainable Development*, *31*, 67–82.

Manetsgruber, D., Wagemann, B., Kondev, B., & Dziergwa, K. (2015). *Risk management for mini-grids: A new approach to guide mini-grid development*. Alliance for Rural Electrification.

Mini-Grid Partnership. (2024). *State of the global mini-grids market report 2024*. SOTM-Report-2024_EN_vFc.pdf

Moner-Girona, M., Ghanadan, R., Solano-Peralta, M., Kougias, I., Bódis, K., Huld, T., & Szabó, S. (2016). Adaptation of Feed-in Tariff for remote mini-grids: Tanzania as an illustrative case. *Renewable and Sustainable Energy Reviews*, *53*, 306–318.

Moner-Girona, M., Solano-Peralta, M., Lazopoulou, M., Ackom, E. K., Vallve, X., & Szabó, S. (2018). Electrification of sub-Saharan Africa through PV/hybrid mini- grids: Reducing the gap between current business models and on-site experience. *Renewable and Sustainable Energy Reviews*, *91*, 1148–1161.

Ockwell, D., & Byrne, R. (2016). *Sustainable energy for all: Innovation, technology and pro-poor green transformations*. Routledge.

Ockwell, D., Byrne, R., Hansen, U. E., Haselip, J., & Nygaard, I. (2018). The uptake and diffusion of solar power in Africa: Socio-cultural and political insights on a rapidly emerging socio-technical transition. *Energy Research & Social Science*, *44*, 122–129.

Oyman, O. (2017). *Auctions as a potential mechanism to accelerate green mini-grids in Africa*. Report prepared for DFID. https://assets.publishing.service.gov.uk/media/59d73990ed915d4937c45b7e/Mini-Grids_Auction_Study_FINAL_FULL.pdf

Pedersen, M. B. (2016). Deconstructing the concept of renewable energy-based mini- grids for rural electrification in East Africa. *Wiley Interdisciplinary Reviews: Energy and Environment*, *5*, 570–587.

Pueyo, A., & DeMartino, S. (2018). The impact of solar mini-grids on Kenya's rural enterprises. *Energy for Sustainable Development*, *45*, 28–37.

PART 1
Insights from a Comprehensive Review of Literature

This part of the book contains four chapters. Chapter 2 presents a review of the literature on the technical sustainability of mini-grids. Chapter 3 deals with the business models and economic/ financial sustainability dimensions of mini-grids. Chapter 4 looks at the governance of mini-grids in the broader context of the electrification of developing countries, and Chapter 5 focuses on the social dimension of sustainability with an emphasis on inclusivity. The state-of-the-art reviews presented in this part of the book set the scene for the subsequent parts and offer valuable insights for mini-grids as an electrification option in the developing countries of Africa.

CHAPTER 2

Technical Sustainability of Mini-Grids in Low-and Middle-Income Countries

D. Bukari,[1] A. Hatamimarbini,[2] D. Kerr,[3] L. Baker,[4] E. Onsongo,[5] T. Sesan,[6] E.N. Sawe,[7] A. Pueyo[8] and S.C. Bhattacharyya [3]

[1]Ghana Climate Innovation Centre, Accra, Ghana (work undertaken while at De Montfort University between November 2020 and January 2022)

[2]Business School, University of Huddersfield, Huddersfield, UK

[3]Institute of Sustainable Futures, De Montfort University, Leicester, UK

[4]Department of Geography, The Open University, Milton Keynes, UK

[5]Nuvoni Centre for Innovation Research, Nairobi, Kenya

[6]Centre for Petroleum, Energy Economics and Law, The University of Ibadan, Ibadan, Nigeria

[7]TaTeDo – Sustainable Energy Services Organisation, Dar Es Salaam, Tanzania

[8]Senior Energy Advisor, New Zealand Ministry of Foreign Affairs and Trade, Wellington, New Zealand (work undertaken between March 2020 and March 2022 as a member of the Institute of Development Studies)

Abstract

In the context of access to electricity, mini-grids have emerged as an electrification strategy in the developing world. However, various technical, economic, socio-political, and governance issues militate against the sustainability of mini-grids. In this review, we critically assess and synthesize the available literature on the technical sustainability of mini-grids with a special emphasis on sub-Saharan Africa (SSA), and highlight lessons for mini-grid projects in the region. This chapter finds that the technical sustainability of mini-grids is influenced by system design, construction quality, operations and maintenance, and future capacity expansion of the systems. Various choices at the design stage and trade-offs for cost minimization often compromise the flexibility of the system, affecting long-term prospects of the plant. Inaccurate data, lack of resources, skills shortages, and irregular or inadequate maintenance have also affected mini-grid projects. In addition, the embeddedness of the technology in the local context also influences the technical sustainability of mini-grids.

This chapter identifies the limitations of existing frameworks for assessing the technical sustainability of mini-grids and proposes a streamlined yet expanded framework for measurement that incorporates the elements of renewability and adequacy of electricity supply over the long term.

Keywords: technical design, mini-grid systems; demand management, adequacy; reliability, sustainability framework

Acronyms

AC	*Alternating current*
AMDA	*African Minigrid Developers Association*
AfDB	*African Development Bank*
Bloomberg NEF	*Bloomberg New Energy Finance*
DC	*Direct current*
DESI	*Decentralised Energy Systems India*
DfID	*Department for International Development, (UK)*
ESMAP	*Energy Sector Management Assistance Program, World Bank*
EUEI-PDF	*European Union Energy Initiative Partnership Dialogue Facility*
EU TAF	*European Union Technical Assistance Facility*
GW	*Gigawatt*
HPS	*Husk Power Systems*
IEA	*International Energy Agency*
IRENA	*International Renewable Energy Agency*
kW	*Kilowatt*
LCR	*Local Content Requirement*
MTF	*Multi-tier Framework*
MW	*Megawatt*
NGO	*Nongovernmental organization*
PV	*Photovoltaic*
SAIDI	*System Average Interruption Duration Index*
SAIFI	*System Average Interruption Frequency Index*
SDG	*Sustainable Development Goals*

SDG7	*Sustainable Development Goal 7*
SEforAll	*Sustainable Energy for All*
SHS	*Solar home system*
SIDA	*Swedish International Development Agency*
SSA	*Sub Saharan Africa*
UNSD	*United Nations Statistics Division*
UNIDO	*United Nations Industrial Development Organization*
USAID	*United States Agency for International Development*
WBREDA	*West Bengal Renewable Energy Development Agency*
WHO	*World Health Organization*

2.1 Introduction

Access to modern energy, including electricity, is critical for the sustainable development of a community or a society. This has been globally recognized through the formal adoption of affordable and clean energy for all as the United Nations Sustainable Development Goal 7 (SDG 7). Evidence of linkages between energy and the SDGs has been demonstrated via extensive literature reviews (e.g., Fuso-Nerini et al., 2018; McCollum et al., 2018; Santika et al., 2019). However, 666 million people across the globe lived without access to electricity in 2023, and there are fears that reaching the target of universal access by 2030 may not be achieved (IEA et al., 2025). Thus, there is a pressing need to accelerate efforts to meet the universal electrification objective by 2030, which will require significant financial investment and the cost-effective application of complementary electrification strategies.

The current energy access deficit is more acute among rural and low-income populations. Although Central and South Asia have seen a significant reduction in the electricity access gap over the past decade, sub-Saharan Africa (SSA) has lagged behind. Electricity access provision has not kept pace with population growth, and in 2023, 451 million rural people lacked access to electricity in this region (IEA et al., 2025), of which many were on an income of less than $1.90 per day. Hence, conventional grid extension, which is often the initial or preferred mode of electrification by governments (Bhattacharyya, 2012), may not be the most technically appropriate or economically feasible option. In fact, the one-size-fits-all approach to electrification has been questioned by various authors (Szabó et al., 2013).

Within this context, mini-grids have emerged as a complementary electrification strategy to grid extension, including in areas facing capacity constraints or weak distribution systems. Electricity provision through the use of mini-grids, if they are well designed, implemented, and operated, can fill a gap between conventional grid extension and stand-alone solar systems by compensating for some of the shortcomings of both. For SSA, urban electricity access reached 82% in 2023, but rural access remains poor, with only 32% of the population having access to electricity in 2023 (IEA et al., 2025) and 85% of the world's remaining rural population without electricity access lived in the region (IEA et al., 2025). However, electricity access measurements in themselves do not necessarily represent the whole picture: reliability and sufficiency of electricity access are still issues in many SSA contexts (Kovacic et al., 2016). Most of the potential of mini-grids for universal electrification will therefore be in hard-to-reach rural areas and islands, far removed from grid coverage, with relatively low levels of income and population densities, where electricity demand is generally expected to be low compared with urban areas.

Over the past decade, the mini-grid sector has seen rapid growth, and in 2022, the World Bank estimated that 48 million people across 134 countries were currently connected to 21,500 mini-grids of various technologies, predominantly hydro and conventional diesel (in ESMAP, 2024). The World Bank further suggests that 490 million people will be cost-effectively electrified by 210,000 mini-grids across the globe to attain universal access by 2030 (ESMAP, 2024).

However, there is limited evidence to understand how mini-grid systems have performed once they have been installed. Evidence on the sustainability of mini-grids is mainly based on project evaluation studies within a country or across different countries (e.g., Ilskog, 2008; Ilskog & Kjellstrom, 2008; Mainali & Silveira, 2015; Katre et al., 2019). There are many related economic, social, political, governance, and environmental dimensions, which, taken together, can threaten or enable the long-term sustainability of such systems. In this chapter, we concentrate on the technical sustainability of mini-grids, from both the design and operational perspectives. When a system can meet its present and future needs reliably, efficiently, and by using clean and renewable sources, we consider that the system has achieved technical sustainability.

In this review, we examine the implementation and technical sustainability of mini-grids in developing countries. We discuss preoperational actions or considerations that have hindered the sustainable implemen-

tation of mini-grids. The main sustainability issues encountered by mini-grids at the operational stage and with respect to future expansion are detailed, and we explore how the success or failure of mini-grids is linked to their energy resource specificities.

2.2 Review Methodology

The literature review follows a structured approach, which is described below.

Scope of review: The scope was limited to technical aspects of mini-grids with a special focus on countries in SSA. However, references from other low- and middle-income countries were also considered. Publications from 2000 onwards were considered in the review. Details are provided in Table 2.1.

Literature search and elimination process: The review has considered academic and policy-oriented literature. Various sources have been used (see Table 2.2) for the literature search. For example, the Scopus database was mainly used for the peer-reviewed literature. Google Scholar and the Google search engine were used to identify policy and gray literature. Websites of specific organizations supporting mini-grids in Africa were also considered.

Predefined search strings were used for the literature identification process. The keywords include mini-grids (and variations thereof), sustainability, availability, data envelopment analysis, performance, adequacy, maintenance, operations, outage, technical efficiency, etc. The material covers both journal articles and gray literature—particularly those produced by international organizations, consulting companies, and nongovernmental organizations (NGOs). The review did not include centralized grids, on-grid supply, and stand-alone units like solar home systems.

The review team logged all the searches and compiled the resulting studies in a spreadsheet. The following information was collated in the spreadsheet: title, year of publication, type of publication, geographic coverage, research questions addressed, relevance, and additional comments. Once searches were complete, the review team categorized studies for inclusion, logging decisions in the spreadsheet. The first inclusion criterion applied was relevance to the main subject of the review. Our assessment of relevance was limited to titles, abstracts, and keywords (where available) for papers in the above databases. The inclusion criteria defined in Table 2.1 were applied successively to titles, abstracts, and full reports. Studies were categorized into three groups—excluded, noted for further assessment, and included. Noted and included studies were then coded using NVivo and organized using an appropriate software package (*Mendeley*).

Table 2.1: Scope of the Review and Inclusion Criteria

Scope Element	*Inclusion Criteria*	*Exclusion Criteria*	*Comments*
Electricity systems	Mini-grids	Centralized, on-grid electricity; decentralized electricity through stand-alone systems like solar home systems, diesel generators, or solar lanterns	Mini-grids are defined as "localized power networks, distributing electricity to a defined area, which can consist of just a few customers in a remote settlement, or hundreds of thousands of customers in a town." We include both "clean" and "dirty" mini-grids. The former use renewable energy sources, or a combination of renewables and fossil fuels (hybrid-mini-grids), while the latter run on fossil fuels. We are interested in comparing the performance of clean and dirty mini-grids.
Geographical scope	Low- and middle-income countries	High-income countries	Although the focus of the review is SSA, and these studies are given higher priority, the purpose of this review is to draw from a wide evidence base in developing countries. The search will start widely and will narrow down depending on the amount of evidence that we find.
Publication date	2000 onwards	Pre-2000 studies	The literature about access to electricity mini-grids before this date is virtually nonexistent.

Table 2.1: (Continued)

Scope Element	*Inclusion Criteria*	*Exclusion Criteria*	*Comments*
Publication format	Journal articles, working papers, evaluations, institutional reports, specialized news outlets	Other (books, book chapters, student papers, dissertations, unpublished works)	Specialist news outlets can capture the current performance and constraints of mini-grids faster than academic and institutional literature. This allows us to take the pulse of the sector while relying on robust literature to draw conclusions on the factors influencing the observed facts.
Methodological approach	Primary and empirical studies that employ quantitative or qualitative data to address our research questions	Secondary, theoretical, simulation, or conceptual studies	The quality of the evidence provided by the literature reviewed will be assessed according to the framework presented in Section 2.6 of this scoping study.
Aims of the study	The literature addresses one or several of our research questions and sub-questions	Other (i.e., technical design of mini-grids, least cost electrification planning or other planning studies, sizing of mini-grids)	
Publication language	English and French	Other	English and French are spoken in many SSA countries, and literature about the subregion is expected to be mainly available in one or both languages.

Table 2.2: Sources of Literature Used in the Survey

Type of Literature	*Source*
Peer-reviewed literature	Scopus, Snowballing
Working papers	Google Scholar, Google search engine
Evaluations and other institutional literature	Websites of specific institutions supporting mini-grids in SSA, such as the "Green Mini-Grid Helpdesk" hosted by the AfDB, the World Bank (ESMAP), DfID, the African Development Bank, the European Union, SIDA, AMDA, IRENA, USAID, and IEA
Specialized press	EU TAF Sustainable Energy News newsletter, Google News, Greentech Media, Minigrids Partnership newsletter

NVivo analysis—The identified literature was analyzed using NVivo, and a range of codes were identified around different themes to support the data query. Themes considered for the technical sustainability included the following:

Quality of equipment and design or installation issues
Technical indicators used
Technical operations, repair, and management
Technical sustainability

Table 2.3 indicates the nodes considered under the different themes.

Table 2.3: Codes for the Thematic Analysis of the Technical Dimension of Mini-Grid Sustainability

Themes	*Nodes*	*Description*
Quality of equipment and installation or design issues	Quality of equipment	Captures any equipment quality concerns reported in the literature
	Design contractor issues	Captures contractor issues related to mini-grid designs

Themes	*Nodes*	*Description*
	Equipment issues	This node gathers information on issues related to quality of mini-grid component parts and how they have affected sustainability.
	Safety of installations	This node stores information on the nature of accidents and other incidents affecting the health of residents in service communities.
	Technical design issues	Captures technical design related problems highlighted in the literature
Technical indicators used	Technical data	Collects information on indicators considered for technical analysis
	Adequacy	Any information on sufficiency of capacity to meet the needs
	Affordability	Any information regarding the cost effectiveness of the service for users
	Availability	This node stores information relation to scheduled service availability of the mini-grid and how that affects sustainability
	Availability of support infrastructure	Information on any controls, networks, storage and back-up systems
	Capacity factor	Information on plant utilisation

(*Continued*)

Themes	*Nodes*	*Description*
	Compatibility with future grid service	Design information regarding grid connectivity options
	Conformance with national standards	Information on technical design standards
	Constancy of Energy	Information on supply reliability
	Cost-effectiveness of design	Any information on value for money
	Daily operation services	Information on operating schedule
	Design	Type of configuration (single source, hybrid, storage or non-storage, etc.)
	Efficiency	Information on technical losses and efficacy
	Energy Utilization	Information on demand sources and distribution of demand
	Equality of energy distribution	Information on technical aspects of distribution of energy
	Legality	Information on legal status
	Power quality	Stores information on voltage and frequency disruptions to power supply and their effect on sustainability
	Primary energy use	Information on the types of energy used for electricity generation
	Reliability	Information on outages and service operation

Themes	*Nodes*	*Description*
	Safety	Information on operational safety
	Security of supply	Information on supply chain reliability, resource constraints, risk of interruption, etc.
	Technical losses	Information on system losses including network losses
	Technology	Information on the types of technology being used
	Well maintained	Nature of maintenance
Technical operations, repair, and management	Technical operation	Captures information on system operation
	Demand management issues	Information on any demand management and flexibility arrangements being used
	Natural disasters, component breakdown, and technology issues	Any information on unforeseen issues faced by the plant
	Power quality issues	Stores information on voltage and frequency disruptions to power supply and their effect on sustainability
	Reliability issues	This node stores information related to scheduled power outages or delivery and how that affect sustainability

(*Continued*)

Themes	*Nodes*	*Description*
	Repair and maintenance and spare parts	This node gathers related information on maintenance and repair issues, practices, and standards, and how they have affected sustainability
	Skills availability and training	This node stores information related to the availability of localised skilled personnel and the capacity building issues that affects sustainability
	Theft and illegal connections	This node stores information related to illegal connection issues and irregularities with payment of bills, and how they affect sustainability
Technical sustainability conclusions		Gathers major conclusions reached regarding why systems are not technically sustainable

2.3 Definition and Features of Mini-Grids

It is important to briefly define the term mini-grid and its features before delving into the main issue of technical sustainability. The purpose is to set the context without entering into the debate around the concept.

2.3.1 Definition

While there are various complementary definitions in the academic and gray literature, the term mini-grid has "multiple meanings, purposes and functions and one through which the often-competing objectives of productive use, energy access and rural electrification are conflated" (Baker, L., Sesan, T., Bhattacharyyra, S., Pueyo, A., Bukari, D., Meena, S.,

Onsongo, E., Oyinlola, M., Sawe, E., Otu-Eleri, E., Uduka. U., Handem, Y., Onjala, B. Katyega, M. [2022] 'Of monopolies and mini grids: case studies from Kenya, Tanzania, Nigeria and Senegal', Sustainability, Inclusiveness and Governance of Mini-Grids in Africa (SIGMA) Project Report (https://www.academia.edu/115593638/Working_Paper_No_1_Of_Monopolies_and_Mini_Grids_Case_Studies_from_Kenya_Tanzania_Nigeria_and_Senegal). There is no consensus regarding the definition of a mini-grid, including in terms of system size, scale, technical features, ownership structure, service area, customer base, generation source, and the nature of the local distribution network (Baker et al., 2022). However, many sources seem to concur that a mini-grid operates at a low- to medium-voltage level, uses a local distribution network for a local group of electricity users, and is stand-alone but can potentially interact with the centralized utility grid under certain circumstances (Bhattacharyya, 2018; Bloomberg NEF and SEforALL, 2020; ESMAP, 2019a, 2019b; IEA, 2011; IRENA, 2019; Tenenbaum et al., 2014; UNIDO, 2017; World Bank, 2000; Yan et al., 2017). In this chapter, we use the term mini-grid to refer to local electricity generation from renewable and nonrenewable sources and supply in both rural and peri-urban areas irrespective of size. According to our definition, the system may either be isolated from or connected to the main electricity grid in order to meet the diverse needs of local consumers.

2.3.2 Features

The installed capacity of a mini-grid can also vary considerably depending on the context and the country, but typically falls within a range of 10 kW to 10 MW (EUEI-PDF, 2014; Muchunku et al., 2018, p. 7). This is as compared to that of a micro-grid, which is usually between 1 and 10 kW (Muchunku et al., 2018). Mini-grids can also be differentiated from solar home systems (SHSs), which are typically smaller and primarily deployed for the provision of energy access such as lighting, radio, and mobile telephone charging, using mobile payment technology for energy service payments. Mini-grids are therefore perceived as better able to support productive use—i.e., the use of energy for income-generating activities—in addition to household energy access (Bhattacharyya & Palit, 2016; Peters et al., 2019).

The system configuration of a mini-grid also varies widely. Generally, a mini-grid system consists of four elements: (1) generation sources, (2) control and monitoring systems, (3) an energy storage facility, and (4) a local distribution network. Different combinations of these compo-

nents give rise to different configurations. Depending on the nature of the current flow in the network, mini-grid systems can be direct current (DC) or alternating current (AC) systems. DC systems avoid conversion losses, but they can serve only a small area due to supply quality issues (Boait, 2014). AC systems are quite common, on the other hand, and although single-fuel systems (e.g., photovoltaic [PV], diesel, mini-hydro, biomass) are widely used, hybrid systems that combine different generation sources such as solar PV and diesel, are gaining popularity due to the greater reliability of supply. When the generation system is renewable-energy-based, battery storage is generally considered to allow better supply reliability.

A number of energy sources can be used to generate electricity that rely on resources available locally, such as the potential energy of water, kinetic energy of wind, heat from solar energy or geothermal sources, and chemical energy derived from fuels such as diesel, biodiesel, bio-methane, and producer gas. A complex chain of processes is required to deliver the usable form of energy to the users, and the complexity increases with the combination of sources used in a hybrid system.

The exploitation of the power of running water remains a major renewable source of energy (36% of renewable electricity capacity and 53% of renewable energy generation, IRENA, 2024). Mini-grids have often used a small or micro hydropower scheme where the potential energy of a stream of water is captured to produce electricity using the head pressure. However, insufficient water availability in the dry season and high discharge in the wet season can affect the reliability of hydropower supply.

The solar PV technology has emerged as the most common technology for mini-grids due to the universal availability of solar energy, coupled with the rapidly declining costs of solar PV panels. The PV panels convert the incoming solar energy into electricity, which can be directly used to meet the needs or stored in a battery for future use, particularly at night. Most PV-based systems also use inverters to offer AC supply to the users.

Diesel generators have been widely used to provide electricity at the local level. They are available in different sizes and are easy to operate, but the availability of diesel and the pollution resulting from burning oil are major concerns here.

Wind turbines and biomass gasification are also used to a limited extent, but resource limitations and technology issues have restricted their wider adoption in mini-grids.

2.4 Design Considerations Affecting Technical Sustainability of Mini-Grids

Decisions and actions at the design and implementation stages of a mini-grid influence and affect its technical sustainability. This section focuses on the design, procurement and installation, and the nontechnical aspects. The evidence from the literature is combined with the experience of the authors to discern the distinctive issues below.

2.4.1 Mini-Grid System Design

As a complex technical system, mini-grids need careful system design from a technical perspective, but it is equally important to consider the appropriateness of the solution for the specific local context for which it is being designed. The quality of service improves when the design offers technical and operational flexibility, reliability of service, and locally manageable system complexities. Our review confirms that poor performance of mini-grids often arises from the lack of adequate consideration of these aspects at the design stage.

For designing a mini-grid system, the importance of appropriate system sizing cannot be overemphasized. Appropriate design is not only relevant for the mini-grid components but also for designing the network. Oversized systems affect financial viability through cost recovery but also create supply-demand mismatches and potential operational issues (Almeshqab & Ustun, 2019; Schnitzer et al., 2014). Undersized systems, on the other hand, lead to other problems, such as significant degradation of the system and wear and tear over time (Arnaiz et al., 2018). Single-phase distribution networks can hinder the integration of productive loads into the grid, preventing the realization of the economic development potentials of communities (Drinkwaard et al., 2010).

The system design is crucially dependent on data to generate reliable primary load profiles. However, in the absence of reliable and timely data availability, designs use load estimates based on previous experience with similar installations (Blodgett et al., 2017), but these may have questionable generalizability. Additionally, the energy resource base of many locations is often unknown, so satellite database platforms are mostly relied upon. While solar and wind resource datasets are readily available from these sources, the same cannot be said for others, such as biomass and

hydro resources, which must be locally estimated, surveyed, or produced. For hydro, such data is often unavailable because gauging the flow duration curves of rivers is proven to be technically challenging, expensive, and time-consuming (Arnaiz et al., 2018).

Generally, the more sophisticated a system is, the higher its initial investment will be, but an expensive and complex system may not be appropriate for a rural resource-constrained area lacking skilled personnel. The cost of such a system may outweigh the benefits (Shakya et al., 2017). Yet, compromising on the size to economize on initial investments leads to reduced plant capacity which, in turn, offers limited flexibility for load growth (Valer et al., 2017). Unanticipated increases in demand and load variations in a small system can be quite significant, especially as the arrival of electricity in a community can attract settlers from nearby locations and swell the local population quickly (Ulsrud et al., 2019; Valer et al., 2017). Similarly, under-reporting of potential demand by survey participants to reduce their own initial investment or future running costs can also lead to inappropriate sizing of the system (Winther, 2012).

Although plant design and sizing retain assumptions related to future demand growth, in remote locations, plants might be operating at significantly lower loads than expected (Díaz et al., 2011; Katre et al., 2019; Lopez- Gonzales et al., 2019; Schnitzer et al., 2014; Ulsrud et al., 2019) or reaching the installed capacity quickly. Ulsrud et al. (2019) found that a solar PV mini-grid in Senegal reached capacity within 15 months of its installation, as a result of which the reliance on diesel generators increased. Low or no electricity tariffs incentivized users to add new appliances, but the plant could not cope with the increase in demand, which led to more frequent power cuts. Shakya et al. (2019) also observed similar issues: the mini-grid with the most affordable tariff and nonmetered connections incentivized the users to use electricity inefficiently, leading to a much higher average consumption level. Lopez-Gonzales et al. (2019) offered examples of both excess capacity and capacity constraints in their micro-hydro system case studies from Venezuela. While systems serving communities connected to road infrastructure have seen demand growth reach the installed capacity of the system due to new trade and commercial activities, systems serving remote communities have significant spare capacity even after a long period of operation. Valer et al. (2017) highlighted that there is demand diversity among rural consumers even within the same community, and although most consumers have a low consumption profile, some with high consumption comparable to urban users are observed.

In a resource-constrained system, there is potential for cost-reliability trade-offs. Shakya et al. (2019) suggest that mini-grid users may prefer to accept reduced reliability over cost. The system design could take advantage of such opportunities through a better understanding of consumers' ability to pay and demand profile and develop a modular expansion plan to cater to demand growth (Fowlie et al., 2019). Concurrently, active demand management also plays an important role in a resource-constrained system (see Box 2.1).

Box 2.1: Dynamic Demand Management in Mini-Grid Systems

In a small system where the demand diversity is limited, dynamic load management is crucial to balance supply and demand. This is more beneficial for mini-grids that require battery storage for peak nighttime demand (Arnaiz et al., 2018; Van Gevelt et al., 2020). Demand management options include load-limiting fuses, mini-circuit breakers, load-shifting agreements, prepayment meters, and remote communication and control systems (Azimoh et al., 2017; Schnitzer et al., 2014; Shakya et al., 2019; Ulsrud et al., 2018). Energy efficiency interventions include training users on the efficient use of energy (Ferrer-Martí et al., 2012), converting existing inefficient lamps to efficient ones, and providing solar water heating and LPG cookstoves to reduce the potential demand (Azimoh et al., 2017).

In Bhutan, a mini-hydro system was prevented from overloading at peak times using a color-coded grid health system. When users switched on their rice cookers simultaneously, the mini-grid could not meet the demand. However, upon installing simple traffic signal system, users could avoid overloading the system by shifting their demand (Shakya et al., 2019). The use of tools such as real-time monitoring systems could allow for more efficient resource use (Katre et al., 2019).

However, there can be issues with demand management systems and smart monitoring: load limiters were fitted to distribution lines rather than individual premises, removing groups of consumers from the network when the system was overloaded (Murni et al., 2013). "Even the smartest technology can be ineffective if it requires human intervention and the incentives of the agents are not perfectly aligned with system success" (Fowlie et al., 2018, p. 13).

2.4.2 Procurement and Installation

Mini-grid performance is also crucially dependent on decisions taken at the procurement and plant installation phase. Inaccurate and inappropriate translation of the design at the project implementation phase, due to skill constraints, financial considerations, or supply quality, leaves a lasting impact on the plant during its entire operating life. Valer et al. (2017) reported poor electrical installations in their case study of Brazil.

> *In field observations, it is not uncommon to encounter poorly made installations, which offer risks to the users and to the system itself. In many communities it was noted that the electrical installations of consumer units did not have switches, circuit breakers, or any protection devices, which is a hazard, and inefficient energy use. (Valer et al., 2017, p. 1039)*

Numminen and Lund (2019) found that poor-quality inverters were a source of failure of AC systems, and this affected the reliability of supply due to long repair times and the inability of vendors to deliver spare parts at remote locations. Quality problems were also reported for control electronics and smart meters. Similarly, the quality of batteries affects solar PV mini-grid operations. Ulsrud et al. (2011) noted that operators have complained about the quality of batteries in the Indian project they investigated. Yadoo and Cruickshank (2012) also found the use of lower-cost components in small hydro plants to be a contributing factor in component failure. Butchers et al. (2020) reported that old electronic load controller designs were a cause of frequent failures in Nepalese projects, and more modern designs would mitigate this issue.

A lack of coordination between consultant designers and construction contractors, and poor contractors' performance guarantees for the construction of mini-grid projects, was reported in Indonesia. Local governments did not always hire professional services to consult with construction workers to save costs, leading to improper installations (Derks & Romijn, 2019).

For mini-grids, which are relatively new technological development, the lack of local expertise acts as a hindrance, particularly in remote locations. Arnaiz et al. (2018) found that, in the case of the Philippines, "local expertise extends to a handful of NGOs dependent on international aid. There is no capability in private commercial industry to build schemes or manufacture machinery, forcing local developers to import equipment, hence increasing scheme cost" (p. 56). Similarly, Arnaiz et al. (2018)

report that equipment lifetimes being reduced by insufficient maintenance regimes, as well as communities repairing civil works (such as de-silting bays) but unable to repair electronic failures in powerhouses themselves. The problem gets more complex with local content requirements (LCRs) specified in some regulations. Derks and Romijn (2019) remarked that in Indonesia, the regulations require 30 to 70% local content in terms of components for mini-grids, but because the local manufacturing quality is not comparable to international standards, "this results in poor-quality components. Alternatively, it leads to increased costs, when components are imported as disassembled parts and then assembled in Indonesia to comply with the LCR requirement" (p. 64).

A related issue was highlighted by Drinkwaard et al. (2011) regarding the availability of suitable technical design capacity locally. In one project, they found that the funding agency asked the municipalities to submit the design of the mini-hydro plant for approval.

> *Since local communities lack the knowledge to design a plant and municipalities rarely know where to find an engineer or organization capable of doing so, their proposals usually have no chance of approval. Those who do know where to get a design done often do not have sufficient financial resources to pay for it. (p. 236)*

Although funding for contracting out the design solves the financial issue, "the problem of finding an experienced person or organization to do the design" remains unresolved (Drinkwaard et al., 2011, p. 236).

Another element that has influenced technical sustainability is the quality of installations. Derks and Romijn (2019) reported that in Indonesia, there was an emphasis on increasing the number of installations while ignoring the quality of service. Poor delivery of equipment and materials has been reported in some projects; for instance, equipment being delivered in open boxes (as opposed to original boxes), missing items at delivery, and items failing within warranties (Draeck & Kottasz, 2017). Three main factors have contributed to the poor quality of installations:

Budget considerations have dictated the search for the lowest price bidder, which resulted in low-quality components and low-quality design. Wiemann et al. (2014) argued that the economic context in rural areas encourages a short-term view of compromising on quality, which then tends to affect the long-term prospects and the lifetime of the projects.

Weak regulations that, for instance, do not specify or incentivize the quality and frequency of maintenance, or include sanctions for noncompliance, hinder quality installations. Palit and Chaurey (2011) argue that quality standards for solar panels, batteries, and other components approved by national technical standards committees have ensured the success of solar PV programs in various South Asian contexts. However, a lack of standardized performance-oriented technical specifications for biomass gasifiers has been identified as a factor affecting the quality and performance of biomass gasifiers in the Indian context.

Inadequate maintenance budgets aggravate the issue further. In the case of Indonesia, annual changes in central government policies also act as a disincentive for local governments to allocate sufficient budgets for operation and maintenance.

Adequate attention to these issues at the design and procurement stage can improve the technical performance of mini-grids in the long run.

2.4.3 Nontechnical Aspects

While technical design of mini-grids plays a crucial role in ensuring high operating performance of mini-grids, the system design should focus not only on technical considerations but also on adapting to local community characteristics (Draeck & Kottasz, 2017). Improved quality of service can be facilitated through flexible technical and organizational solutions (Ulsrud et al., 2019). This requires a systems perspective that captures the embedding of the technological solution in the local social context. Inadequate attention to the wider nontechnical issues can jeopardize the prospects of a mini-grid project.

Local resource use and locally relevant technological designs are important considerations. For a mini-hydro project in remote Sri Lanka, "the design of the renewable energy mini-grid system had to ensure that locally available resources were used" (Draeck & Kottasz, 2017, p. 71). Similarly, in three Indian pilot projects, design modifications and local adjustments were made to foreign technologies. However, unforeseen technical challenges were faced at the project implementation and operation stages that required expert intervention and support (Draeck & Kottasz, 2017).

Similar issues of technology mismatch for hydropower projects were reported by Drinkwaard et al. (2010). An imported turbine suitable for high water heads was a misfit for local low water-head conditions, and the project

developer had to develop turbines suitable for local conditions. The imported electrical control systems were incompatible with locally designed turbines, and this required a redesign of the control system itself. While this case offers new learning opportunities and the development of a niche low-cost technology, such component-matching initiatives are not replicated everywhere and many projects continue to rely on imported designs and components.

Nontechnical issues at the design stage include uncontrolled connections, disputes between different parties, and a breakdown of trust between the community and government structures. Such issues can lead to system overload, disconnection, and the unsustainable operation of the system (Brent & Rogers, 2010). Moreover, dissatisfied users are less likely to pay for the service.

In one example from Peru described by Lillo et al. (2015), the communities were not included in the system design's decision-making process, as a result of which the system failed to fully meet their needs. For instance, a DC system was installed in one location, but because of the difficulties in finding appropriate DC appliances for use in remote areas, the users were unhappy. In another example, Shakya et al. (2019) observed that mini-grids without metering arrangements at the customer premises did not encourage users to save electricity and in some cases, users did not bother to switch the lights off during the day.

Smart meters and stand-by generators incorporated at the design stage can support flexible consumption patterns and supply-demand balancing. This is often recommended as the best practice. However, smart technology is not a panacea for technical issues in remote locations, where local capacity to absorb and manage it is limited.

2.5 Influence of Operations and Maintenance on the Technical Sustainability of Mini-Grids

The benefits of the mini-grids are realized through the successful operation and maintenance of the system, and consequently, the operating and maintenance routines, choices, and practices affect the availability of mini-grids, quality of power, and the reliability of the plants. These are elaborated below.

2.5.1 Availability

The availability indicator has been a topic of interest in the literature. The average duration of supply per day is often reported through surveys

or plant records, with some studies focusing on plant availability. For example, in Nepal, Shakya et al. (2019) reported that the supply availability for solar, solar-wind, and solar-diesel mini-grids is less than 8 hours per day, while mini-hydro sites offer 23 hours of service per day. The capacity constraints of these plants and the variability of supply are major factors contributing to the limited duration of supply. In Western China, supply durations have declined from 12 hours to 3 hours over 5 years due to irregular supply schedules (Shyu, 2013). Planned maintenance is often factored into possible operating hours, indicating lower availability. Micro-hydro plants in Sulawesi and Sumatera were available on average for 63% of the expected time, while the highest was 96% (Purwanto & Afifah, 2016). Common faults in electro-mechanical equipment and problems with channels, forebays, and blockages were reported. Katre et al. (2019) found that in India, energy use remained low and much below the available capacity, with the daily average plant capacity use being 37% across the projects surveyed. The oldest site recorded a 48% capacity use, indicating that demand growth is not automatic. Public lighting performance was poor, with only 13% of sites meeting internal lighting targets due to malfunctions, poor-quality components, and limited plant capacity. Lopez-Gonzalez et al. (2018) found that the average annual consumption of communities does not exceed 63% of the generating capacity, confirming the system design's ability to meet local community demand but also suggesting that spare capacity could be used to support future demand.

2.5.2 Reliability

Reliability of supply normally indicates the quality of service in terms of frequency and duration of interruptions. While users usually prefer an uninterrupted supply, evidence from the literature suggests that this hardly exists in the context of mini-grids, especially beyond the first few years of installation (Ngowi et al., 2019; Purwanto & Afifah, 2016; Ribeiro et al., 2012; Shakya et al., 2019; Shyu, 2013). In Nepal, micro-hydro and PV-battery mini-grids faced an average of 3 interruptions per week, while solar-wind and solar-diesel systems had more, ranging from 4 to 14 interruptions weekly (Shakya et al., 2019). Some micro-hydro projects experience 2 to 4 outages per month due to garbage blockages (Purwanto & Afifah, 2016). In some cases, outages were attributed to user behavior and expectations, e.g., exceeding load limits in a Senegalese case

(Ulsrud et al., 2019), while in other cases, such as in Venezuela, 76.1% of end-users were satisfied with the low failure rate of hybrid micro-grids (Lopez-Gonzales et al., 2018).

Maintenance practices and technical issues also affect mini-grid reliability. Proper maintenance plays a role in minimizing downtime, as evidenced by Husk Power Systems (HPS) mini-grids (Almeshqab & Ustun, 2019; Schnitzer et al., 2014). They achieved this through a thorough risk evaluation of the services, covering the design, fuel supply, and maintenance. Regular maintenance work by the company has been identified as the main factor behind this achievement (Almeshqab & Ustun, 2019).

Conversely, in Haiti, diesel systems suffered from poor functionality, high losses, and theft, while in India, plants operated by Decentralised Energy Systems (India) Private Limited experienced higher downtime due to cable problems (Almeshqab & Ustun, 2019). Exceptional performance with no interruptions in the second year of operation was reported in a solar and wind system, showing the impact of well-maintained and well-designed systems (Ribeiro et al., 2012).

Some cases highlight the unpredictable nature of supply, which hampers reliability. For instance, in China, the irregular supply was a common complaint from households (Shyu, 2013), while overloaded plants failed to provide reliable supply during specific hours in a case in Tanzania (Ngowi et al., 2019). Odarno et al. (2017) reported a case from Tanzania where a mini-hydro plant needed to shut down during a low-flow period: water flows were low enough that the plant was only able to generate 40% of its nameplate capacity, and needed to shut down to prevent turbine damage due to cavitation issues from the reduced flow.

However, Ulsrud et al. (2019) reported that detailed information on outages is not always available. In one of the Senegalese villages, users reported several hours of outages a number of times per week but were unable to provide more precise details. These outages were apparently due to limited battery capacity and battery failure resulting from excess demand. "One reason for such power outages was the overloading of appliances by the customers. If they exceeded the power limit for the block they had subscribed to, the smart meter would automatically switch the electricity supply off for this connection. The electricity would come back on automatically" (Ulsrud et al., 2019, p. 79). In a comparable study, Murni et al. (2013) suggested that where the load limit is more generous and the system has excess capacity, users could afford to use more appliances without causing system outages or overloading.

Reliability of supply has also been compromised due to natural calamities or extreme events. For instance, Sharma and Palit (2020) reported damage to an inverter due to a lightning strike at a site in India, while Lopez-Fernandez et al. (2019) highlighted supply interruptions of hydro plants during dry seasons and distribution system failures due to lightning.

Schnitzer et al. (2014) highlight the importance of a reliable supply for making a viable mini-grid business. When the service is reliable, users are willing to pay for the service, but if the tariffs are not high enough, the operator is unable to pay for fuels and undertake maintenance. The service becomes erratic, and the mini-grid ceases to function. A delicate balancing act is therefore required.

2.5.3 Power Quality

Lillo et al. (2015), in their study of mini-grids in Peru, found that the quality of service varies by technology and the system type (individual or mini-grid). The service quality was better for mini-hydro systems due to the ease of operations and maintenance tasks in centralized systems compared to other technologies, and the failure rate was higher in individual systems compared to mini-grids, attributed to a lack of user experience and training. Ulsrud et al. (2019) found that the quality of service is closely related to the flexibility offered by the system through technological and organizational solutions. Stand-by generators that could be brought in when demand exceeded capacity improved availability and reduced outages.

Arnaiz et al. (2018) remarked that the distance to the repair shop and the lack of availability of replacement parts affected the quality of service. Azimoh et al. (2017) noted that the

> *a majority of the representatives from households, businesses and public institutions stated that they experience fluctuation in the electricity supply, which has damaged both household and business appliances. Fluctuations in the electricity supply are also caused by the issues of the synchronization of the generators with the PV system, resulting in manual operation and unscheduled interruption during the process. (p. 226)*

2.5.4 Adequacy

The adequacy of power supply from the mini-grids indicates to what extent the available capacity of a mini-grid is able to meet the demand. A technically

sustainable system would always be able to meet the demand. However, in reality, mini-grids face challenges due to design choices, changes in the underlying business environment, and system operation and maintenance practices.

As indicated previously, capacity choices made at the design stage affect supply adequacy. Lopez-Gonzales et al. (2018) found in their case study of hybrid micro-grids in Venezuela that the weighted average consumption per house was 89% of the value considered at the design stage, confirming that the technical design of the hybrid mini-grid was consistent with the real consumption of rural communities. They also found that consumption in micro-hydro communities was 40% higher than in rural communities connected to the grid, meaning the plant was able to supply the demand of the community and improve their quality of life. Plants designed with sufficient capacity margin or design flexibility ensure adequacy of supply, but the financial implications of overcapacity often limit this choice.

However, short-termism in capacity choices leads to consumer dissatisfaction. Shyu (2013) found that most users (more than 70% of survey participants) in their case study expressed frustration over the inability of the solar PV station to meet the demand, which resulted from insufficient capacity. The supply duration was short and unpredictable. Similarly, for a Tanzanian mini-hydro plant, Ngowi et al. (2019) reported that the installed plant capacity was not adequate to meet the peak demand. Arnaiz et al. (2018) also found that users reported concerns about adequate power supply from the mini-hydro plants they surveyed as demand increased over time. Derating (reduction in generation capacity) of plants due to aging made it difficult for plants to cope with demand growth.

2.5.5 Maintenance

The importance of regular maintenance for system reliability and safe operation needs no elaboration. The system design presumes that the plant operators would carry out a minimum number of preventive maintenance activities to ensure proper functioning of the system (Butchers et al., 2020). Reductions in failure rates through better servicing lead to overall cost savings (Valer et al., 2017). However, budget-constrained operators tend to compromise on preventive maintenance of mini-grids. Inadequate maintenance adversely affects mini-grid operations and performance, resulting in poor technical sustainability outcomes. Such a decision has health and safety implications and the repairs after breakdown often turn out to be a more expensive option.

Butchers et al. (2020) reported that of the 24 mini-hydro plants they studied in Nepal, only one had a maintenance schedule of which the activity was mostly corrective in nature. Numminen and Lund (2019) identified technical problems with inverters affecting the reliability of supply, and further issues from long repair times and the refusal of repair companies to service remote areas. Azimoh et al. (2017) noted that the availability of spare parts for imported mini-grid components was a challenge. Diversifying the supply chain by using several manufacturers can be a solution (Valer et al., 2017), but lack of local capacity often is a hindrance. The above observations prompted Mainali and Silveira (2015) to conclude that low-maintenance technologies, and those with well-defined supply chains and technical expertise availability, are preferable in mini-grid contexts.

In remote locations, finding suitable repair and maintenance expertise remains a challenge. Maintenance contracting is often considered as a possible solution, but short-term contracts can lead to reduced contractor investment in the project and broken promises if the contractor finds more lucrative options. Ulsrud et al. (2011) reported an example from India where the implementing agency tried to address such a problem by opting for a longer-term contract (from short-term contracts of 6 months to year to longer-term contacts of up to 10 years). Managing long-term contracts, however, requires a strong organizational capacity, which remains in short supply in most countries.

2.5.6 Other Considerations and Challenges

Writing about mini-grids in Senegal, Ulsrud et al. (2019) highlighted the importance of flexibility as an aspect of electricity service.

> *The Enersa mini-grids were characterized by high flexibility for the users, much more so than other solar micro-and mini-grids. There was flexibility in terms of the various subscriptions, and flexibility in terms of the timing of consumption. Electricity could be used at any time, and the amount consumed could be varied from day to day. The possibility of receiving additional power and thus adding larger loads also provided flexibility. This flexibility was facilitated by technical and organisational solutions, such as the smart meters, which facilitated the Block system, the upfront payments, the company's willingness to accept breaks in supply, and the use of a diesel generator. The generator could be switched on when there was high demand for power. The degree of flexibility*

> *was further influenced by the power capacity of each power plant relative to the local demand for electricity. (Ulsrud et al., 2019, p. 80)*

Draeck and Kottasz (2017) reported the synchronization issue of a solar PV system with a diesel generator set in a project in The Gambia. Voltage fluctuations from the gen-set were the main issue, and an automatic voltage regulator was required to maintain the voltage excursion within limits. There were initial issues with batteries at the same site. Batteries cracked during off-load and had to be replaced. Additional air-conditioning arrangements were required to ensure appropriate operating temperatures for the batteries. Díaz et al. (2011) noted that "if load consumption is low, whatever the reason, batteries prone to overcharge. Then, the PV array generation is regulated or even interrupted to protect them" (p. 2514).

For a hybrid system involving a small hydropower plant and a bio-gasifier in Sri Lanka, Draeck and Kottasz (2017) found that the bio-gasifier required sophisticated inputs and that the locally collected feedstock did not often meet the technical requirements. Inappropriate operation of the system led to its breakdown. The remote location also required that local operators from the community be trained to maintain the plant alongside ensuring the availability of expert advice and support on-demand from nearby towns. This case also highlighted the issue of technology adaptation to local environments. The technology supplier may not fully realize the local challenges, and local stakeholders need time to undertake numerous trials and experiments to develop a full appreciation of the technology. Expert intervention and sufficient time are required to ensure the success of the adaptation of innovative technologies.

2.6 Assessment of Technical Sustainability of Mini-Grids

This section presents a synthesis of frameworks and approaches for assessing the technical sustainability of mini-grids (Section 2.6.1) and the indicators used for the assessment of the sustainability of mini-grids (Section 2.6.2).

2.6.1 Approaches and Frameworks

Various studies have attempted to analyze the sustainability of electrification initiatives, including those for mini-grids. A nonexhaustive review of these approaches is presented here. Ilskog (2008) and Ilskog Kjellstrom

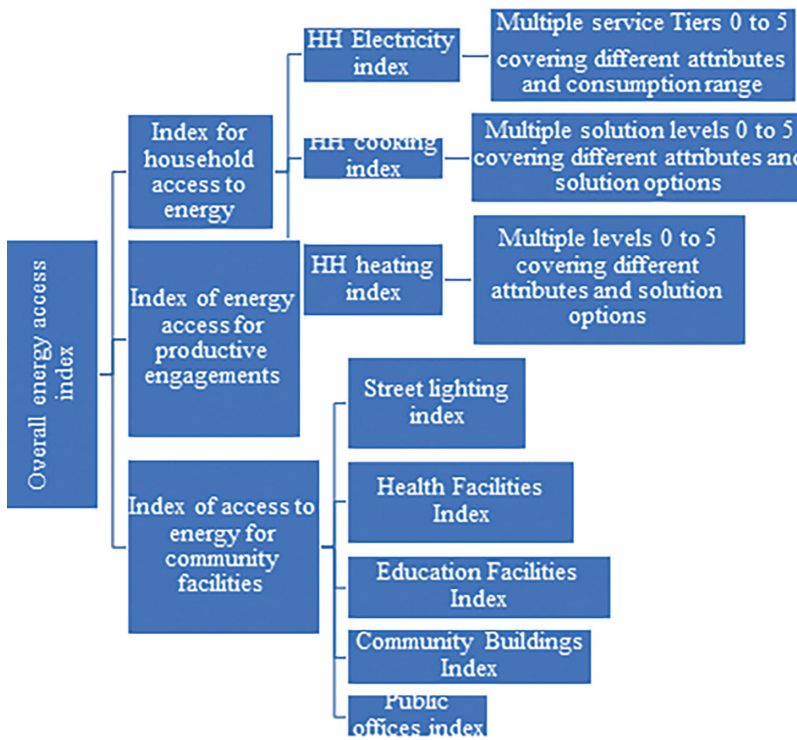
(2008) present an early attempt of sustainability assessment of rural electrification where they defined technical sustainability as follows: "the technical sustainability is facilitated if the technical infrastructure locally available meets the requirements of the technology installed, if the technology used can provide the service needed and if favorable technical performance leads to low costs for the services". This definition places emphasis on maintaining the service during the entire project lifetime but appears to ignore the issue of continuing the service beyond the project life. It also pays little attention to clean and renewable energy supply, and accordingly, a diesel power plant will be a sustainable option if it is maintained well during its lifetime, if it meets all national standards, and if it manages client relations well. This definition requires qualifiers to ensure technical sustainability.

According to Bhattacharyya (2012) and Bhattacharyya et al. (2014), technical sustainability of an energy service is achieved when the system can meet the present and future needs reliably, efficiently, and by using clean and renewable sources. While this definition is better aligned with the Sustainable Development Goals, Katre and Tozzi (2018) point out the weakness in terms of measurability and suitability for case applications. Rahmann et al. (2016), on the other hand, place the emphasis on currently available technologies and claim that technical sustainability must ensure that the implementation of the project is possible with the "*current available technologies without compromising the operation of critical elements.*" This definition neither considers the needs of the future generations nor pays attention to cleaner sources of supply.

Mainali and Silveira (2015) have designed and applied a multi-dimensional Energy Technology Sustainability Index consisting of five dimensions: technical, economic, social, environmental, and institutional. The technical dimension measures the reliability and efficiency of the technology using three indicators: energy availability, system conversion efficiency, and reliability. The application of the index to different technologies was done for three different years—2005, 2010, and 2015—to capture technological advancements and changes in market conditions. They also assess the uncertainty of economic data using three cost scenarios (minimum, probable, and maximum). However, the technical dimension does not really focus on the renewability of the resources and ability of the system to meet the present and future needs of the users.

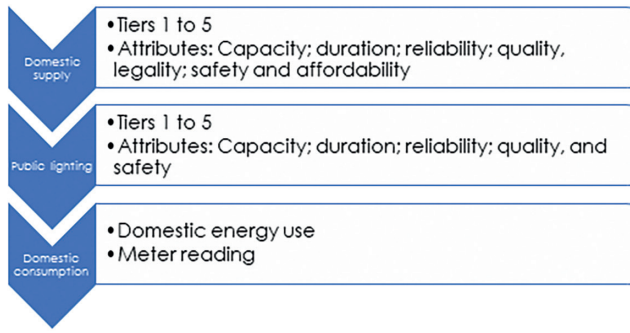
Since ESMAP (2015) proposed the multi-tier framework (MTF) for measuring energy access, researchers have adopted the idea for analyzing technical sustainability. The MTF disaggregates the overall energy access into household energy access, access to productive use of energy, and access to energy for community facilities. Each component is assessed with a specified set of subcomponents, where each subcomponent considers different socio-economic tiers and a range of attributes to measure energy access (see Fig. 2.1). For example, seven attributes are considered for household electricity supply, namely, capacity, duration of supply, reliability, quality, affordability, legality, and health and safety. Similarly, different attributes are used for electricity consumption, cooking energy supply, and heating services. Although the purpose of the MTF framework is to assess energy access, the attributes and socio-economic contexts are relevant for sustainability analysis.

Figure 2.1: Multi-tier Framework for Energy Access Measurement



Source: Based on ESMAP (2015).

Figure 2.2: Technical Sustainability Framework Used by Katre and Tozzi (2018)



Source: Katre and Tozzi (2018).

Katre and Tozzi (2018) have retained the MTF principles for the technical sustainability assessment of decentralized energy systems. The technical dimension is disaggregated into three components (see Fig. 2.2): domestic supply, street lighting, and domestic consumption. For each component, five tiers of service and seven attributes, as suggested in the MTF for household electricity supply, are considered.

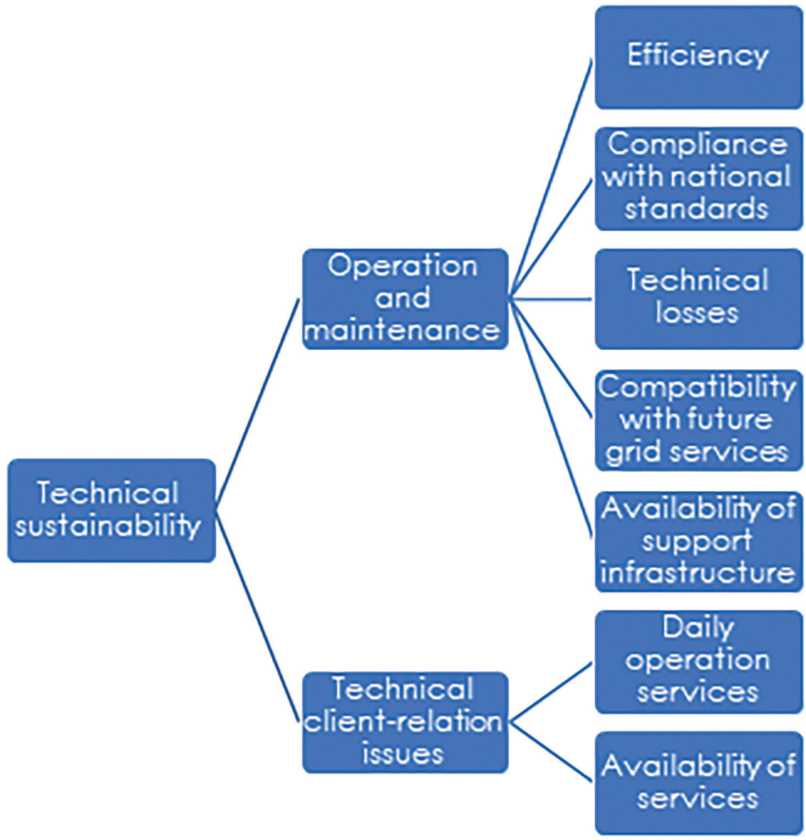
While this approach allows a detailed assessment of services considering different uses and consumption patterns, extensive data requirements make the approach less user-friendly. Groh et al. (2016) argue that the framework is confusing, as it combines supply with energy poverty, and the indices have some redundancy and ambiguity. They also argue that measurements using MTF are sensitive to "changes in parameter values, the application of different algorithms and data availability." We also note that there is no specific attention given to assess the ability of the system to meet current and future needs, which reduces its appeal for measuring technical sustainability of mini-grid systems.

Many other studies have reported a sustainability index for assessing the contribution of mini-grids to sustainable development, where the technical dimension is also covered. Examples include Rahmann et al. (2016).

2.6.2 Indicators for Technical Sustainability

Ilskog (2008) and Ilskog and Kjellstrom (2008) used seven indicators to assess technical sustainability grouped under two themes: operation and maintenance and technical client-relation issues (see Fig. 2.3). As indicated earlier, there is no emphasis on the use of renewable resources here

Figure 2.3: Technical Indicators Used by Ilskog (2008)



Source: Ilskog (2008).

and service continuity beyond the project life, which are significant limitations of this approach.

Bhattacharyya (2012) and Bhattacharyya et al. (2014) have used the following seven indicators to measure the technical sustainability of a service:

Ability to meet present and future domestic needs;
Ability to meet present and future productive needs;
Reliability of supply;
Reliance on clean energy sources;
Technical efficiency;
Reliance on local resources;
Availability of support services.

Table 2.4: Indicators and Attributes Used in the Multi-tier Framework

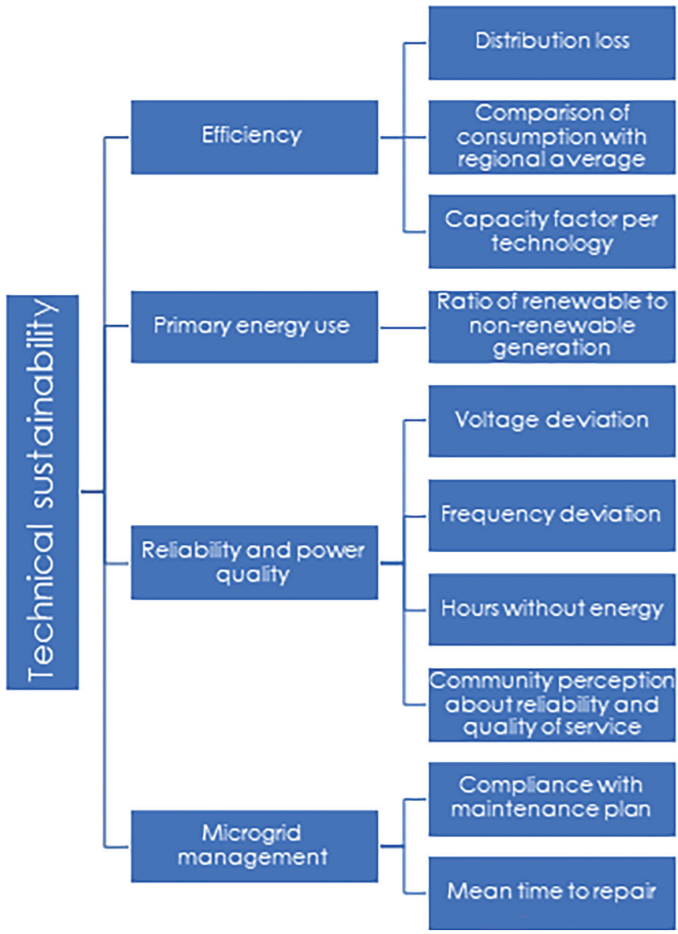
Attributes	*Units*	*Tier 0*	*Tier 1*	*Tier 2*	*Tier 3*	*Tier 4*	*Tier 5*
Peak capacity	W		Min 3	Min 50	Min 200	Min 800	Min 2,000
	Daily Wh		Min 12	Min 200	Min 1,000	Min 3,400	Min 8,200
	Or services		Lighting of 1,000 lm hr/day	Electrical lighting, air circulation, television, and phone charging are possible			
Availability	Hours per day		Min 4 hours	Min 4 hours	Min 8 hours	Min 16 hours	Min 23 hours
	Hours per evening		Min 2 hours	Min 2 hours	Min 3 hours	Min 4 hours	Min 4 hours
Reliability						Max 14 disruptions per week	Max 3 disruptions per week of total duration <2 hours

Table 2.4: (Continued...)

Attributes	*Units*	*Tier 0*	*Tier 1*	*Tier 2*	*Tier 3*	*Tier 4*	*Tier 5*
Quality						Voltage problems do not affect the use of desired appliances	
Affordability					Cost of a standard package of 365 kWh/year <5% of household income		
Legality						Bill is paid to the utility, prepaid card sellers, or authorized representative	
Health and safety						Absence of past accidents and perception of high risk in the future	

Source: ESMAP (2015).

Figure 2.4: Indicators Used for Technical Sustainability in the Composite Sustainability Index proposed by Rahmann et al. (2016)



Source: Rahmann et al. (2016).

However, the indicators were not elaborated, and the study offered a high-level application that limits its applicability to mini-grid projects as such.

The MTF-based assessments use a differentiated level of service attributes for different service tiers (see Table 2.4). It can be noticed that the prescriptive nature of various attributes (such as capacity or usage, availability, or reliability) and the subjectivity of the chosen values make the framework less aligned with the concept of sustainability. For

example, there is a presumption that higher tiers of service will offer a better quality of life, and this sets the aspirational goal of the population at the highest tier of service (Tier 5). However, as the framework is silent about the nature of energy resources, the higher tier of service and the representative values used for them may be in direct conflict with the environmental dimension of sustainability and may exert pressures on planetary boundaries. These aspects have not received adequate attention in the applications of MTF for sustainability analysis of energy services, such as those reported by Katre and Tozzi (2018) or Katre et al. (2019).

Rahmann et al. (2016) have assessed the technical sustainability of mini-grids from four perspectives: resource use efficiency, implying that the proper use of energy by the users; nature of primary energy use; reliability and power quality; and micro-grid management. Figure 2.4 presents the indicators used to measure these perspectives. It can be noticed that indicators used here are not always conventional, and some may be difficult to relate to as well. For example, the efficiency dimension considers distribution loss, which may not be a major issue for a mini-grid and may not be easy to estimate. The purpose of comparing consumption against the regional average is not evident, and it is unclear how this relates to resource use efficiency. The primary energy use dimension deals with the renewable energy share in the generation mix and could have been termed more appropriately. In terms of reliability and quality, the data on frequency and voltage deviations at the local level are unlikely to be available. More importantly, no consideration is given to issues like component failure, supply inadequacy, and ability of the system to meet future needs.

It is clear from the above review that there is no consensus regarding the indicator-based analysis of the technical sustainability of mini-grids or energy access projects. Studies have not always considered the data requirements for such evaluations, and data limitations reduce the replicability of the evaluation schemes as well.

2.7 Discussions and Framework for Technical Sustainability

2.7.1 Reflection on Literature Review

Based on the thematic analysis of the above literature, several observations can be made regarding the technical sustainability of mini-grids.

Ensuring adequate, reliable, and cost-effective renewable energy-driven electricity supply in the long term through mini-grids requires careful planning, design, development, and operation of the plants. Strong path dependence is introduced through technology selection and design choices made ex-ante at the time of project identification, site selection, and project design. These choices influence the long-term prospects of a plant, and unless these activities are appropriately carried out, the technical performance of the plant will be compromised, and the technical sustainability of the project gets affected.

Being technical in nature, the system design choices made at the project preparation stage are influenced by expert judgments and trade-offs involving nontechnical considerations (such as initial investment cost). The literature offers various examples questioning the appropriateness of the resulting solution to the local conditions, including the following:

- Oversized micro-hydro projects that remained underutilized for most of the project life (e.g., Almeshqab & Ustun, 2019; Schnitzer et al., 2014),
- Inadequately sized systems that failed to cater to demand growth and became a source of user dissatisfaction (e.g., Arnaiz et al., 2018; Murni et al., 2013; Ulsrud et al., 2019),
- Poorly chosen smart metering system that hindered operational performance of the system instead of enhancing it (e.g., Fowlie et al., 2018; Shakya et al., 2019).

Inappropriate technology choice can arise due to several factors, such as lack of accurate data and information, and lack of user participation at the design stage. Use of proxies for local demand, demand growth, and resource availability (such as water flow for hydropower) has been widely reported as a challenge. In addition, poor engagement with local stakeholders also leads to user dissatisfaction due to systems not meeting their needs (Lillo et al., 2015). If the technology selection process fails to recognize the social dynamics (such as trust in government agencies, disputes within the communities, or customs and social norms) due to poor stakeholder participation, the system resilience gets affected.

The reliability of the systems has been affected by the quality of installations, particularly civil works for hydropower stations, and the quality of materials supplied (either missing items or items failing within the warranty period). Poor quality of installations has also been

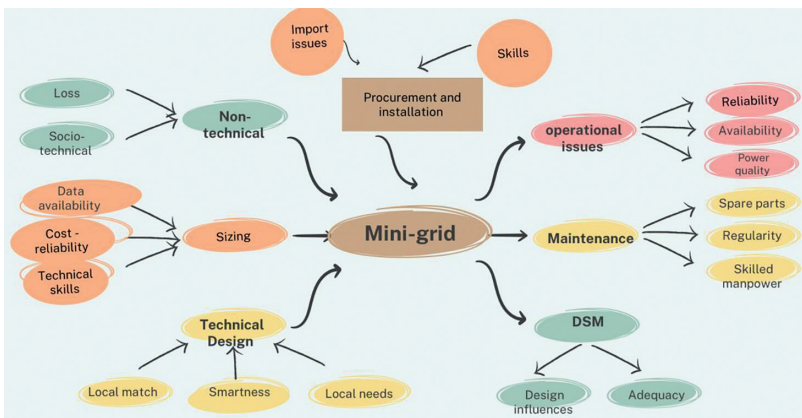
associated with poor workforce skills, but the focus on cost reduction and the prevalence of weak regulations are also highlighted as contributing factors.

The trade-offs between technology options and cost-saving options often play an important role in the availability of the plants and the reliable performance. Preference for cost minimization can lead to limited capacity, sacrifice of components (such as batteries in a PV system), or compromises that can have health and safety implications.

The quality of equipment supply and availability of skilled manpower affect the project implementation stage. Delays in the delivery of imported components and supplies, as well as poor quality and incomplete supplies, have been reported. The appropriateness of imported technologies for the local conditions has also been indicated as an issue affecting the project implementation and long-term performance of mini-grid projects.

The relationship between the different elements discussed earlier is captured in Figure 2.5.

Figure 2.5: Elements of Mini-Grid Technical Sustainability



Long-term reliable operation of mini-grids depends on ex-ante design and project implementation factors, as well as postimplementation operation, maintenance, and planned expansion activities. The adequacy of a mini-grid in terms of its ability to meet the needs of users is closely related to plant sizing decisions, attrition or loss of capacity over time due to wear and tear (e.g., PV derating per year), as well as demand growth that happens postinstallation. Excess capacity at the initial stage acts as insurance

for future demand growth but the high initial cost can make the project less attractive to the users and project developers. A low reserve margin at the project development stage, on the other hand, introduces the risk of poor reliability of supply as demand grows or capacity derates. The delicate balance is not easy to strike, and flexibility options such as demand-side management or user expectations management play an important role here.

The operating performance of mini-grids decides the availability of mini-grids as well as their service quality in terms of reliability and power quality. The availability of skilled manpower in remote rural locations remains a major challenge, and the reliance on make-shift operators with limited technical training exposes the technical system to operating risks. In addition, the absence of scheduled maintenance due to cost considerations and the lack of maintenance capacity at the local level makes the system vulnerable to malfunctioning and reduces the reliability of supply. Ultimately, the consumer satisfaction is compromised, which affects cost recovery and makes a project economically vulnerable.

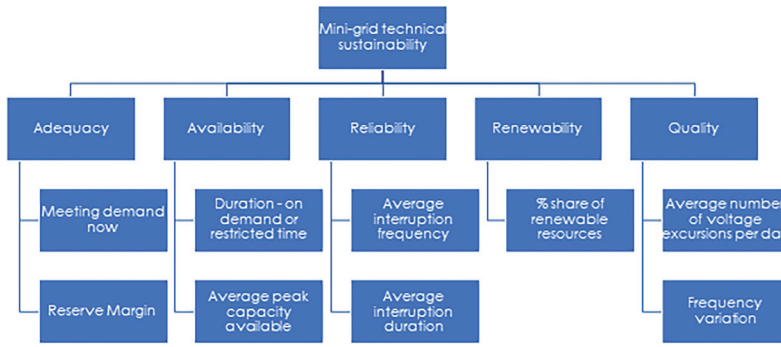
The ability to expand the system thus becomes hostage to the financial strength of the mini-grid. Although the design considerations may offer expansion opportunities (e.g., the modular design of PV systems), the ability to realize these options ultimately hinges on the financial strength of individual projects. Given that many projects hardly generate any financial surplus, and given the lack of support for funding such expansions from other sources, the long-term technical sustainability of mini-grids remains a challenge.

2.8 Framework for Technical Sustainability

The review of the technical sustainability suggests that while a wide range of indicators have been considered, several issues remain. First, the ability of the indicators to measure the desired effect is not always clear. For example, the comparison of consumption with the regional average used in Rahmann et al. (2016) or the prescriptive thresholds for different tiers used in the MTF is difficult to justify. Second, the data availability limits the application of very data-intensive frameworks. A framework that can provide a reasonable picture of the technical sustainability need not be too complex or impose too much demand on data. Third, the framework must consider the long-term perspective and respect the dimensions of sustainability, such as renewability and meeting future needs. Most of the frameworks prioritize short-term needs over long-term demands. Fourth, the framework should be easy to use and interpret and should allow comparison across different mini-grids at a specific time and at different points in time.

Based on the above, a simple index is suggested here in Figure 2.6. Five indicators are used in the framework, with an equal weight of 20% for each indicator, namely, adequacy, availability, reliability, renewability, and quality.

Figure 2.6: Technical Sustainability Framework



The proposed scoring system is as follows (Table 2.5):

The score will be out of 25, but for ease of appreciation, the final score will be converted out of 100 by multiplying it by 4. Mini-grids scoring 20 will be considered poorly sustainable, those between 20 and 60 are moderately sustainable, and those with scores above 60 will be considered sustainable.

2.9 Summary and Future Perspectives

This chapter has provided a review of the literature of the technical sustainability of global mini-grid projects, and the dimensions associated with technical sustainability. It has, through an extensive literature search and qualitative literature analysis, identified the key concepts relating to technical sustainability as defined in the literature, and grouped these concepts into categories of features that mini-grids share, and that can be assessed and measured on the ground to determine the technical sustainability of a project.

Mini-grid technical sustainability emerges through two distinct phases: first, in the design phase, where the mini-grid system is being determined and significant path-dependency can be found, and second, in the operations and maintenance phase, where the system is operational and needs to be maintained in order to realize its potential. In the design phase, factors such as the quality of installation, the sizing and component matching of the system, the appropriateness of the technology, and the availability of locally manufactured components and expertise to install them all contribute to the potential future technical sustainability of the system. In the operational phase, main-

Table 2.5: Scoring Methodology

Measures	*Indicators*	*Weight (%)*	*Base (=1)*	*Standard (=3)*	*High (=5)*
Adequacy	Ability to meet demand now	50	Barely meeting the demand	Meeting most of the time	Always meeting the demand
	Reserve margin	50	0–5% margin	10–20% margin	25% margin
Availability	Duration	50	Only for limited or restricted time	Available during specified hours	On demand (any-time)
	Peak capacity	50	Basic lighting and phone charging	Supply to support commonly used appliances	Supply to support aspirational needs
Reliability	Average number of interruptions	50	<1 per week	<1 per month	<2 per year
	Average duration of interruption	50	<10% of time	<5% of the time	<1% of time
Renewability	Percentage of renewable supply	100	<50%	50–80%	80–100%
Quality	Average number of voltage excursions	50	<10 per day	<5 per day	<1 per day
	Frequency variations	50	+/- 2Hz	+/- 1 Hz	+/- 0.5 Hz

taining the supply of the mini-grid is critical to the technical sustainability of the system, which includes maintaining the availability, adequacy, reliability, and quality of supply. These factors all feed into consumer satisfaction, which is maintained if the system can keep up with both the demands of users (both domestic and commercial) at the time of installation, and the aspirational demands of users, both current and potential into the future.

However, this review has also assessed the current frameworks available in the literature for determining the technical sustainability of mini-grids, and identified a number of critical gaps in their assessment criterion, including the lack of assessment of the renewability of energy used in the mini-grid, and the lack of assessment of the potential of mini-grids to supply future, aspirational energy needs for consumers. This has led to the proposal of a new assessment framework for the technical sustainability of mini-grids, focusing on five primary indicators and nine sub-indicators, each with an assigned weighting, that will be simple to use both in the field and at the design stage. This assessment framework captures the adequacy of supply, the availability of supply, the reliability of supply, the renewability of energy sources, and the quality of electricity provided, in order to determine the ability of a mini-grid to meet the present and future needs of connected consumers.

References

Almeshqab, F., & Ustun, T. S. (2019). Lessons learned from rural electrification initiatives in developing countries: Insights for technical, social, financial and public policy aspects. *Renewable and Sustainable Energy Reviews*, *102*, 35–53.

Arnaiz, M., Cochrane, T. A., Calizaya, A., & Shreshta, M. (2018). A framework for evaluating the current level of success of micro-hydropower schemes in remote communities of developing countries. *Energy for Sustainable Development*, *44*, 55–63.

Azimoh, C. L., Klintenberg, P., Mbohwa, C., & Wallin, F. (2017). Replicability and scalability of mini-grid solution to rural electrification programs in sub-Saharan Africa. *Renewable Energy*, *106*, 222–231.

Baker L H et al 2022 Of monopolies and mini grids: case studies from Kenya, Tanzania, Nigeria and Senegal sustainability, inclusiveness and governance of mini-grids in Africa (SIGMA) project report (available at: www.sigma-gcrf.net/resources/working-papers)

Bhattacharyya, S. C. (2012). Energy access programmes and sustainable development: A critical review and analysis. *Energy for Sustainable Development*, *16*(3), 260–271.

Bhattacharyya, S. C. (2018). Minigrids for the base of the pyramid market: A critical review. *Energies*, *11*, 813. http://doi.org/10.3390/en11040813

Bhattacharyya, S. C., & Palit, D. (2016). Mini-grid based off-grid electrification to enhance electricity access in developing countries: What policies may be required? *Energy Policy*, *94*, 166–178. http://doi.org/10.1016/j.enpol.2016.04.010

Bhattacharyya, S. C., Palit, D., & Kishore, V. V. N. (2014). Suite of off-grid options in South Asia. In S. Bhattacharyya & D. Palit (Eds.), *Mini-grids for rural electrification of developing countries* (pp. 11–36). Springer.

Blodgett, C., Dauenhauer, P., Louie, H., & Kickham, L. (2017). Accuracy of energy use surveys in predicting mini-grid user consumption. *Energy for Sustainable Development*, *41*, 88–105.

Bloomberg NEF and SEforALL. (2020). *State of the Global Mini-grids Market Report 2020, the Minigrids Partnership Report*. Retrieved July 14, 2023, from https://www.seforall.org/system/files/2020-06/MGP-2020-SEforALL.pdf

Boait, P. (2014). Technical aspects of mini-grids for rural electrification. In S. Bhattacharyya & D. Palit (Eds.), *Mini-grids for rural electrification of developing countries* (pp. 37–61). Springer.

Brent, A. C., & Rogers, D. E. (2010). Renewable rural electrification: Sustainability assessment of mini-hybrid off-grid technological systems in the African context. *Renewable Energy*, *35*(1), 257–265.

Butchers, J., Williamson, S., Booker, J., Tran, A., Karki, B., & Gautam, B. (2020). Understanding sustainable operation of micro-hydropower: A field study in Nepal. *Energy for Sustainable Development*, *57*, 12–21.

Derks, M., & Romijn, H. (2019). Sustainable performance challenges of rural microgrids: Analysis of incentives and policy framework in Indonesia. *Energy for Sustainable Development*, *53*, 57–70.

Díaz, P., Peña, R., Muñoz, J., Arias, C. A., & Sandoval, D. (2011). Field analysis of solar PV-based collective systems for rural electrification. *Energy*, *36*(5), 2509–2516. https://doi.org/10.1016/j.energy.2011.01.043

Draeck, M., & Kottasz, E. (2017). *Renewable energy-based mini-grids: The UNIDO experience* (Working paper 1/2017). United Nations Industrial Development Organisation.

Drinkwaard, W., Kirkels, A., & Romijn, H. (2010). A learning-based approach to understanding success in rural electrification: Insights from Micro Hydro projects in Bolivia. *Energy for Sustainable Development*, *14*(3), 232–237.

ESMAP. (2015). *Beyond connections: Energy access redefined*. Technical Report 08/15, Energy Sector Management Assistance Program, World Bank. https://openknowledge.worldbank.org/bitstream/handle/10986/24368/Beyond0connect0d000technical0report.pdf?sequence=1&isAllowed=y

ESMAP. (2019a). *Mini grids for half a billion people: Market outlook and handbook for decision makers*. ESMAP Technical Report 014/19. Energy Sector Management Assistance Program, World Bank. https://openknowledge.worldbank.org/handle/10986/31926

ESMAP. (2019b). *State of the global mini-grids market report 2020*. https://www.seforall.org/system/files/2020-06/MGP-2020-SEforALL.pdf

ESMAP (2024) 'Tracking SDG 7, results worldwide'. https://trackingsdg7.esmap.org/

EUEI-PDF. (2014). *Mini-Grid Policy Toolkit: Policy and business frameworks for successful mini-grid rollouts*. European Union Energy Initiative Partnership Dialogue Facility.

Ferrer-Martí, L., Garwood, A., Chiroque, J., Ramirez, B., Marcelo, O., Garfí, M., & Velo, E. (2012). Evaluating and comparing three community small-scale wind electrification projects. *Renewable and Sustainable Energy Reviews*, *16*(7), 5379–5390.

Fowlie, M., Khaitan, Y., Wolfram, C., & Wolfson, D. (2018). *Solar microgrids and remote energy access: How weak incentives can undermine smart technology*. Energy Institute WP295, Energy Institute at Haas. https://haas.berkeley.edu/wp-content/uploads/WP295.pdf

Fuso-Nerini, F., Tomei, J., Seng To, L., Bisaga, I., Parikh, P., Black, M., Borrion, A., Spataru, C., Castán-Broto, V., Anandarajah, G., Milligan, B., & Mulugetta, Y. (2018). Mapping synergies and trade-offs between energy and Sustainable Development Goals. *Nature Energy*, *3*, 10–15.

Groh, S., Pachauri, S., & Rao, N. D. (2016). What are we measuring? An empirical analysis of household electricity access matrix in Bangladesh. *Energy for Sustainable Development*, *30*, 21–31.

IEA. (2011). *The role of energy storage for mini-grid stabilisation, PVPS T11-02*. International Energy Agency.

IEA, IRENA, UNSD, World Bank and WHO. (2025). *Tracking SDG7: The Energy Progress Report, 2025*. World Bank. https://www.iea.org/reports/tracking-sdg7-the-energy-progress-report-2025

Ilskog, E. (2008). Indicators for assessment of rural electrification—An approach for comparison of apples and pears. *Energy Policy*, *36*, 2665–2673.

Ilskog, E., & Kjellstrom, B. (2008). And they lived sustainably ever after? Assessment of rural electrification cases by means of indicators. *Energy Policy*, *36*, 2674–2684.

IRENA. (2019). *Innovation landscape brief: Renewable mini-grids*. International Renewable Energy Agency. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Renewable_mini-grids_2019.pdf?la=en&hash=CFE9676B470A96F7A974CB619889F5810A06043E

IRENA. (2024). *Renewable Energy Statistics 2024*. International Renewable Energy Agency.

Katre, A., & Tozzi, A. (2018). Assessing the sustainability of decentralised renewable energy system: A comprehensive framework with analytical methods. *Sustainability*, *10*, 1058. https://doi.org/10.3390/su10041058

Katre, A., Tozzi, A., & Bhattacharyya, S. (2019). Sustainability of community-owned mini-grids: Evidence from India. *Energy, Sustainability and Society*, *9*(2). https://doi.org/10.1186/s13705-018-0185-9

Kovacic, Z., Smit, S., Musango, J. K., Brent, A. C., & Giampietro, M. (2016). Probing uncertainty levels of electrification in informal urban settlements: A case from South Africa. *Habitat International*, *56*, 212–221.

Lillo, P., Ferrer-Marti, L., Boni, A., & Fernandez-Baldor, A. (2015). Assessing management models for off-grid renewable energy electrification projects using the Human Development approach: Case study in Peru. *Energy for Sustainable Development*, *25*, 17–26.

Lopez-Gonzales, A., Ferrer-Marti, L., & Domenech, B. (2018). Sustainability and design assessment of rural hybrid microgrids in Venezuela. *Energy*, *159*, 229–242.

Lopez-Gonzales, A., Ferrer-Marti, L., & Domenech, B. (2019). Long-term sustainability assessment of micro-hydro projects: Case studies from Venezuela. *Energy Policy*, *131*, 120–130.

Mainali, B., & Silveira, S. (2015). Using a sustainability index to assess energy technologies for rural electrification. *Renewable and Sustainable Energy Reviews*, *41*, 1351–1365.

McCollum, D. L., Zhou, W., & Bertram, C. (2018). Energy investment needs for fulfilling the Paris agreement and achieving the sustainable development goals. *Nature Energy*, *3*, 589–599.

Muchunku, C., Ulsrud, K., Palit, D., & Jonker-Klunne, W. (2018). Diffusion of solar PV in East Africa: What can be learned from private sector delivery models?. *Wiley Interdisciplinary Reviews: Energy and Environment*, 7(3), e282

Murni, S., Whale, J., Urmee, T., Davies, J. K., & Harries, D. (2013). Learning from experience: A survey of existing micro-hydropower projects in Ba'Kelalan, Malaysia. *Renewable Energy*, *60*, 88–97.

Ngowi, J. M., Bångens, L., & Ahlgren, E. O. (2019). Benefits and challenges to productive use of off-grid rural electrification: The case of mini-hydropower in Bulongwa-Tanzania. *Energy for Sustainable Development*, *53*, 97–103.

Numminen, S., & Lund, P. (2019). Evaluation of the reliability of solar micro-grids in emerging markets – Issues and solutions. *Energy for Sustainable Development*, *48*, 34–42.

Odarno, L., Sawe, E., Swai, M., Katyega, M. J. J., & Lee, A. (2017). *Accelerating mini-grid deployment in sub-Saharan Africa, lessons from Tanzania*. TaTEDO and World Resources Institute. https://www.wri.org/research/accelerating-mini-grid-deployment-sub-saharan-africa-lessons-tanzania

Palit, D., & Chaurey, A. (2011). Off-grid rural electrification experiences from South Asia: Status and best practices. *Energy for Sustainable Development*, *15*(3), 266–276.

Purwanto, W. W., & Afifah, N. (2016). Assessing the impact of techno socioeconomic factors on sustainability indicators of microhydro power projects in Indonesia: A comparative study. *Renewable Energy*, *93*, 312–322.

Rahmann, C., Nunez, O., Valencia, F., Arrechea, S., Sager, J., & Kammen, D. (2016). Methodology for monitoring sustainable development of isolated mini-grids in rural communities. *Sustainability*, *8*, 1163. https://doi.org/10.3390/su8111163

Ribeiro, L. A. D. S., Saavedra, O. R., Lima, S. L., de Matos, J. G., & Bonan, G. (2012). Making isolated renewable energy systems more reliable. *Renewable Energy*, *45*, 221–231.

Santika, W. G., Anisuzzaman, M., Bahri, P. A., Shafiullah, G. M., Rupf, G. V., & Urmee, T. (2019). From goals to joules: A quantitative approach of interlinkages between energy and the Sustainable Development Goals. *Energy Research & Social Science*, *50*, 201–214.

Schnitzer, D., Lounsbury, D. S., Carvallo, J. P., Deshmukh, R., Apt, J., & Kammen, D. M. (2014). *Microgrids for rural electrification: A critical review of best practices based on seven case studies*. Energy Access Practitioners Network, United Nations Foundation. https://rael.berkeley.edu/publication/microgrids-for-rural-electrification-a-critical-review-of-best-practices-based-on-seven-case-studies/

Shakya, A. K. (2017). *Economic Importance of Public Transit Investment in Kathmandu Valley* (Doctoral dissertation).

Shakya, B., Bruce, A., & McGill, I. (2019). Survey based characterisation of energy services for improved design and operation of standalone microgrids. *Renewable and Sustainable Energy Reviews*, *101*, 493–503.

Sharma, R. K., & Palit, D. (2020). A coevolutionary perspective on decentralised electrification: A solar mini-grid project in India. *International Journal of Sustainable Society*, *12*, 202–219. https://doi.org/10.1504/IJSSOC.2020.109773

Shyu, C. W. (2013). End-users' experiences with electricity supply from stand-alone mini-grid solar PV power stations in rural areas of western China. *Energy for Sustainable Development*, *17*(4), 391–400.

Szabó, S., Bódis, K., Huld, T., & Moner-Girona, M. (2013). Sustainable energy planning: Leapfrogging the energy poverty gap in Africa. *Renewable and Sustainable Energy Reviews*, *28*, 500–509.

Tenenbaum, B., Greacen, C., Siyambalapitiya, T., & Knuckles, J. (2014). *From the bottom up: How small power producers and mini-grids can deliver electrification and renewable energy in Africa; Directions in development—Energy and mining*. World Bank.

Ulsrud, K., Muchunku, C., Palit, D., & Kirubi, G. (2019). *Solar energy, mini-grids and sustainable electricity access: Practical experiences, lessons and solutions from Senegal*. Routledge.

Ulsrud, K., Rohracher, H., Winther, T., Muchunku, C., & Palit, D. (2018). Pathways to electricity for all: What makes village-scale solar power successful? *Energy Research and Social Science*, *44*, 32–40.

Ulsrud, K., Winther, T., Palit, D., Rohracher, H., & Sandgren, J. (2011). The solar transitions research on solar mini-grids in India: Learning from local cases of innovative sociotechnical systems. *Energy Sustainable Development*, *15*(3), 293–303.

UNIDO. (2017). *Renewable Energy-based Mini-grids: The UNIDO Experience*. Inclusive and Sustainable Industrial Development Working Paper Series, WP1/ 2017. United Nations Industrial Development Organisation. https://www.unido.org/sites/default/files/2017-03/Minigrid_report_Jan2017.v19_FINAL29906_0.pdf

Valer, R. L., Monito, A. R. A., Ribeiro, T. B. S., Zilles, R., & Pinho, J. T. (2017). Issues in PV systems applied to rural electrification in Brazil. *Renewable and Sustainable Energy Reviews*, *78*, 1033–1043.

Van Gevelt, T., Zaman, T., George, F., Bennet, M. M., Fam, S. D., & Kim, J. E. (2020). End-user perceptions of success and failure: Narratives from a natural laboratory of rural electrification projects in Malaysian Borneo. *Energy for Sustainable Development*, *59*, 189–198.

Wiemann, M., Rolland, S., & Glania, G. (2014). *Hybrid mini-grids for rural electrification: Lessons learned*. Alliance for Rural Electrification.

Winther, T. (2012). Electricity theft as a relational issue: A comparative look at Zanzibar, Tanzania, and the Sunderban Islands, India. *Energy for Sustainable Development*, *16*(1), 111–119.

World Bank. (2000). *Mini-Grid Design Manual*. Energy Sector Management Assistance Program Technical Series; ESMAP technical paper no. 007. https://openknowledge.worldbank.org/handle/10986/20310

Yadoo, A., & Cruickshank, H. (2012). The role of low carbon electrification technologies in poverty reduction and climate change strategies: A focus on renewable energy mini-grids with case studies in Nepal, Peru and Kenya. *Energy Policy*, *42*, 591–602.

Yan, J., Zhai, Y., Wijayatunga, P., Mohamed, A. M., & Campana, P. E. (2017). Renewable energy integration with mini/micro-grids. *Applied Energy*, 201, 241-244.

CHAPTER 3

Understanding Business Models and Access to Finance for Mini-Grid Development in Sub-Saharan Africa

Adriana Fajardo, [1] Lucy H. Baker, [2] Temilade Sesan, [3] Subhes Bhattacharyya, [4] Daniel Kerr, [4] Maneno Katyega[5] and Andrew Barnett [6]

[1]Independent Consultant, Washington, DC, USA
[2]Geography and Environment Studies, The Open University, Milton Keynes, UK
[3]Center for Petroleum, Energy Economics and Law, University of Ibadan, Ibadan, Nigeria
[4]De Montfort University, Leicester, UK
[5]TaTedo, Centre for Sustainable Energy Services, Dar-es-Salam, Tanzania
[6]The Policy Practice, Brighton, UK

Abstract

This chapter is based on a comprehensive literature review of publications from academia, industry, governmental, and international institutions relating to business models, finance, and operational risks and challenges of mini-grids in sub-Saharan Africa (SSA). First, we investigate different business models that exist for mini-grids in SSA and provide insight into the opportunities and challenges of each approach. Second, we identify access to finance as a prominent challenge to further expansion of "third-generation" solar or solar-hybrid mini-grids in the region. Finally, we examine some of the key investment, regulatory, and operational risks and challenges in the sector's current and future development. The study sheds light on the challenges and opportunities faced by the evolving sector in the region and consider successful approaches and best practices to advance sustainable energy access. In doing so, it responds to the need for more clarity between the optimistic promises and enthusiasm expressed in influential energy publications regarding solar mini-grid development in SSA, and the level and quality of finance available for mini-grids in the region. Crucially, while financial sustainability is often regarded as the main challenge for mini-grid expansion, there is a

complementary need for proven, successful, and scalable business models. We conclude that there is no one-size-fits-all solution for mini-grid business models in SSA. Success depends on specific external and internal challenges unique to each context. Optimistic narratives around private-sector participation may not always translate into greater accessibility and affordability and, notwithstanding progress in recent years, securing adequate external finance remains a key challenge.

Keywords: mini-grids, business models, sub-Saharan Africa, financial sustainability, energy access, risks

Acronyms

A-B-C Model	*Anchor Business Consumer Model*
AFD	*French Development Agency*
AfDB	*African Development Bank*
AMDA	*Africa Minigrid Developers Association*
ARE	*Alliance for Rural Electrification*
CAPEX	*Capital expenditure*
CIF	*Climate Investment Funds*
DFI	*Development finance institution*
EPC	*Engineering, Procurement, and Construction*
ESMAP	*Energy Sector Management Assistance Program*
GIZ	*German Corporation for International Cooperation*
GEP	*Global Electrification Platform*
IEA	*International Energy Agency*
IRENA	*International Renewable Energy Agency*
KMM	*Key Maker Model*
O&M	*Operation and maintenance*
OPEX	*Operating expenditure*
PAYG	*Pay-as-you-go*
PPA	*Power purchase agreement*
PPP	*Public–private partnership*
PV	*Photovoltaic*

REA	*Rural Electrification Agency*
RECP	*Africa–EU Renewable Energy Cooperation Programme*
RBF	*Results-based finance*
RESCO	*Renewable energy service companies*
SDG	*Sustainable Development Goals*
SSA	*Sub-Saharan Africa*

3.1 Introduction

By 2022, 650 million people globally lacked access to electricity, most of them in sub-Saharan Africa (SSA), where 58% of the continent's population lives in rural areas (World Bank, 2023). Significant gains in energy access worldwide between 2015 and 2019 have since been undermined by the COVID-19 pandemic, Russia's invasion of Ukraine, and global inflation. Electrification progress has particularly lagged behind rural population growth in SSA. By 2021, SSA's access deficit was almost the same as in 2010, casting doubt on the electrification efforts promoted by national and international players. Based on figures at the time of writing, more than 500 million people will need to be connected in order for SSA to achieve the Sustainable Development Goal 7 (SDG 7) target of "access to affordable, reliable, sustainable, and modern energy for all" by 2030, including 380 million connected to mini-grid systems (ESMAP, 2022, p. 35).

Despite the growth of the solar and solar-hybrid mini-grid sector in recent years, there is a disconnect between the enthusiasm expressed by energy and development institutions regarding the sector's actual and potential contribution to the realization of energy access for all in SSA, and the level of finance and investment currently provided. According to estimations of ESMAP's Global Electrification Platform, from the $91 billion investment requirement in SSA to connect 380 million people through mini-grids, almost all in solar-hybrid systems, by 2022 less than 10% had been approved (ESMAP 2022). Commitments from development finance institutions (DFIs), including the World Bank, Climate Investment Funds (CIFs), French Development Agency (AFD), the African Development Bank (AfDB), and the German Corporation for International Cooperation (GIZ), currently dominate the financing landscape for mini-grids in SSA and serve to leverage private-sector investments.

Moreover, while financial sustainability is often put forward as the most significant challenge for mini-grid expansion (Moner-Girona et al., 2018; Ogeya et al., 2021; Tsuchiya et al., 2020), it is also vital to recognize the complementary need for proven, successful, and scalable business models (ESMAP, 2019), a term that we use to refer to ownership and management, revenue generation, customer focus, and implementation approaches. The nature of the business model plays a crucial role in ensuring the financial viability and long-term success of any mini-grid project.

With this in mind, we carry out a literature review in order to, first, explore the different mini-grid business models that currently exist in SSA and provide insights into the opportunities and challenges of each approach. Second, we identify access to finance as a prominent challenge to the further expansion of "third-generation" or solar or solar-hybrid mini-grids in the region. In so doing, we explore the different configurations of actors, institutions, and processes involved in the provision of finance and investment for the sector. Finally, we examine some of the key investment, regulatory, and operational risks and challenges in the sector's current and future development. Through such a study, we shed light on the challenges faced by the evolving sector in the region and identify lessons about how mini-grids could contribute to energy access goals more effectively.

The term mini-grid refers to a low-voltage or medium-voltage generation and electricity distribution network that can operate in isolation from the main grid, but also connect to it should the network expand. The nature of a mini-grid is such that power can be generated much closer to the point of consumption (ESMAP, 2019). Sometimes referred to as the "missing middle" between the centralized electricity grid and solar home systems (SHSs), there is no clearly agreed definition of a mini-grid in terms of size, generation capacity, customer base, or energy source. It is a term through which the often-competing objectives of productive use, energy access, and rural electrification are conflated (Baker et al., 2022).

The installed capacity of a mini-grid can also vary considerably depending on the context and the country, but typically falls within a range of 10 kW to 10 MW (Muchunku et al., 2018, p. 7). This, as compared to that of a micro-grid, is usually between 1 and 10 kW (Muchunku et al., 2018). Mini-grids can also be differentiated from SHSs, which are based on direct current (DC) and are largely deployed for the provision

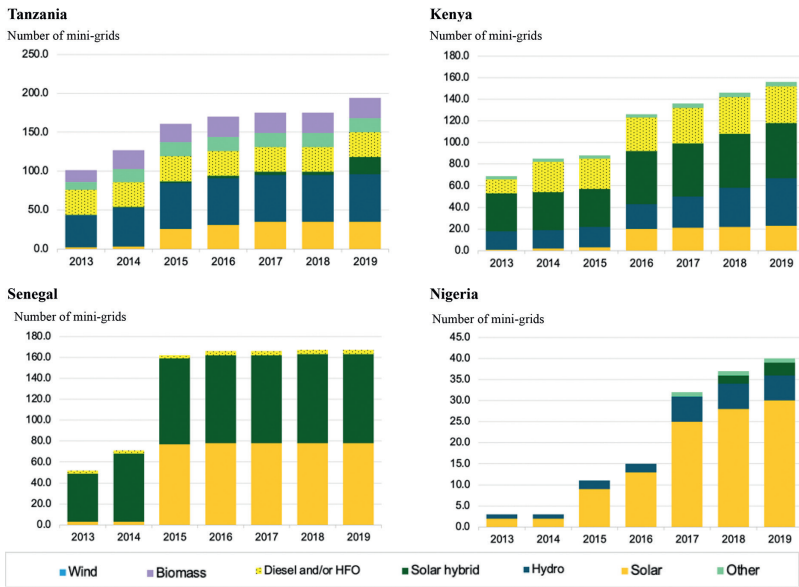
of energy access such as lighting, radio, and mobile telephone charging. While SHSs sit under tiers one to three of the multi-tier framework for measuring electricity access, mini-grids generally sit in tiers four and five (World Bank et al., 2015) and can be converted to alternating current (AC).

While larger mini-grids are better suited for more densely populated communities with higher demand levels, SHSs and smaller mini-grids are considered the most cost-effective solution to connect poor, remote, and often rural communities (AMDA, 2022; ESMAP, 2022). Mini-grids are perceived as being able to support productive use in addition to energy access (Bhattacharyya & Palit, 2016). According to the Africa Minigrid Developers Association (AMDA, 2020, p. 41), in SSA, mini-grids can be deployed faster than the main grid and provide more reliable electricity, including to productive use customers.

The falling price of solar technology and battery storage has encouraged the growth of solar PV and solar-hybrid or "third-generation" mini-grids, as compared to previous systems, which were predominantly diesel and hydro-powered (ESMAP, 2019). At the time of writing, 50% of the approximately 21,500 existing mini-grids worldwide were solar PV-generated (ESMAP, 2022, p. 30). Figure 3.1 shows the increasing trend in solar mini-grids in four different countries of the region.

Experience to date has shown that finding a balance between affordable service provision and adequate cost recovery is a key challenge for the financial viability of mini-grids in the region, particularly where the project serves low electricity consumers with limited ability to pay in remote locations. Various options have been put forward in this instance, including the provision of public subsidies for either the project capital expenditure (CAPEX) and/or the tariff, and the anchor customer-based model. However, as we find, there is no "gold-standard" business model for financial sustainability and scalability. Additionally, the lack of quantitative evidence in the literature hinders the ability to compare and accurately correlate business models with financial outcomes. Similarly, while evidence from the literature points to hybrid ownership, partially subsidized, the inclusion of anchor customers, and financial bundling portfolios as the most promising business strategies, no bulletproof mini-grid business model has proven to always work for SSA. Success is highly context-specific depending on external and internal challenges (Franz et al., 2014; Safdar, 2017).

Figure 3.1: Mini-Grids by Type of Technology in Tanzania, Kenya, Senegal, and Nigeria



Source: Authors' own, using information from BlombergNEF database, 2022.

The structure of this chapter is as follows. Section 3.2 describes the methodology used for the literature review. Section 3.3 unpacks the different approaches to business models, while Section 3.4 explores the main actors, institutions, and processes involved in accessing finance for third-generation mini-grids in SSA. Section 3.5 examines the main investment risks and challenges of the mini-grid sector to date. This chapter concludes with a summary of the literature review findings by each type of business model, suggesting that a deeper understanding of business models is required, given that the positive narrative toward private-sector participation does not necessarily make electricity more accessible and affordable for users at the last mile.

3.2 Literature Review Methodology

This literature review draws from academic articles and reports by the energy industry published between 2005 (the earliest year for which publications

on mini-grids were available) and 2022. Publications were selected based on their relevance to the development of the mini-grid sector, particularly their analysis of the SSA context. Industry reports covering other developing countries and global perspectives were also analyzed. A search process was carried out using the following academic databases: Scopus, ResearchGate, and Google Scholar. While there are a limited number of academic articles specific to mini-grid business models, the review examined the literature focusing on the socio-economic performance and sustainability of the sector. The scope of the review is briefly summarized in Table 3.1.

The literature reviewed consisted of 109 documents, of which 52% were peer-reviewed academic papers and 48% were gray literature and media. The literature consulted was mainly in English, except for some country reports in French. In reflection of the sector's development, most publications focus on the last eight years, from 2015 to 2022, followed by the preceding six years, with relatively fewer publications covering the period between 2006 and 2007. The growing number of papers and reports on mini-grids in recent years reflects an increasing interest and relevance of the role of mini-grids in energy access in developing countries, particularly in SSA. Countries including Tanzania, Kenya, and India are the most analyzed in the literature, suggesting that one of the limitations of the literature is the lack of comparative case studies from elsewhere.

This research also included quantitative analysis from databases, such as BloombergNEF. However, the absence of quantitative methods

Table 3.1: Scope of the Review

Scope Element	*Inclusion Criteria*
Electricity systems	Mini-grids
Geographical scope	Low- and middle-income countries (particularly SSA)
Publication date	2005 onwards (due to the lack of publications before this year)
Publication format	Journal articles, working papers, evaluations, institutional reports, and media
Methodological approach	Primary and empirical studies using quantitative or qualitative data
Publication language	English and French

Source: Authors.

to assess the influence of business models on mini-grid profitability hindered the capacity to compare their financial sustainability. The former suggests the need for mini-grid databases and more case-study analyses on business models to reach comparable information among and within countries.

The literature analysis was conducted using Nvivo software, and the information was coded in three main areas: business models, access to finance, and risks and challenges. Within each section, a list of sub-codes aggregates the most significant themes mentioned in the literature, as described in Table 3.2.

3.3 Unpacking Mini-Grid Business Models

There is no single definition of a business model in the literature—the term is used differently according to value creation, operations, and delivery structures. As a result, the description of a business model can serve different purposes. Business models for mini-grids are defined in the literature according to different approaches to ownership and operations management (AfDB, 2016; ECREEE, 2016; Franz et al., 2014; Korkovelos et al., 2020; Peters et al., 2019; Safdar, 2017), the revenue models (Schnitzer et al., 2014), the customer focus (Knuckles, 2016; Ramachandran et al., 2016), and the delivery and imple-

Table 3.2: Literature Review Coding

Main Code	*Business Models*	*Risks and Challenges*	*Access to Finance*
Sub-codes	Ownership Source of revenue Customer focus Implementation	Regulation and market access Demand and sizing Macroeconomic risks Affordability Governance Skills and technical Social risks	Type of funding Sources of funding

Source: Authors' own.

mentation schemes (ARE, 2014; Weston et al., 2018). The ownership approach is the model that is most covered in the literature, by multiple authors and international development agencies. In this section, we disaggregate the different typologies identified in the literature, providing a summary of the various mini-grid business models and approaches and insights into the challenges and opportunities of each type in the SSA context.

3.3.1 Ownership and Management Models

Mini-grid ownership models vary according to who holds and operates the project's assets, including generation and distribution: these include public utility, private sector, community, and hybrid models. The ownership model often depends on the initial source of financing and the party responsible for managing the operations after installation. This characterization of business models is the one most commonly used by industry reports. However, there is a lack of sufficient quantitative information regarding business models that allows for comparison. For example, according to the BloombergNEF 2022 database, out of the 984 mini-grids identified in four countries in SSA (Nigeria, Senegal, Tanzania, and Kenya), only 470 were defined by ownership type. Table 3.3 shows the number of mini-grids in those four countries by ownership model, indicating that public ownership is the predominant model in Senegal and Kenya, as compared to Tanzania and Nigeria, where the private sector has a larger market share.

The nature of mini-grid ownership also depends on the regulatory framework where the mini-grid is implemented BNEF (2019) and context-specific variables, such as geography, and socio-economic and political factors (Safdar, 2017). As discussed below, the literature suggests that none of the established ownership models has proven successful in SSA. However, according to industry reports, including by the AfDB and Bloomberg NEF, the public–private partnership (PPP) model has the most potential for scale up, by leveraging collaboration and the advantages of each sector, assuming that the appropriate balance between private and public ownership and control can be established (AfDB, 2016; BNEF (2019); ESMAP, 2022, p. 152).

Table 3.3: Number of Mini-Grids by Ownership Model

Country	*Total database*	*Public*	*Private*	*Public Private Partnership (PPP)*	*Community*	*Unknown*
Nigeria	67	1	45	10	1	10
Senegal	431	107	1	6	7	310
Tanzania	278	36	112	5	42	83
Kenya	208	70	6	4	17	111
Total	984	214	164	25	67	514

Source: Authors' own, using information from BloombergNEF Database (2022).

3.3.1.1 Public Utility Model

Under a public utility model, the national electricity utility owns and operates the mini-grids, as is the case in Senegal and Kenya, for instance, (see Table 3.3) and is responsible for installing, managing, and maintaining the system. The initial financing is likely to be provided by the utility and subsidized by public funds from government or DFIs through support for national electrification programs (AfDB, 2016; IED, 2013; Safdar, 2017). This model is seen as crucial to meeting the social objectives of electricity access and, in some countries, e.g., Namibia and South Africa, the utility often matches the grid's national tariffs, which are cross-subsidized by other customers (AfDB, 2016; RECP, 2014; Safdar, 2017).

State-owned mini-grids are relatively common in SSA, and national utility companies have been key players in early mini-grid development in SSA, including Tanzania Electricity Supply Company Limited in Tanzania and Kenya Power and Lighting Company in Kenya (Baker et al., 2022; ESMAP, 2019), though they have primarily depended on conventional technologies and hybrid systems (Pedersen, 2017). Despite the potential role that the public utility model could play in electricity provision, the industry often perceives it as more expensive and inefficient than privately developed mini-grids, and there is inconsistent evidence on the success of this model (Antonanzas-Torres et al., 2021; ARE, 2014). Indeed, as some argue, most utilities in SSA are not financially solvent, sell at a loss, often lack the necessary technical expertise, and frequently prioritize social and political outcomes over financial sustainability (ESMAP, 2022, p. 152; Trimble et al., 2016; USAID, 2017).

3.3.1.2 Private Model

In this model, a private company develops, owns, and operates the mini-grid, as is the case, for instance, in Tanzania and Nigeria (see Table 3.3). The funding can come from different sources, including private equity, commercial loans, and subsidized finance such as grants, results-based finance, or public sector loan guarantees (AfDB, 2016; Franz et al., 2014; Safdar, 2017). The demands and expectations of equity investment are such that the mini-grid must provide returns proportionate to the risk, which is a challenge, given the lack of cost-reflective tariffs in certain countries (Weston et al., 2018).

In recent years, the private sector has largely developed third-generation mini-grids in parallel with technological innovation and cost reductions in solar components (ESMAP, 2022, p. 82).

International energy institutions have called for more extensive private participation in SSA's rural electrification targets, arguing that with appropriate investment, the private sector model is better able to provide higher quality service and efficiency than other ownership models (ARE, 2014; ESMAP, 2022; IEA, 2022). Access to subsidies or grants may enable the expansion of this business model. That said, private participation has faced its own challenges, and few initiatives have achieved financial sustainability due to the lack of cost-reflective tariffs covering investment and operational costs.

The increasing interest of the private sector in mini-grids is influenced by regulatory frameworks that promote market access for private-sector investment (AfDB, 2016; ESMAP, 2022; Safdar, 2017). However, for the private sector to recover its investment costs, it tends to prioritize locations with commercial viability, including where anchor customers and productive users with higher demand are present (Safdar, 2017, p. 17). Consequently, scaling up private sector participation in mini-grid development relies on regulatory frameworks that permit developers to charge cost-reflective tariffs (ESMAP, 2019; Knuckles, 2016).

3.3.1.3 Hybrid Model

Hybrid models combine the features of public and private models, with different parties building, owning, and operating the distribution and generation assets of the mini-grid. These models are based on a division of responsibilities through various contractual arrangements including PPPs, renewable energy service companies (RESCOs), concessions, power purchase agreements (PPAs), and others, as discussed in Table 3.4. The shift toward private participation, together with the need for public utility involvement in reaching last-mile communities, calls for the right balance between private and public participation and a clear regulatory framework that sets out the roles and responsibilities of both parties.

The most common hybrid models are PPPs with public ownership and private operation or split-asset models with public ownership of the distribution assets and developers owning the generation assets (BNEF (2019); ESMAP, 2022, p. 152). According to Gershenson et al. (2015), the private

Table 3.4: Contractual Options for Hybrid Models

Public–Private Partnership (PPP)	Contractual agreement between a public and a private party that combines financing, ownership, and management capacities.
Renewable Energy Service Company (RESCO)	RESCO companies work similarly to utilities at a smaller scale, whereby the assets are purchased and owned by the government, while RESCOs operate and maintain the mini-grid.
Concession Model	A holder of a concession, usually a private developer, has beneficial terms for providing electricity services. Those terms can be translated in preferential market access for specific timeframes or specially designed tariffs for the area of operation.
Power Purchase Agreement (PPA)	A PPA is a contractual arrangement between the public and private sector parties for the delivery of electricity, where the public entity will purchase the power generated by the private energy producer over a certain time frame and under an agreed tariff structure. A PPA is also mandatory for the public utility to sell power to a private company, which is also a distribution network operator.

Source: Authors' compilation based on relevant literature cited in this section.

sector finds risk allocation more efficient in this structure than fully privately funded ones, as developers have a greater influence in defining the project's risks and benefiting from de-risking mechanisms from the public sector. It has been argued that PPP structures can overcome government

budgetary constraints, diversify project risk between actors, and optimize the expertise and efficiencies of the private sector.

The participation of the private sector in mini-grid development has been driven primarily by concessional instruments from DFIs and climate investment institutions, including low-interest and long-tenor project loans, public guarantees, and grant-based capacity-building programs (ESMAP, 2022, p. 131), building on the industry discourse of utility inefficiency and promoting private sector participation.

ESMAP (2022) has argued that one of the success factors of hybrid models is the collaboration between different players, bringing together experience in the sector, access to finance, technical capacity, and operational efficiencies. However, others have indicated that these models rely on the clarity of property rights regarding the assets, governance and technical arrangements, and interconnection policies concerning the utility's grid expansion (Safdar, 2017; Weston et al., 2018). Currently, there is a lack of quantitative analysis and case studies to demonstrate the effectiveness of this approach in enhancing the profitability of mini-grids.

3.3.1.4 Community Model

In this model, the mini-grid is owned and operated by a local community that may have received mini-grid assets from a government program, a nonprofit organization, or a development institution (BNEF, 2019). Communities may also receive external support in designing, financing, and installing the mini-grids, such as grants and in-kind contributions (AfDB, 2016; Peters et al., 2019; Safdar, 2017). This model is more common in isolated rural areas that do not attract private sector or utility interest because of the high cost of supply and where consumers may be too poor to afford cost-covering tariffs (ARE, 2014; ECREEE, 2016). This model is predominant in development aid electrification projects aiming to empower local actors (AfDB, 2016). Community-owned and operated mini-grids often require technical assistance and support to train staff in operations and finance to provide a solid economic model that can continue in the long run.

Some authors have pointed out difficulties in building local capacity and the risk of donor dependency, raising questions regarding this model's sustainability and long-term viability (Duran & Sahinyazan, 2021; Franz et al., 2014; Yadoo, 2012). Others argue that community models often

require subsidies, continuing funding, and technical support (Gershenson et al., 2015). Ilskog and Kjellström (2008) suggest that the sustainability of the community model could improve if it operates as a rural power cooperative, whereby financial discipline mirrors a private model.

3.3.2 Consumer-Focused Models

While it is often assumed that mini-grids will provide access to low-income, rural, and isolated communities, developers and financial actors generally consider the level of electricity demand within such communities too low to ensure the economic sustainability of the system (Peters et al., 2019). Many have therefore argued that the limited ability of low-income households to pay increases the need to foster productive energy use and integrate larger commercial and anchor customers to increase demand (AfDB, 2016; AMDA, 2020, p. 40; Pueyo et al., 2020). Likewise, ESMAP (2022, p. 117) points out that mini-grid sustainability relies on increasing the productive uses of electricity, stimulating demand, and community engagement.

Under consumer-focused models, new approaches to incentivize productive energy use have become a priority for designing and implementing many mini-grid projects. However, there is little available evidence to date about whether strategies to promote productive use are succeeding in improving mini-grid profitability. While some studies show positive impacts, e.g., Kirubi et al. (2009), others show no evidence of improvement in enterprise profits and productivity (Pueyo & DeMartino, 2018).

3.3.2.1 Households and Small Businesses Approach

In low-income markets, off-grid solar systems often serve households and small businesses, sometimes providing electricity for a lower price than other energy sources, such as kerosene (Knuckles, 2016). However, mini-grid tariffs, which are often more expensive than subsidized grid electricity, can create an affordability barrier for off-grid populations. Indeed, there was little evidence in the literature to suggest that mini-grids can achieve long-term financial sustainability by focusing on household and small-business customers alone (Peters et al., 2019; Pueyo & DeMartino, 2018). In rural SSA, the average consumption per mini-grid customer

tends to be very low, with limited ability to pay (AMDA, 2020, p. 37). Moreover, rural electricity demand tends to fluctuate alongside seasonal household income and so fails to match the regular expected demand estimate for the systems (Peters et al., 2019).

Various authors have therefore called for increasing and promoting productive users and facilitating access to appliances, e.g., water pumps, freezers, and milling machines, and fostering community engagement in order to stimulate demand, achieve a sizable and stable load, and ultimately the revenue streams of the developer (Bahaj & James, 2019; Sharma & Palit, 2020; Uamusse et al., 2020). To do this, ESMAP (2022, p. 8) argued that increasing the uptake of productive use equipment would require approximately $3.6 billion in affordable consumer finance.

The Key Maker Model (KMM), which combines mini-grid operations with an energy-intensive commercial activity, stands out among approaches to promote productive uses (Peterschmidt, 2019a) and has been pioneered by the Tanzanian mini-grid developer, JUMEME (Pueyo et al., 2022). Under the KMM, the mini-grid developer diversifies from electricity generation by offering only electricity with another complementary pre-processed good. This secondary business line is energy-intensive, e.g., manufacturing, often using the natural resources and supply chains already available in the community. For instance, the mini-grid company buys local agricultural products, processes them using electricity generated by the mini-grid, and transports them to be sold in urban areas. This way, the developer sets up a stable demand for the mini-grid while making profits further downstream (Peterschmidt, 2019a, p. 8). However, a key challenge of the KMM relates to the capacities and knowledge needed to operate a business beyond the mini-grid (Pueyo et al., 2022).

3.3.2.2 Anchor Business Consumer—A-B-C Model

The A-B-C model was first developed in India in association with the telecom sector (SEforAll, UKAID & TEA, 2024). Under this model, a large industrial customer with a high and stable load, such as an agro-processing or mining company that requires access to reliable electricity for their operations, or a group of industrials with reliable cash flows, act as an anchor client. The electricity supply for these customers is prioritized, followed by small productive users and households (ESMAP, 2022; Franz et al., 2014; Ramachandran et al., 2016). This model aims for stable

revenue that improves the sustainability of mini-grid operations, reducing the risk of connecting smaller consumers with lower payment capacity by lowering the unit cost of electricity (Beath et al., 2021). The mini-grid size may be defined primarily by the demand needs of the anchor load. Two examples include Sincro Sitewatch in Tanzania and Kirchner Solar in Uganda (EAPN, 2018; EEP, 2015).

While the main success factor of the A-B-C model is the long-term relationship with the anchor customer, prioritizing the demands of the anchor customer can limit the mini-grid capacity to extend connections and guarantee service reliability to smaller users, raising questions about the extent to which it will increase access to energy for low-income households (Bhati & Singh, 2018). Moreover, the lack of availability of large businesses in many rural areas may limit the scalability of this business model. The nature of this model could also lead to cherry-picking and neglect of poorer communities (EEP, 2015).

3.3.3 Cost Recovery Models

Business models can differ in their financial and organizational structure between for-profit, partially subsidized, and fully subsidized (Schnitzer et al., 2014). These business models also differentiate between commercial and noncommercial operated mini-grids defined by the approach to tariff revenue versus subsidized systems. The sustainability and inclusivity of cost recovery models depend on finding a balance between for-profit and subsidized approaches. When more grants and subsidies are provided, it results in lower tariffs, which, in turn, makes the service more affordable for end users.

3.3.3.1 For-Profit Model

The for-profit model refers to mini-grids that must cover their investment and operational costs through tariff collection. This model focuses on the customers' payment capacity, particularly looking at productive users (Schnitzer et al., 2014). For-profit models share the same commercial approach as the private ownership business model, as both require cost-reflective tariff structures (Schnitzer et al., 2014). This model therefore prioritizes medium- to large-sized electricity consumers and commu-

nities with greater demand and payment capacity. Concerns have been raised that the nature of this business model is unlikely to assist with access to energy for low-income consumers. Not least, the low payment capacity in many rural areas and the inability to apply cost recovery tariffs pose a challenge to the model's viability. The need for tariff subsidization has therefore been emphasized as a solution (Knuckles, 2016; Muchunku et al., 2018).

3.3.3.2 Partially Subsidized Model

There is a strong call in much of the literature for the need for subsidies to guarantee cost-reflective tariffs that match those of the utility. Approaches that involve the public sector as a stakeholder in mini-grid projects allow for the implementation of cross-subsidized tariffs.

The partially subsidized model is based on grants or subsidies from government electrification programs and DFIs for initial investment costs but relies on tariff collection to cover operations and maintenance. The social orientation of the funded capital requires that the mini-grid guarantee energy access to a pool of off-grid customers while assuring the tariff collection for its operation (Antonanzas-Torres et al., 2021; Schnitzer et al., 2014). Therefore, this model mixes the need for financial sustainability with the purpose of providing access to multiple types of customers. Facilitating affordable tariffs requires the mini-grid developer to innovate in the project's economic structure, for instance, allowing differential tariffs by type of customer, smart metering and pay-as-you-go (PAYGO) systems (Schnitzer et al., 2014). The most significant challenge for the viability of this model is its dependence on subsidized support and the risks of not offering a cost-effective and affordable supply.

3.3.3.3 Fully Subsidized Model

While the literature consulted argues strongly for the need for subsidies, the evidence is inconsistent on the level of assistance required and the best financial structures with which to channel it. Moreover, while financial support may allow for the setting of affordable tariffs, fully subsidized models may challenge developer autonomy and set a dependency on the donor.

The fully subsidized model covers all its costs through subsidies or grants from the government and DFIs, in-kind contributions from communities, and tariff collection to cover a percentage of the operation and maintenance expenses. This model follows the interest of the funding source, commonly targeting areas with low payment capacity or a remote or difficult-to-reach location, and often works with local communities to stimulate electricity demand (Schnitzer et al., 2014). Therefore, the developer allows a tariff structure that fits the affordability needs of the consumer rather than prioritizing cost recovery through tariff collection. The fully subsidized business model is similar to the community ownership models, as both are fully funded by a third party and focus on social impact over financial sustainability. This model depends on a clearly defined role for each party involved, strong engagement with communities to build local capacity and long-term engagement from donors (Schnitzer et al., 2014).

3.3.4 Bundling Models

Building an investment portfolio of mini-grids, which may involve bundling projects by location, operations, and/or financial structures can help lower costs and risks for developers and investors (Franz et al., 2014, Safdar, 2017; Weston et al., 2018). Bundling initiatives are attractive for private players and financial institutions due to their potential to help scale up the mini-grid market size, lower operational costs, and ensure economies of scale in project management, procurement, and installation (Bhattacharyya & Palit, 2016; ESMAP, 2022, p. 66).

3.3.4.1 Clustering and Operational Bundling

The clustering approach aggregates mini-grids in neighboring villages in order to provide an interlinked electricity market through distribution lines and smart control systems (Waswa, 2021). Mini-grids are bundled under an operational management structure to economize overheads, such as administration, maintenance, and transport costs (Franz et al., 2014; Safdar, 2017). The operation of a group of mini-grids in the same region can lead to lower installation costs per system and makes operation and maintenance activities more efficient (Moner-Girona et al.,

2018). As a result, DFIs are increasingly encouraging operators with proven track records to implement this model to accelerate scalability (ESMAP, 2022).

However, while clustering can help to lower the cost of capital for mini-grid operators and reduce transaction costs for investors, distribution remains a capital-intensive activity. Few investors have shown interest in paying for distribution costs in the SSA energy market, instead relying on the participation of utilities (Safdar, 2017; Weston et al., 2018). Moreover, there is little evidence about whether these approaches improve mini-grid profitability or whether regulatory frameworks are leaning toward creating a single structure through integrating mini-grids (Safdar, 2017; Sharma & Palit, 2020). Although this model establishes opportunities for economies of scale, the literature points to technological challenges and the need for strong managerial and operational skills to succeed, limiting its scalability capacity in SSA.

3.3.4.2 Portfolio Diversification and Financial Bundling

The financial bundling approach aggregates projects into an investment portfolio to reduce risk and encourage private investment. This approach is partly a response to the high-risk perception of investors toward the mini-grid sector (BNEF (2019); Weston et al., 2018). A portfolio of mini-grids diversifies the investment risk by matching investors with pooled funds of bundled mini-grid projects that can benefit from economies of scale, lowering the transaction costs and the capital costs per connection (ESMAP, 2019; Gershenson et al., 2015; Weston et al., 2018). Some authors suggest that portfolio diversification of mini-grids lowers the investment risks related to high transaction costs, market risks of investing in a single geographical jurisdiction, and the unfavorable risk-return profiles of many projects (Gershenson et al., 2015; Malhotra et al., 2017). This approach, they argue, can therefore reduce finance costs, increase the scale of the investment, and unlock the participation of new financiers. Alternative portfolio diversification strategies are identified in the literature, e.g., by geography (urban and rural), delivery models (EPC and energy as a service), and by sector (commercial, agriculture, and industrial) (Huber et al., 2021).

3.4 Access to Finance: Actors, Institutions, and Processes

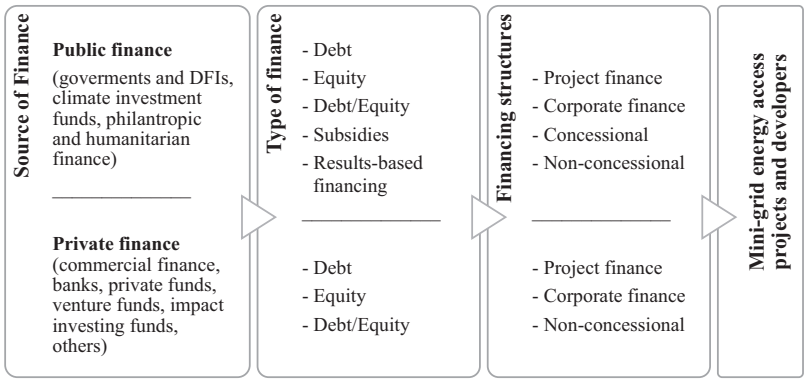
The lack of access to finance has been identified as one of the most significant obstacles to mini-grid expansion in developing economies, particularly SSA (Peterschmidt, 2019b; Phillips et al., 2020; Wang et al., 2020). As mentioned earlier, ESMAP (2022) has called for 380 million people in SSA to be connected to mini-grids by 2030 in order to help meet the targets of SDG7, for which an estimated $91 billion in investment will be needed. By 2021, about 60% of mini-grid financing in SSA came from governments and development partners (AMDA, 2022, p. 13), but according to ESMAP (2022), to reach the 2030 electrification goal, at least 50% of any future funding will need to come from private investment. While the involvement of DFIs has been critical in encouraging the private sector to participate in the market and helping it overcome some of the perceived risks due to lack of scale, developer track record, regulatory uncertainties, and limited electricity demand (BNEF, 2019), commercial financiers are calling for additional subsidies and guarantees over concessional capital. In SSA, grant and concessional capital deployment is not flowing at a rate that fully supports existing pipelines, impacting mini-grids' ability to scale, and limiting new commercial investments (AMDA, 2022, p. 14).

In addition, as previously discussed by IRENA (2015), there is a clash of perspectives between DFIs and project developers. While funding agencies indicate that there is no shortage of funding, developers state that they find it difficult and time-consuming to comply with all the procedures and checks required before any public funds can be approved. Accordingly, there is a problem with funds reaching the projects in a timely manner.

To understand the financial needs of the mini-grid sector, it is critical to look at the sources of finance available and the financing options and structures, which vary among public and private institutions (see Fig. 3.2). DFIs have been the most prominent players in the sector to date.

As debt has increased its participation in the sector in the last few years, equity has declined (ESMAP, 2022). While the increasing availability of debt suggests that the mini-grid sector is maturing, debt finance remains expensive and often carries an interest rate of 15% or more for developers in SSA (Agenbroad et al., 2018). Therefore, the financial sustainability of developers still relies on subsidies at different stages of project development. The evidence from the literature is strong and consistent in suggesting that no unique source of finance can overcome

Figure 3.2: Phases of Access to Finance



Source: Authors' own analysis based on relevant literature cited in this section.

all the barriers and risks of the mini-grid sector (Bahaj & James, 2019; BNEF (2019).; Weston et al., 2018). Likewise, the scalability of mini-grids requires different financing packages combining equity, debt, subsidy, and de-risking mechanisms according to the needs of different mini-grid business models.

According to BNEF (2020), increasing the availability of long-term equity and debt in mini-grid projects through project finance is required to move forward a mature, decentralized energy market in SSA where developers can access financing to continue developing projects. As mini-grids are typically built on the developer's balance sheet, the investor is exposed to all other risks that the company faces (BNEF, 2019). Isolating mini-grid assets from the companies that own and operate them, and allocating the infrastructure and operational risks to the developer, allows for the aggregation of mini-grid assets into large, diversified portfolios that can attract long-term equity and debt (Huber et al., 2021).

3.4.1 Sources of Finance: From Public and Private

Public funding from governments and DFIs plays a key role in supporting the scalability of the mini-grid sector by providing grants, subsidies, concessional loans, and loan guarantees (BNEF, 2019). Indeed, in SSA, public finance for up-front capital investment in mini-grids has increased in the

last decade (ESMAP, 2022; Hosier et al., 2017). By 2021, in SSA, 60% of mini-grid funding has been from national and international sources (AMDA, 2022, p. 13). Fifteen international DFIs and development partners have collectively committed more than $2.4 billion for mini-grid development in SSA to date, excluding funding to governments for technical assistance and research (ESMAP, 2019, 2022). Of this funding, which has largely focused on energy access, the World Bank accounted for 25% by 2021 (ESMAP, 2022). However, DFIs' funding for mini-grids is observed to lean toward countries with active private-sector involvement and a robust legal and regulatory framework that supports mini-grid development, including Tanzania, Rwanda, and Nigeria (Bukari et al., 2021; Odarno et al., 2017). Countries with higher market entry barriers for private players and lower electricity demand, therefore, find it harder to secure finance from DFIs. The lack of coordination between bilateral and multi-lateral DFIs for mini-grid programs has also been raised as a problem (Dye, 2020).

As an infrastructure development activity with high up-front capital costs, the mini-grid sector requires patient, long-term capital with low return expectations. However, the low volume of transactions and high-risk perception of the projects have discouraged private sector investment. Moreover, the tenure of private debt capital is usually too short for the nascent mini-grid market, and the "bridging capital" (i.e., capital with high-risk appetite, low return expectations, and long tenure) is missing (Bhattacharyya, 2018). Public-sector financing structures are therefore essential in encouraging private sector participation in mini-grids by decreasing perceptions of investment risk (REPP & AMDA, 2023).

Compared to public-sector finance from governments, DFIs, and climate investment funds, there has been limited private investment for mini-grids in SSA (and indeed elsewhere). Most private investment in the mini-grid sector has been made possible through parallel support from de-risking mechanisms with DFIs, given that grants and subsidies from governments or DFIs can increase confidence in future cash flows for private investors (Bukari et al., 2021; Weston et al., 2018). For instance, in Tanzania, the World Bank's International Development Association (IDA) has provided risk guarantees to mini-grid investors.

Private investors, including commercial banks, private equity funds, venture capital funds, and impact investors, among others, have invested in the mini-grid sector through equity, debt, and grant structures. In recent years, impact investors, such as Acumen, Bamboo

Capital Partners, Cross-boundary Energy, and InfraCo Africa, have increased their commercial interest in supporting mini-grids while recognizing the project's social impact and are therefore willing to accept lower-than-market returns. Sometimes, they offer loans at single-digit interest rates, lasting up to 10 years (BNEF (2019), p. 94).

3.4.2 Type of Finance

Developers face various barriers and challenges in accessing the different types of funding, as summarized below. While the shift toward private participation in mini-grid development increases the call for equity participation, debt and grant alternatives from multilateral DFIs represent an essential block for lowering the risk perception of equity investors.

3.4.2.1 Debt

There are two main types of debt finance: commercial loans and concessional loans. While commercial debt is often provided by local and regional banks, usually at double-digit interest rates, with shorter repayment terms, concessional debt is often provided by national energy agencies and DFIs at lower, sometimes single-digit, interest rates and for more extended periods (Baker, 2022; BNEF (2019), p. 94).

Developers face a significant obstacle in many SSA countries due to the reluctance of commercial banks to provide affordable debt finance to mini-grid projects. This reluctance often stems from a lack of mini-grid knowledge by the banks, meaning that they perceive mini-grids as a financially risky endeavors (ESMAP, 2022; Odarno et al., 2017). In addition, in many SSA countries, local banks lack sufficient technical expertise to conduct due diligence and project appraisals, which increases the interest rate and capital costs for the developer (UNDP, 2018). Consequently, access to debt through local banks often requires additional support from financial institutions that provide guarantees to the lender.

Access to commercial debt finance is easier for private investors with previous track records and suitable balance sheets (Baker, 2022). In contrast, a small community-owned project will struggle to meet the lending requirements. The organization may have no formal standing, no previ-

ous credit record, very limited own funding, and hardly any security for loan guarantee purposes. This limits the ability of such organizations to integrate with the mainstream capital market and to ensure the financial sustainability of their projects (Bhattacharyya, 2018). Moreover, given that developers must always repay loans regardless of performance, such a risk is often too great for a smaller actor.

In some instances, governments and DFIs offer concessional loans to help mini-grid developers address the risk perception of commercial lenders, so that commercial lenders can be repaid first (ESMAP, 2022). However, accessing concessional loans can involve relatively complex due diligence and high transaction costs, making it more accessible for larger projects and mature developers and very difficult for small and local developers (Weston et al., 2018). There are further challenges to obtaining concessional debt. For instance, lenders prefer to finance developers with existing operating assets or those with a proven track record. As with commercial debt, there is a preference for "high-impact" projects, limiting funds for early-stage developers. Concessional loans are often difficult to obtain and require a long time to process, as well as having onerous requirements for implementation, management, oversight, and reporting. Such challenges can make it impossible for a smaller developer to access even concessional debt despite the lower interest rates.

3.4.2.2 Equity

Thus far, the majority of equity investment in mini-grids has come from impact investment funds (ESMAP, 2022; Safdar, 2017), as discussed in Section 4.1, though other sources include funds from project developers, corporate sponsors, and commercial investors. Raising equity for mini-grids in most markets in SSA is challenging due to unproven business models and a lack of guarantees over investment returns (BNEF, 2019).

As indicated in Figure 3.2, mini-grid developers can either raise equity and/or debt through multiple financing structures, including project finance and corporate finance. The choice between the two depends on the developer's financial strategy and the nature of the funding requirements. Project finance targets the financing needs of a single project and structures the financing around the cash flows generated by that project. Corporate finance raises equity and/or debt at the company level and

involves using the company's overall assets to secure returns for investors and creditors rather than solely relying on the revenues generated by a specific project (Baker, 2022). While project finance is primarily available for larger projects run by developers with a well-established track record, smaller projects are more likely to use corporate finance. However, project finance requires project aggregation at different levels to achieve bankable projects with guaranteed cash flows. Neither is easy to achieve (REPP & AMDA, 2023).

The key challenges to accessing and managing equity investment include: uncertainty about future macroeconomic conditions, which discourages investment; developers often cannot charge fully cost-reflective tariffs because many potential consumers cannot afford to pay, reducing their investment recovery capacity; as with commercial lenders many potential private investors lack experience with mini-grids, considering them too risky; and despite the long-term nature of a mini-grid project, some investors may still expect more immediate and short-term returns.

3.4.2.3 Subsidies

SSA's mini-grid sector needs some degree of subsidy to bridge the gap between the high cost of infrastructure and the low incomes of the communities they serve (AMDA, 2022). Subsidies, which are often provided by DFIs and administered by the government, can be provided during different stages of a mini-grid project: CAPEX subsidies cover up-front capital costs, while demand-side subsidies may also be required to match affordability in rural and densely populated communities (see Table 3.5). CAPEX subsidies may also support the construction and user connections as a substitute for debt and equity funding. While making mini-grids a viable option for electrification requires significant subsidies to achieve a cost-reflective tariff regime for developers that also matches the ability to pay for end users (Weston et al., 2018), there are numerous challenges to accessing them. First, subsidies are limited in availability, subject to stiff competition, and allocated in small amounts as compared to the total investment costs. The process to access them has high transaction costs, usually lacks transparency, and is highly bureaucratic; and providers of subsidies often impose conditions that may limit the developer action plan.

Table 3.5: Types of Subsidies

Subsidy	*Description*
Pre-investment subsidies	*Pre-investment subsidies are provided to support market and resource assessments, geospatial planning, pre-feasibility and feasibility studies, and technical assistance (ESMAP, 2019). This type of subsidy is available primarily through DFIs.*
Up-front capital subsidy	*This type of subsidy is necessary to cover mini-grid's high initial investment costs. The CAPEX subsidy is disbursed before the mini-grid installation, and calculated based on installation cost, the number of connections, and the internal project rate of return (IRR) (Franz et al., 2014). Up-front grants have been the most common subsidy for mini-grids (ESMAP, 2019).*
Demand-side subsidies	*Demand-side subsidies target the tariff structure, such as lifeline tariffs, and provide subsidies to customers for purchasing energy-efficient appliances and productive equipment. These subsidies are available through government programs and electrification plans. Subsidizing the demand enables more extensive electricity use while improving the mini-grid's revenues (ECA & AMDA, 2020).*

Source: Authors' compilation based on relevant literature cited in this section.

3.4.2.4 Results-Based Financing

Results-based financing (RBF), also known as performance-based grants, provides a subsidy according to the number of successful connections met by the mini-grid BNEF (2019). RBF has been given by DFIs to mini-grid entrepreneurs, and some governments are also starting to adapt this mechanism. RBF is perceived to provide greater control and certainty over the project, and to reduce the risks of early-stage financing, providing a mechanism to combine commercial funding with subsidies, where the former provides the initial investment costs with the guarantee of returns after installation (Bukari et al., 2021; ECA & AMDA, 2020).

In SSA, RBF emerged in 2019 in six African countries: Nigeria, Algeria, Ethiopia, Mali, Burkina Faso, and Togo, led by DFIs (Antonanzas-Torres et al., 2021). For example, Nigeria's performance-based grant (PBG) program has made $150 million available to mini-grid developers, offering between $350 and $600 per new connection with a minimum total grant of $10.000 per mini-grid (ESMAP, 2019). This program was launched in 2018 as part of the Nigerian Electrification Project (NEP), supported by the World Bank and the AfDB, which aims to increase the participation of hybrid solar mini-grids in 250 designated sites, with a total budget of $48 million (BNEF (2019), p. 130).

3.5 Exploring Key Risks and Challenges

The literature on mini-grid business models indicates that success is highly context-specific depending on internal and external challenges (BNEF, 2019), where the former includes project-specific aspects that the mini-grid developer can control or avoid, and the latter are uncontrollable for the developer, exogenous, and inherent to a specific market or country.

Investment risks in mini-grids relate to factors that reduce the developer's probability of having sufficient cash flow to repay the debt or meet the expected return (BNEF (2019); EEP, 2015; ESMAP, 2020). Thus, the risks associated with mini-grid projects in SSA are often not aligned with the risk-return expectations of international investors. While improvements in technology and the involvement of DFIs in the mini-grid sector have reduced perceptions of investor risk, the absence of proven business models and market challenges has increased it (BNEF (2019); ESMAP, 2022). Achieving the industry call to increase private sector investment in mini-grids requires reducing the internal and external challenges that raise the investors' risk perception and addressing the developers' barriers to affordable financing. The main areas of risk are summarized in Table 3.6 and discussed in more detail below.

3.5.1 External Risk for Mini-Grids

3.5.1.1 Regulation and Market Access

A lack of policy and regulation for mini-grid development and indeed in electricity governance more generally is perceived as the most sig-

Table 3.6: Summary of Risks and Challenges for Mini-Grids

Risks and Challenges		*Elements*	*Coping Mechanisms*
External Risks	*Regulation and market access*	*Licensing processes* *Tariff-setting rules* *Rules for main grid arrival and mini-grid integration*	*Reduce the sizing of mini-grids* *Bundling mini-grids into portfolios* *Grid-interconnection ready technologies*
	Demand uncertainty and poor forecasting	*Lack of accurate demand data* *Errors in sizing the mini-grid*	*Use technology to improve data reliability* *Stimulate productive uses of electricity* *De-risking finance mechanisms*
	Country and macroeconomic risks	*Inflation* *Currency mismatch between funding and revenues* *Exchange-rate fluctuations*	*Use long-term currency volatility assessment* *Access and availability of credit in local currency*

Table 3.6 (Continued)

Internal Risks	*Customer credit and nonpayments risk*	*End users' limited and unpredictable income* *Enforcement of payment collection mechanisms*	*Prepaid collection methods (e.g., PAYGO)* *Smart metering systems* *Financing for productive equipment*
	Governance risk	*Developer's track record and expertise* *Transparency and monitoring*	*Clear accounting and reporting mechanisms* *Integration of ESG standards*
	Labor risk	*Lack of a skilled local workforce* *Lack of adequate technical resources*	*Investing in local operations and management capacity* *Ensuring the supply of quality spare parts*
	Community engagement challenges	*Risk of nonacceptance due to public opinion, lack of transparency, and low local workforce involvement* *Low social perception of the service*	*Implementing clear communication channels* *Involvement of traditional authorities and local champions* *Timely available information on tariffs and service*

Source: Authors' compilation based on relevant literature cited in this section.

nificant challenge by developers and investors (AfDB, 2016; AMDA, 2022; BNEF (2019)). In 2014, most countries in SSA lacked specific policies for mini-grids in their national electrification plans (EEP, 2015), for which reason mini-grid development in the region has often occurred without national regulation (Baker et al., 2022). However, in some countries this has shifted in recent years, including in Nigeria, Kenya, and Tanzania.

Obtaining licensing or authorization for mini-grids is often a lengthy and bureaucratic process lacking in clarity, particularly in countries where mini-grid developers are governed and regulated by the same institutions that oversee national utilities. For instance, as AMDA explores, the requirement in many countries that each mini-grid project go through the same licensing process as a grid-connected, utility-scale project creates a heavy burden on mini-grid developers and can serve as a barrier to access (AMDA, 2020).

Critical areas of regulatory risk include market entry procedures, rules for tariff setting, and policies relating to the arrival of the main grid into the vicinity of the mini-grid (see Table 3.6, BNEF (2019); ESMAP, 2022; SE4ALL & AfDB, 2019). In certain countries in SSA, national and/or local regulations may prevent or inhibit cost-reflective tariffs for mini-grids, as is the case, for instance, in Senegal, which reduces cost recovery options for developers (Weston et al., 2018). Investment uncertainty is further increased by the unpredictability of tariff policy, which may result from changes in government and political pressure from vested interests (Baker et al., 2022; Gershenson et al., 2015).

Perhaps the most significant concern for investors and developers is the risk that the utility may extend the national grid to the community being served by the mini-grid, particularly in countries where there is no regulation or compensation for such circumstances (Baker et al., 2022; ECA & AMDA, 2020; Muchunku et al., 2018). The uncertainty as to whether or not developers will be able to recoup their investment in the case of grid arrival may pose as a deterrent (Bukari et al., 2021). One possible way to mitigate this risk is for developers to ensure that their systems are technically capable of connecting with the main grid and other mini-grid projects, though this would still require mini-grid operators to be able to lease the distribution assets of the centralized utility. Consequently, the literature calls for policy guarantees that provide clear conditions about operating alongside the main grid and compensation schemes (Tenenbaum et al., 2014).

3.5.1.2 Demand Uncertainty and Poor Forecasting

Low demand is one critical element of risk for both developers and investors. Developers use demand estimates to inform the sizing and design of the mini-grid and thus, to secure financing. However, as mentioned in Table 3.6, errors in assessing the electricity demand can lead to forecasting errors and revenue deficits, directly affecting investment returns (Peters et al., 2019). Given that demand for mini-grid electricity varies widely within and between countries, estimating demand remains challenging for developers (ESMAP, 2022, p. 81). It is also difficult to accurately project the future electricity demand of a mini-grid before electrification (Bahaj & James, 2019; Hartvigsson et al., 2021).

The lack of familiarity with electricity provision, use, and cost in rural communities is challenging for data reliability (Bahaj & James, 2019). As a result, the load profile assessment might not reflect the reality of electricity consumption, increasing the risk of under- or oversizing the mini-grid. While large mini-grids increase the initial and operational costs, a smaller generation capacity may decrease the quality of service for the end user (Hartvigsson et al., 2021). There are various options to mitigate such risk. First, a geospatial approach using geographic information system (GIS) software and associated web-based and mobile technologies can be used to perform more accurate site assessments and extend the availability of data (ESMAP, 2019). Second, encouraging income-generating activities through the financing of productive use appliances, or tariffs that encourage electricity consumption for productive use (ECA & AMDA, 2020). Finally, the provision of concessional loans from DFIs, which guarantee repayment first to private investors, can help de-risk some of the demand uncertainty, as discussed in Section 3.4.2.

3.5.1.3 Political and Macroeconomic Risks

Country-specific risks, including political instability, social unrest, and macroeconomic conditions such as currency risks and inflation, extend beyond the context of any individual mini-grid project (see Table 3.6, Baker, 2022). However, they are likely to increase the cost of capital for mini-grid developers who will also need to demonstrate their capacity to minimize these risks when possible (ESMAP, 2019; Malhotra et al., 2017).

International valuations of country risks, such as the Marsh World Risk Review (2021) and the World Bank Doing Business Ranking (2021), offer initial assessments for international investors. However, conducting thorough due diligence on a project remains crucial for making investment decisions (ESMAP, 2019). While political risk assessment examines a country's fiscal and monetary policies, legal and regulatory challenges, and social unrest risks, the Doing Business Ranking measures the ease of starting a business in a specific country (see Table 3.7). A comparison based on the Doing Business Ranking indicates that Kenya, for example, provides a more favorable regulatory environment and lower country risk than Tanzania, given the latter's business environment and regulatory framework.

In summary, country-specific risks and broader economic conditions

Table 3.7: Doing Business Ranking 2020

Country	*Global Rank (total 190)*	*Rank within SSA (total 48)*
Kenya	56	3
Nigeria	131	17
Senegal	123	16
Tanzania	141	22

Source: Authors' own, adapted from Doing Business Ranking (World Bank, 2020).

can impact the feasibility and financing costs of mini-grid projects, and thorough due diligence is essential to assess investment viability in a specific context.

Returning to the risks in Table 3.6, inflation significantly affects tariff setting for mini-grids, directly impacting the developer's operational costs, revenue, and the financial sustainability of the investment (Odarno et al., 2017). Developers are usually not allowed to change their tariffs once the tariff schedule has been approved and must therefore adjust tariffs to allow for inflation at the outset (ESMAP, 2020; Ilskog & Kjellström, 2008). Local currency depreciation will also impact financing and revenue costs, given that most mini-grid financing in SSA is in a foreign currency, such as dollars or euros, while revenues are received in local currency over the lifespan of the project of approximately 20 years (Franz et al., 2014; Gershenson et al., 2015). Foreign investors and debt financiers will

therefore look at the long-term exchange rate to assess currency volatility risk. Although international hedging tools are available, e.g., locking the exchange rate in for all or part of the duration of the investment, this option would increase the cost of capital for developers. Avoiding those risks requires credit availability in local currency, which is still limited in SSA (see Section 3.4.2).

3.5.2 Internal Challenges for Mini-Grids

3.5.2.1 Customer Credit and Nonpayment Risk

Penetration of third-generation mini-grids has grown based on increasing consumer demand for electricity services, as well as innovations in telecommunications, which have enabled the rise of smart metering and PAYGO models for small-scale systems (Baker et al., 2022; BNEF (2019)). Although data that has been enabled from new technologies provides lenders and investors with more confidence regarding the end-user payment capacity and affordability, mini-grids are still exposed to credit risk and nonpayment by end users (GOGLA, 2019). In addition, the high up front cost of connection and payment for the electricity service poses an entry barrier for the most vulnerable customer. The willingness and/or ability to pay often becomes a challenge when mini-grid tariffs are compared to tariffs from the main grid, or the community expects assistance programs that provide lower-cost electricity access (Peters et al., 2019; Schmidt et al., 2013). Some low-income households in SSA may not be able to budget for high and regular energy costs, particularly as compared to traditional energy sources such as kerosene (Inensus in AfDB, 2016; Bahaj & James, 2019).

In addition to the introduction of PAYGO systems, prepaid electricity metering schemes have also been introduced in mini-grid design and implementation, including in Kenya, Tanzania, Uganda, Nigeria, and Rwanda, with the aim of addressing nonpayment risk, reducing the operational costs of the individual collection of payment, and providing greater transparency for the consumer on electricity use and costs (Bahaj & James, 2019; IEA, 2022; Jack & Smith, 2015). Third-generation mini-grids are already integrating smart meters that provide prepaid options for end users while incentivizing customers to use efficient household appliances and equipment for income-generating activities (ESMAP,

2022, p. 69; Niyonteze et al., 2019). For productive users with limited or seasonal cash flows, waiving the flat rate standing charge and facilitating access to credit for equipment would reduce their credit risk. Mini-grid developers could partner with financing agencies or equipment sellers to support access to credit for productive equipment. Therefore, strategies to decrease credit risk must also reflect the needs of both households and productive users in terms of an affordable tariff structure and workable payment collection method.

3.5.2.2 Governance Risk

The literature review on business models suggests that investors consider governance concerns from the experience of the mini-grid developer in decision-making, and monitoring (Franz et al., 2014; Peters et al., 2019). Investors require that developers internalize the feasibility assessments, fulfill the technical standards, and set transparent accounting and reporting mechanisms (ESMAP, 2022). In addition, the developer's track record is essential to access finance and improve scalability, given that, as companies develop more expertise, they become more attractive in investment terms for equity and debt investors (BNEF, 2019). Finally, integrating environmental, social, and governance (ESG) standards facilitates the governance risk assessment and reduce potential conflict of interest between financiers and developers (IEA, 2022).

3.5.2.3 Labor Challenges

The need to develop appropriate human capital for the scale up of third-generation mini-grids is often challenged by the lack of a skilled local workforce, particularly given the geographical remoteness of the systems (ESMAP, 2022, p. 287). Mini-grid developers are usually required to integrate capacity building with community engagement strategies in order to train local staff to carry out operation and maintenance, thereby reducing the need for external support and lowering the project's operational costs (Duran & Sahinyazan, 2021; Lillo et al., 2015). In some countries, support is provided for capacity building of local technicians, for instance, in Tanzania by the Rural Energy Agency.

The lack of adequate technical resources, such as spare parts in the local market and poor quality of components, adds to the labor risk and challenges, increasing the reliance on external consultants and suppliers and raising the operational cost of the project (Azimoh et al., 2017; Sharma & Palit, 2020; Yadoo & Cruickshank, 2012). Therefore, investing in operations and management capacity building, training at a local level, and ensuring the supply of spare parts in the medium and long term is essential to reduce the labor and technical skills risk for mini-grids.

3.5.2.4 Community Engagement Challenge

Inadequate or inappropriate community engagement can create socio-economic challenges, which in turn affects the successful implementation of a project by undermining local support, reducing electricity demand from the end users, and increasing the risk of local disputes and nonpayment (Malhotra et al., 2017). Unfavorable public opinion, lack of transparency, insufficient local workforce involvement, and poor local capacity development are some of the elements that can contribute to the risk of nonacceptance of the mini-grid (Franz et al., 2014). Misleading information regarding tariffs and/or the reliability of the service will also create mistrust of the energy provider and the system among users, who in turn are more likely to miss payments (Lillo et al., 2015; Peters et al., 2019). Potential challenges may also arise from business models that prioritize commercial users and limit access to energy for low-income customers, thereby exacerbating existing inequalities in access to electricity.

All of these challenges highlight the importance of addressing the communities' needs, concerns and expectations in mini-grid development, adopting a holistic approach to providing energy access to low-income consumers, and ensuring equitable electricity distribution. As Duran and Sahinyazan (2021) explore, working with local authorities and including local champions to connect the community to the mini-grid helps to reduce reputational risks. Likewise, providing accessible and continuous communication regarding the tariffs and the service strengthens trust. Effective community engagement is a challenge for mini-grid developers (Chaurey et al., 2012), for which reason, ESMAP (2022) argues that it is important to involve them in every phase of the mini-grid project.

3.6 Conclusion

The positive narrative with regards to the key role that third-generation mini-grids can play in achieving SDG7 goals in SSA has so far come mainly from the private sector and DFIs. Consequently, the industry calls for further private sector participation in third-generation mini-grids in SSA, especially to reach rural, dispersed, and densely populated communities with high demand levels. In this review, we have explored the various different mini-grid business models that currently exist; the main actors, institutions, and processes involved in accessing finance for third-generation mini-grids; and some of the key investment risks and challenges to the further deployment of mini-grids in the region. We find that various mini-grid business models exist to support advancing universal electrification in the region, which may vary by ownership, cost recovery, customer focus, and implementation strategy. While evidence from the literature points to hybrid ownership, the role of subsidies, the inclusion of anchor customers, and financial bundling portfolios as promising business strategies, there is no gold-standard business model for mini-grid development that is financially sustainable, scalable, and replicable. Mini-grid business models are still evolving and adapting to various economic, social, and political variables. Their success and scalability are context-specific and depend on multiple internal and external challenges.

The lack of quantitative analysis on mini-grid financial performance makes it difficult to know whether specific approaches to the mini-grid business model will have more or less sustainable outcomes. Mini-grid experiences across the region suggest that balancing affordable service provision with acceptable cost recovery remains difficult to achieve (Bhattacharyya et al., 2019; Moner-Girona et al., 2018; Pueyo & DeMartino, 2018). While financial sustainability is often considered the most significant challenge for mini-grid expansion, this is affected by other critical factors that drive the risk perception of financiers, including regulatory uncertainties, tariff regulation, low electricity demand, and low payment capacity in rural communities. With this in mind, we now offer the following five conclusions.

First, the categorization of business models is very diverse. Each of the models explored sheds light on the different success factors (see Section 3.3). However, the literature has focused on the nature of ownership. Operations are led either by the public utility, the private sector, the community, or a blended approach where both governments and private developers have shared obligations. All of these approaches have been shown to work

under different circumstances. In Tanzania, for example, the deployment of mini-grids based on PPPs in rural areas has been quite successful. However, contrary to the dominant narrative that prioritizes private models away from monopoly utilities, expanding energy access depends on identifying the right balance between private and public ownership and control, as a private sector approach does not necessarily make electricity more accessible and affordable for users at the last mile.

Second, a mini-grid focused on cost recovery would require that operation and maintenance costs be recovered from tariffs and/or targeted public subsidies that allow remote and rural populations to access electricity at the same subsidized price as their urban counterparts. There is therefore a balance to be struck between private competitiveness and public support. As regards the customer-focused approach, the literature suggests that one way to make the mini-grid business model viable would be to pursue an A-B-C model that provides a consistently high load to cover investment and operational costs. Long-term contracts with anchor clients can guarantee a large portion of mini-grid revenue, improve the project's financial sustainability, support up-front fees, and help attract long-term financing. However, the lack of anchor customers in SSA challenges the viability of this model, which explains DFIs' interest in stimulating and supporting productive use. Moreover, the literature is still incipient and contradictory on the impact of productive use mini-grids on income generation. Finally, the literature suggests that operational and financial bundling of mini-grids is a potential solution for the challenges of economic sustainability because it can create economies of scale, reduce transaction costs, and promote diversification of risks. However, the lack of examples in the literature limits the ability to conclude the scalability of this model in SSA.

A third conclusion relates to access to finance as a key challenge. The evidence presented in the literature is clear that no unique source of finance can overcome all the barriers and risks of the market. Moreover, the scalability of the mini-grid sector requires different financial arrangements combining grants, equity, debt, subsidy, and de-risking instruments. The literature consistently suggests that most mini-grid developers require grants for the initial stages, such as construction, installation, and user connection. Thus far nonreimbursable grants to fund CAPEX for mini-grids under rural electrification programs have been the most committed financing for the sector in developing countries. In contrast, some developers have also raised debt or equity from either foundations or commer-

cial finance, which requires them to show a certain level of return from their business operations and minimize risk.

Fourth, the literature indicates that the success of a mini-grid project is highly context-specific and dependent on internal and external challenges. The former includes project-specific aspects that the mini-grid developer may be able to control or influence, while the latter are beyond the control of the developer and often inherent to a specific market or country. According to the literature reviewed, the greatest risks and challenges in the SSA mini-grid sector relate to regulation and market access, followed by the risk of grid arrival, and the lack of a sizable and stable demand. The risks associated with mini-grid projects in SSA countries are mostly external, leaving the investor's risk perception as the risk the developers face and need to overcome. The lack of proven business models increases the risk perception from commercial investors that interpret the lack of coping mechanisms as a lack of expertise in the sector. Thus, the high requirements regarding the developer's track record and collaterals from financiers reflect an imbalance between financial expectations of returns and the challenges mini-grid developers face. These conditions prioritize larger, mature, and often international developers, limiting opportunities for local mini-grid endeavors. Thus, achieving the industry call to increase private sector investment in mini-grids requires reducing the internal and external challenges that raise the investors' risk perception and coping with the developers' barriers to affordable financing.

Finally, the gray literature in particular points to macroeconomic challenges, nonpayment risk by mini-grid customers, and governance, social, and technical challenges. But this literature has primarily built on qualitative analysis, and there are few publicly available quantitative assessments of the impact of those risks on the profitability of mini-grids. A deeper critical and comparative analysis of different business models' coping mechanisms could therefore help to understand the complex success factors that could define the most sustainable approach to mini-grids.

References

AfDB. (2016). Green mini grids in sub-Saharan Africa: Analysis of barriers to growth and the potential role of the African Development Bank in supporting the sector, Energy 4 Impact. African Develop-

ment Bank. https://www.energy4impact.org/sites/default/files/2024-09/pdf_green_mini-grids_a4_version_finale.compressed.pdf

Agenbroad, J., Carlin, K., Ernst, K., & Doig, S. (2018). *Mini grids in the money: Six ways to reduce mini grid costs by 60 per cent for rural electrification.* Rocky Mountain Institute.

AMDA. (2020). *AMDA's benchmarking Africa's Mini grids Report 2020*. Africa Minigrid Developers Association.

AMDA. (2022). *AMDA's benchmarking Africa's Mini grids Report 2022*. Africa Minigrid Developers Association.

Antonanzas-Torres, F., Antonanzas, J., & Blanco-Fernandez, J. (2021). State-of-the-art of mini grids for rural electrification in West Africa. *Energies*, *14*(4), 990. https://doi.org/10.3390/en14040990

ARE. (2014). *Hybrid mini grids for rural electrification: Lessons learnt*. Alliance for Rural Electrification.

Azimoh, C. L., Klintenberg, P., Mbohwa, C., & Wallin, F. (2017). Replicability and scalability of mini grid solution to rural electrification programmes in sub-Saharan Africa. *Renewable Energy*, *106*, 222–231. https://doi.org/10.1016/J.RENENE.2017.01.017

Bahaj, A., & James, P. (2019). Electrical minigrids for development: Lessons from the Field. *Proceedings of the IEEE*, *107*(9), 1967–1980. https://doi.org/10.1109/JPROC.2019.2924594

Baker, L. (2022). Procurement, finance, and the energy transition: Between global processes and territorial realities. *Environment and Planning E: Nature and Space*, *5*(4), 1738–1764.

Baker, L., Sesan, T., Bhattacharyya, S., Pueyo, S., Bukari, D., Meena, S., Onsongo, E., Oyinlola, M., Sawe, E., Otu-Eleri, E., Uduka, U., Handem, Y., Onjala B., & Katyega, M. (2022). *Of monopolies and mini grids: Case studies from Kenya, Tanzania, Nigeria, and Senegal*. University of Sussex. Journal contribution. https://hdl.handle.net/10779/uos.23490773.v1

Beath, H., Hauser, M., Sandwell, P., Gambhir, A., Few, S., Chambon, C. L., & Nelson, J. (2021). The cost and emissions advantages of incorporating anchor loads into solar mini grids in India. *Renewable and Sustainable Energy Transition*, *1*, 100003. https://doi.org/10.1016/J.RSET.2021.100003

Bhati, P., & Singh, M. (2018). *Mini grids in Uttar Pradesh: Policy lessons*. Centre for Science and Environment.

Bhattacharyya, S. C. (2018). Mini grids for the base of the pyramid market: A critical review. *Energies*, *11*, 813. https://doi:10.3390/en11040813

Bhattacharyya, S. C., & Palit, D. (2016). Mini grid based off-grid electrification to enhance electricity access in developing countries: What policies may be required? *Energy Policy*, *94*, 166–178. https://doi.org/10.1016/J.ENPOL.2016.04.010

Bhattacharyya, S. C., Palit, D., Sarangi, G. K., Srivastava, V., & Sharma, P. (2019). Solar PV mini grids versus large-scale embedded PV generation: A case study of Uttar Pradesh (India). *Energy Policy*, *128*, 36–44. https://doi.org/10.1016/J.ENPOL.2018.12.040

BNEF (2019). Solar for businesses in sub-Saharan Africa. https://data.bloomberglp.com/professional/sites/24/BNEF_responsAbility-report-Solar-for-Businesses-in-Sub-Saharan-Africa.pdf.

Bukari, D., Kemausuor, F., Quansah, D. A., & Adaramola, M. S. (2021). Towards accelerating the deployment of decentralised renewable energy mini grids in Ghana: Review and analysis of barriers. *Renewable and Sustainable Energy Reviews*, *135*, 110408. https://doi.org/10.1016/J.RSER.2020.110408

Chaurey, A., Krithika, P. R., Palit, D., Rakesh, S., & Sovacool, B. K. (2012). New partnerships and business models for facilitating energy access. *Energy Policy*, *47*(1), 48–55. https://doi.org/10.1016/J.ENPOL.2012.03.031

Duran, A. S., & Sahinyazan, F. G. (2021). An analysis of renewable mini grid projects for rural electrification. *Socio-Economic Planning Sciences*, *77*, 100999. https://doi.org/10.1016/J.SEPS.2020.100999

Dye, B. (2020). *Rwanda's electricity boom and the danger of too much power*. The Policy Practice.

EAPN. (2018). *Interview with Wim Jonker Klunne, Lead Coordinator of EEP Africa*. The Energy Access Practitioner Network.

ECA & AMDA. (2020). *Benchmarking Africa's Minigrids*. Nairobi.

ECREEE. (2016). *Mapping and assessment of existing clean energy mini grid experiences*. ECOWAS Regional Centre for Renewable Energy and Energy Efficiency. https://www.ecreee.org/wp-content/uploads/2024/01/100117_comprehensive_ecreee_report_hobson_eseoghene.pdf

EEP. (2015). Opportunities and challenges in the mini grid sector in Africa lessons learned from the renewable and sustainable energy reviews. *The Energy and Environment Partnership covering Southern and East Africa*, *10*, 246–258.

ESMAP. (2019). *Mini grids for half a billion people: Market outlook and handbook for decision makers*. Energy Sector Management Assistance Program, Technical Report 014/19. World Bank.

ESMAP. (2022). *Mini grids for half a billion people: Market outlook and handbook for decision makers*. Energy Sector Management Assistance Program. World Bank.

Franz, M., Peterschmidt, N., Rohrer, M., & Kondev, B. (2014). *The Mini grid Policy Toolkit*. https://www.ren21.net/Portals/0/documents/Resources/MGT/MinigridPolicyToolkit_Sep2014_EN.pdf

Gershenson, D., Tilleard, M., Cusack, J., Cooper, D., Monk, A., & Kammen, D. (2015). Increasing private capital investment into energy access: The case for mini grid pooling facilities. *United Nations Environment Programme*, pp. 1-97, *28*(1).

GOGLA. (2019). *Investing in the off-grid solar sector: What you need to know*. Global Association for the Off-grid Solar Energy Industry. https://www.gogla.org/reports/investing-in-the-off-grid-solar-sector-what-you-need-to-know/

Hartvigsson, E., Ehnberg, J., Ahlgren, E. O., & Molander, S. (2021). Linking household and productive use of electricity with mini grid dimensioning and operation. *Energy for Sustainable Development*, *60*, 82–89. https://doi.org/10.1016/j.esd.2020.12.004

Hosier, R. H., Bazilian, M., Lemondzhava, T., Malik, K., Motohashi, M., & Vilar Ferrenbach, D. (2017). *Rural electrification concessions in Africa: What does experience tell us?* World Bank Group.

Huber, M., Namockel, N., Rezgui, R., Küppers, M., & Heger, H. J. (2021). Electrification seeds – A flexible approach for decentralised electricity supply in developing countries. *Energy for Sustainable Development*, *62*, 176–185. https://doi.org/10.1016/J.ESD.2021.04.001

IEA. (2022). *Africa Energy Outlook 2022*. International Energy Agency. https://iea.blob.core.windows.net/assets/220b2862-33a6-47bd-81e9-00e586f4d384/AfricaEnergyOutlook2022.pdf

IED. (2013). *Support Study for DFID "Identifying the gaps and building the evidence base on low carbon mini grids" Final Report*. Innovation Energy Development. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/278021/IED-green-min-grids-support-study1.pdf

Ilskog, E., & Kjellström, B. (2008). And then they lived sustainably ever after? Assessment of rural electrification cases by means of indicators. *Energy Policy*, *36*, 2674–2684.

IRENA. (2015). Accelerating off-grid renewable energy, IOREC 2014, Key Findings and Recommendations. International Renewable Energy Agency.

Jack, B. K., & Smith, G. (2015). Pay as you go: Prepaid metering and electricity expenditures in South Africa. *American Economic Review*, *105*(5), 237–241.

Kirubi, C., Jacobson, A., Kammen, D. M., & Mills, A. (2009). Community-based electric micro-grids can contribute to rural development: Evidence from Kenya. *World Development*, *37*(7), 1208–1221. https://doi.org/10.1016/J.WORLDDEV.2008.11.005

Knuckles, J. (2016). Business models for mini grid electricity in base of the pyramid markets. *Energy for Sustainable Development*, *31*, 67–82. https://doi.org/https://doi.org/10.1016/j.esd.2015.12.002

Korkovelos, A., Zerriffi, H., Howells, M., Bazilian, M., Rogner, H.-H., & Nerini, F. F. (2020). A retrospective analysis of energy access with a focus on the role of mini grids. *Sustainability, 12*(5), 1793. https://doi.org/10.3390/su12051793

Lillo, P., Ferrer-Martí, L., Boni, A., & Fernández-Baldor, Á. (2015). Assessing management models for off-grid renewable energy electrification projects using the Human Development approach: Case study in Peru. *Energy for Sustainable Development*, *25*, 17–26. https://doi.org/10.1016/J.ESD.2014.11.003

Malhotra, A., Schmidt, T. S., Haelg, L., & Waissbein, O. (2017). Scaling up finance for off-grid renewable energy: The role of aggregation and spatial diversification in derisking investments in mini grids for rural electrification in India. *Energy Policy*, *108*, 657–672. https://doi.org/10.1016/J.ENPOL.2017.06.037

Moner-Girona, M., Solano-Peralta, M., Lazopoulou, M., Ackom, E. K., Vallve, X., & Szabó, S. (2018). Electrification of sub-Saharan Africa through PV/hybrid mini grids: Reducing the gap between current business models and on-site experience. *Renewable and Sustainable Energy Reviews*, *91*, 1148–1161. https://doi.org/10.1016/J.RSER.2018.04.018

Muchunku, C., Ulsrud, K., Palit, D., & Jonker-Klunne, W. (2018). Diffusion of solar PV in East Africa: What can be learned from private sector delivery models? *Wiley Interdisciplinary Reviews: Energy and Environment*, *7*(3). https://doi.org/10.1002/wene.282

Niyonteze, J. D., Zou, F., Asemota, G. N., & Bimenyimana, S. (2019). Solar-powered mini grids and smart metering systems, the solution to Rwanda energy crisis. *Journal of Physics Conference Series*, *1311*, 012002.

Odarno, L., Sawe, E., Maneno, S., Katyega, J., & Lee, A. (2017). *Accelerating Mini grid Deployment in sub-Saharan Africa: Lessons from Tanzania*. Washington, DC: World Bank.

Ogeya, M., Muhoza, C., & Johnson, O. W. (2021). Integrating user experiences into mini grid business model design in rural Tanzania. *Energy for Sustainable Development*, *62*, 101–112. https://doi.org/10.1016/J.ESD.2021.03.011

Pedersen, R. H. (2017). The political Economy of Petroleum Investments and Land Acquisition Standards in Africa: The case of Tanzania. *Resources Policy*, *52*, 217–225. https://doi.org/10.1016/j.resourpol.2017.03.006

Peters, J., Sievert, M., & Toman, M. A. (2019). Rural electrification through mini grids: Challenges ahead. *Energy Policy*, *132*, 27–31. https://doi.org/10.1016/J.ENPOL.2019.05.016

Peterschmidt, N. (2019a). *JUMEME's Tilapia business – Proof of concept for the Key Maker Model*. Unpublished corporate document, JUMEME and INENSUS.

Peterschmidt, N. (2019b). *Stepping up support to Solar Mini grid PPPs through the next phase of operational risk mitigating policy*. Green Mini-Grid (GMG) Help Desk for the Sustainable Energy for All (SE4All) Africa Hub, hosted by the African Development Bank (AfDB).

Phillips, J., Attia, B., & Plutshack, V. (2020). *Lessons for modernizing energy access finance, Part 2 – Balancing competition and subsidy: Assessing Mini grid Incentive Programmes in sub-Saharan Africa*. Energy Access Project. https://energyaccess.duke.edu/publication/balancing-competition-and-subsidy/

Pueyo, A., & DeMartino, S. (2018). The impact of solar mini-grids on Kenya's rural enterprises. *Energy for Sustainable Development*, 45, 28-37.

Pueyo, A., Carreras, M., & Ngoo, G. (2020). Exploring the linkages between energy, gender, and enterprise: Evidence from Tanzania. *World Development*, *128*, 104840.

Pueyo, A., & DeMartino, S. (2018). The impact of solar mini grids on Kenya's rural enterprises. *Energy for Sustainable Development*, *45*, 28–37. https://doi.org/10.1016/J.ESD.2018.04.002

Pueyo, A., & Maestre, M. (2019). Linking energy access, gender and poverty: A Review of the literature on productive uses of energy. *Energy Research and Social Science*, *53*, 170–181.

Pueyo, A., Ngoo, G., Daulinge, E., & Fajardo, A. (2022). *Transforming energy access – Promoting inclusive productive uses of energy from Solar Mini grids in Lake Victoria, Tanzania, IDS Research Report*. Institute of Development Studies.

Ramachandran, N., Pai, R., & Parihar, A. K. S. (2016). Feasibility assessment of Anchor-Business-Community model for off-grid rural electrification in India. *Renewable Energy*, *97*, 197–209. https://doi.org/10.1016/J.RENENE.2016.05.036

RECP. (2014). *Mini grid policy toolkit: Policy and business frameworks for successful mini grid roll-outs*. https://www.ren21.net/Portals/0/documents/Resources/MGT/MinigridPolicyToolkit_Sep2014_EN.pdf

REPP & AMDA. (2023). How to unlock financing for mini grids in Africa at scale through multi-stakeholder collaboration. Africa Minigrid Developers Association. https://africamda.org/wp-content/uploads/2024/09/How-to-unlock-financing-for-mini-grids-in-Africa-at-scale-through-multi-stakeholder-collaboration.pdf

Safdar, T. (2017). *TR9: Business models for mini grids*. Smart Villages Research Group. https://repp.energy/wp-content/uploads/2023/05/How-to-unlock-financing-for-mini-grids-at-scale.pdf

Schmidt, T. S., Blum, N. U., & Sryantoro W. R. (2013). Attracting private investments into rural electrification — A case study on renewable energy-based village grids in Indonesia. *Energy for Sustainable Development*, *17*(6), 581–595. https://doi.org/10.1016/j.esd.2013.10.001

Schnitzer, D., Carvallo, J., Lounsbury, D., Deshmukh, R., Apt, J., & Kammen, D. (2014). Microgrids for Rural electrification: A critical review of best practices based on seven case studies. https://doi.org/10.13140/RG.2.1.1399.9600.

SE4ALL & AfDB. (2019). *Mini grid market opportunity assessment*. Part of the Green Mini grid Market Development Programme. SE4ALL Africa Hub & African Development Bank.

Sharma, K. R., & Palit, D. (2020). A coevolutionary perspective on decentralised electrification: A solar mini grid project in India. *International Journal of Sustainable Society*, *12*(3), 220–237. https://doi.org/10.1504/IJSSOC.2020.109773

Szabó, S., Pinedo Pascua, I., Puig, D., Moner-Girona, M., Negre, M., Huld, T., Mulugetta, Y., Kougias, I., Szabó, L., & Kammen, D. (2021). Mapping of affordability levels for photovoltaic-based electricity generation in the solar belt of sub-Saharan Africa, East Asia and South Asia. *Scientific Reports*, *11*(1), 3226. http://doi.org/10.1038/s41598-021-82638-x

Tenenbaum, B., Greacen, C., Siyambalapitiya, T., & Knuckles, J. (2014). From the bottom up: how small power producers and mini grids can deliver electrification and renewable energy in Africa. World Bank.

Trimble, C. P., Kojima, M., Perez Arroyo, I., & Mohammadzadeh, F. (2016). *Financial viability of electricity sectors in sub-Saharan Africa: Quasi-fiscal deficits and hidden costs*. Washington, DC: World Bank. Policy Research Working Paper.

Tsuchiya, Y., Swai, T. A., & Goto, F. (2020). Energy payback time analysis and return on investment of off-grid photovoltaic systems in rural areas of Tanzania. *Sustainable Energy Technologies and Assessments*, *42*, 100887. https://doi.org/10.1016/J.SETA.2020.100887

Uamusse, M. M., Tussupova, K., Persson, K. M., Bengtsson, L., & Berndtsson, R. (2020). Access to sustainable electrification: Possibilities for rural Mozambique. *Cogent Engineering*, *7*(1), 1–19. https://doi.org/10.1080/23311916.2020.1765688

UNDP. (2018). *Derisking Renewable Energy Investment (DREI): Derisking Matrix*. UNDP.

USAID. (2017). *Practical Guide to the Regulatory Treatment of Mini grids*. Energy Division, Office of Energy & Infrastructure, Bureau for Economic Growth, Education, and Environment (E3). United States Agency for International Development.

Wang, R., Hsu, S.-C., Zheng, S., Chen, J.-H., & Li, X. I. (2020). Renewable energy microgrids: Economic evaluation and decision making for government policies to contribute to affordable and clean energy. *Applied Energy*, *274*. https://doi.org/10.1016/j.apenergy.2020.115287

Waswa, L. (2021). Leveraging microgrid clusters for enhanced electrification - A case for sub-Saharan Africa. Grid Professionals Group, Energy Central.

Weston, P., Kalhoro, W., Lockhart, E., Reber, T., & Booth, S. (2018). *Financial and operational bundling strategies for sustainable micro-grid business models*. Golden, Colorado: National Renewable Energy Laboratory

World Bank. (2020). *Doing business ranking*. Doing Business Archive. https://archive.doingbusiness.org/en/rankings

World Bank. (2023). *Rural population (% of total population) - sub-Saharan Africa*. World Bank Group Data. https://data.worldbank.org/indicator/SP.RUR.TOTL.ZS?locations=ZG

Yadoo, A. (2012). *Delivery models for decentralised rural electrification case studies in Nepal, Peru, and Kenya*. International Institute for Environment and Development (IIED).

Yadoo, A., & Cruickshank, H. (2012). The role for low carbon electrification technologies in poverty reduction and climate change strategies: A focus on renewable energy mini grids with case studies in Nepal, Peru, and Kenya. *Energy Policy*, *42*, 591–602. https://doi.org/10.1016/J.ENPOL.2011.12.029

CHAPTER 4

Of Monopolies and Mini-Grids: Case Studies from Kenya, Tanzania, Nigeria, and Senegal

Lucy Baker,[1] Temilade Sesan,[2] Subhes C. Bhattacharyyra,[3] Dramani Bukari,[4] Shukuru Meena,[5] Muyiwa Oyinlola,[3] Estomih Sawe,[5] Elsie Onsongo,[6] Ana Pueyo,[7] Ewah Otu-Eleri,[8] Unico Uduka, [8] Yuri Handem[9] and Beryl Onjala [6]

[1]Geography and Environment Studies, The Open University, Milton Keynes, UK
[2]Center for Petroleum, Energy Economics and Law, University of Ibadan, Ibadan, Nigeria
[3]De Montfort University, Leicester, UK
[4]Ghana Climate Innovation Centre, Accra, Ghana (work undertaken while at De Montfort University between November 2020 and January 2022)
[5]TaTedo, Centre for Sustainable Energy Services, Dar-es-Salam, Tanzania
[6]Nuvoni Centre for Innovation Research, Nairobi, Kenya
[7]Senior Energy Advisor, New Zealand Ministry of Foreign Affairs and Trade, Wellington, New Zealand (work undertaken between March 2020 and March 2022 as a member of the Institute of Development Studies)
[8]International Centre for Energy, Environment and Development, Abuja, Nigeria
[9]Independent Consultant, Dakar, Senegal

Abstract

Recent advances in decentralised renewable electricity systems have undermined long-held assumptions that electricity access and rural electrification can only be achieved via the extension of the national grid. Renewable energy and solar hybrid mini grids have been promoted as one low-cost option to meet Sustainable Energy for All's commitment to universal energy access by 2030, because of their potential to connect low-income, rural and/or dispersed communities for whom the cost of extending the main grid is considered too expensive. As this chapter discusses in relation to Kenya, Tanzania, Nigeria and Senegal, new private sector actors in renewable energy mini grids have started to emerge in recent years, marking a shift away from large-scale diesel or hydro mini grids run by government utilities, and small-scale mini grid development previously led by bi-lateral donors and community organisations. However, there have been considerable governance and regulatory

challenges to the development and deployment of renewable energy mini grids at scale, which has often taken place in the absence of national regulation rather than because of it. Moreover, some state-owned electricity utilities and associated institutions have been resistant at once to new private sector actors and decentralised systems. Meanwhile, the term 'mini grid' lacks a common definition and is simultaneously associated with energy access as well as productive use, despite the often-competing objectives of these end uses. This paper unpacks some of these dynamics through an extensive desk-based study of grey and academic literature and a regulatory comparison of the four case study countries. Building on scholarship from development and energy geography, we argue that a more granular analysis is needed to account for the complex and evolving processes of electricity decentralisation in low- and middle-income countries

Keywords: Africa, electricity governance, energy access, mini-grids, Nigeria, rural electrification

Acronyms

AC	*Alternate current*
AMADA	*Africa Minigrid Developers Association*
ANER	*L'Agence Nationale d'Energies Renouvelables*
ASER	*L'Agence Sénégalaise d'électrification rurale (Senegalese Agency for Rural Electrification)*
CAPEX	*Capital Expenses*
CRSE	*La Commission de Régulation du Secteur de l'Électricité*
DC	*Direct Current*
Discos	*Distribution Companies*
DFI	*Development finance institution*
DFID	*Department for International Development, UK*
ECREEE	*ECOWAS Centre for Renewable Energy and Energy Efficiency*
EPRA	*Energy and Petroleum Regulatory Authority*
EPSRA	*Electric Power Sector Reform Act (Nigeria)*
ERC	*Energy Regulatory Commission*
ERIL	*Electrification Rurale d'Initiative Locale*
ESMAP	*Energy Sector Management Assistance Program*
EWURA	*Energy and Water Utilities Regulatory Authority*
FCDO	*Foreign Commonwealth and Development Office*

GDP	*Gross Domestic Product*
GenCos	*Generating companies*
GIZ	*Deutsche Gesellschaft für Internationale Zusammenarbeit*
GW	*Gigawatts*
IEA	*International Energy Agency*
INEP	*Integrated national Electrification Plan*
IPD	*Independent Power Distributor*
IPP	*Independent Power Producer*
IRENA	*International Renewable Energy Agency*
KNES	*Kenya Electrification Strategy*
KPLC	*Kenya Power and Lighting Company*
kW	*Kilowatt*
LCPDP	*Least Cost Power Development Plan*
LMICs	*low and Medium-income countries*
LPDSE	*La Lettre de Politique de Développement du Secteur de l'Energie*
MoEP	*Ministry of Energy and Petroleum*
MPE	*Ministère du Pétrole et des Energies*
MW	*Megawatt*
NEP	*National Electrification Project*
NEPA	*National Electric Power Authority (Nigeria)*
NERC	*Nigerian Electricity Regulatory Commission*
NGO	*Nongovernmental organization*
PAYGO	*Pay as you go*
PHCN	*Power Holding Company of Nigeria*
PPER	*Programmes Prioritaires d'Electrification Rurale*
PSE	*Plan Sénégal Emergent*
PV	*Photovoltaic*
REA	*Rural Electrification Agency (Kenya, Nigeria)*
REA(T)	*Rural Energy Agency (Tanzania)*
REF	*Rural Electrification Fund (Nigeria)*
REREC	*Rural Electrification and Renewable Energy Corporation*
REMP	*Renewable Energy Master Plan*
RESIP	*Rural Electrification Strategy and Implementation Plan*
SDG7	*Sustainable Development Goal 7*
SEforAll	*Sustainable Energy for All*

Sénélec	*Société Nationale l'Électricité du Sénégal*
SHS	*Solar home system*
SPP	*Small power producer*
SREP	*Scaling-up Renewable Energy Program*
SSA	*Sub-Saharan Africa*
TANESCO	*Tanzania Electric Supply Company Limited*
TEDAP	*Tanzania Energy Development and Access Project*
USAID	*United States Agency for International Development*

4.1 Introduction

In recent years, notable progress has been made toward achieving Sustainable Development Goal 7 (SDG 7) and the UN Sustainable Energy for All (SEforAll) initiative to provide universal access to electricity by 2030. According to Energy Sector Management Assistance Program (ESMAP, 2024), by 2023, 666 million people lacked access to electricity, of whom 565 million were in sub-Saharan Africa (SSA). The continent now accounts for 85% of the global population without electricity, of which the majority in rural areas. While the number of people with access to electricity has increased significantly since 2010, progress stalled between 2020 and 2023, particularly as a result of the economic and supply chain impacts of the COVID-19 pandemic and Russia's invasion of Ukraine. Moreover, the increase in levels of electricity access has failed to keep up with population growth in absolute terms and based on current trends, the realization of universal access by 2030 is unlikely to be met (IEA et al., 2025). Meanwhile, there is no single internationally accepted or adopted definition of "electricity access," including under SDG 7. While the World Bank's multi-tier framework has gone some way to address this (see Table 4.1) conventional measurements still obscure much more complex realities and different levels of access (Ulsrud, 2020).

It is well-acknowledged that tackling the electricity access gap requires nothing short of a socio-technological transformation in which decentralized and off-grid renewable electricity generation, including mini-grids, will play a key role (Peters et al., 2019). To that end, over the past decade there has been a consistent increase in the installation of mini-grids globally and particularly in SSA. Installations are over six times higher compared with those in 2018 (SEforAll et al., 2024). While there are various projections regarding the potential of mini-grids to provide electricity

access, in 2022, ESMAP estimated that mini-grids could be the least-cost option for connecting up to 430 million people (ESMAP, 2022). To date, mini-grids in SSA have been built, owned and operated under various models by various entities including state-owned utilities, public sector agencies, nongovernmental organizations (NGOs), local communities, the private sector, or some or all of the above depending on the political and socio-economic context of the country or region in question and the size and structure of the mini-grid (Fajardo et al., 2025).

While in previous decades some of the largest developers of mini-grids were national utility companies, including TANESCO in Tanzania and Kenya Power and Lighting Company (KPLC) in Kenya, where mini-grids were for the most part hydro- or diesel-powered, respectively, the last decade has seen a growing shift to solar-powered or "third-generation" mini-grids by private sector developers and investors (SEforAll et al., 2024). This shift, which began in Kenya in 2011, is now evolving elsewhere on the continent.

Despite a diversity of definitions as discussed in Section 4.3, the term "mini-grid" refers to a low-voltage or medium-voltage generation and electricity distribution network that can operate in isolation from the main grid but also connect to it should the network expand (Tenenbaum et al., 2014). The nature of a mini-grid is such that power can be generated much closer to the point of consumption, thereby reducing the probability of service failure and energy losses often experienced on the distribution or transmission network. Mini-grids are often conceptualized as a disruptive innovation given their potential to radically change the way in which electricity is produced, consumed, purchased, regulated, financed, and owned. Because they are technologically flexible and modular, mini-grids can cater to needs at multiple scales, from basic services such as lighting, mobile phone charging, and small appliances (e.g., fans and radios); to productive uses such as grain milling, water purification, and fish drying; and institutional electricity needs (e.g., schools, clinics, and businesses).

While the extension of the national electricity grid was the dominant strategy for electrification until recently, technical, logistical, and economic limitations make it difficult or even impossible to reach remote, dispersed, low-income communities. Although grid extension programs continue, innovations in renewable, decentralized, and stand-alone systems of varying size and scale are starting to disrupt electricity landscapes across SSA (Ahlborg, 2018; Gaiya et al., 2025). As discussed in Section 4.3, these innovations, including geospatial planning and digital technologies, are co-evolving with rapidly declining costs and economies of scale across the solar photovoltaic (PV) value chain.

For such reasons, third-generation mini-grids are seen as a potential game changer for cost-effective, pro-poor, low-carbon, universal electrification (Sesan, 2021) and have been proposed as a "third alternative to rural electrification, coming between the option of large-scale grid extension and pico-scale stand-alone solutions like solar home systems (SHSs) or solar lanterns" (Pedersen, 2016). Such systems are seen as better able to reach remote, dispersed, and/or informal settlements, where the cost of connection to the centralized national grid is prohibitive.

Despite this positive narrative, there are considerable governance and regulatory challenges inherent in the roll out of third-generation mini-grids. Many countries with low levels of electricity access and/or high levels of inequality either lack clear procedures for such integration or are still in the process of developing them. Moreover, because mini-grids are at once power producers and power distributors, with the potential to "spatially reorganize" the electric grid, they have met with resistance from incumbent institutions of centralized electricity because of the threat that they pose to their political and economic control (Boamah & Rothfuß, 2020).

Our study responds to calls for a deeper understanding of the evolving conflict and co-existence between the extension of the national electricity grid, and decentralized and off-grid systems (Ojong, 2022; Rothfuß & Boamah, 2020, p. 165), given that much of the literature on rural electrification and energy access in low- and middle-income countries (LMICs) to date has been dominated by perspectives from engineering and economics and tended to privilege the technological and financial barriers. Such perspectives are often focused on definitions of "business models" (Muchunku et al., 2018), rather than considerations of the political and economic complexities of regulation and governance.

With this in mind, we undertook a comparative analysis of how mini-grids are regulated and governed, and the key challenges to their introduction in Nigeria, Kenya, Tanzania, and Senegal. The latter two countries were considered among the global leaders in terms of the technical and regulatory frameworks that they developed to attract private sector investment (ESMAP 2019, p3). However, Nigeria and Kenya and currently global leaders in terms of the number of mini-grids and total installed capacity (SEforAll et al 2024, p25). Our study was guided by the following questions for each country: (i) *What are the key institutions, actors, and processes involved in electricity governance at the national level? (ii) What regulatory and policy frameworks for mini-grids have been introduced thus far? (iii) What key regulatory challenges remain for the future deployment of mini-grids?*

The research for this chapter was carried out between 2020 and 2022, with some further updates added at the time of publishing in 2025. The chapter is based on a critical review of peer-reviewed academic literature in English, and French in the case of Senegal, on electricity governance and decentralized electricity systems in the case study countries, mainly retrieved from Scopus and Google Scholar. Approximately 80 academic articles were read in detail. The academic literature was supplemented and triangulated with grey literature and publicly available sources, including from international institutions such as the World Bank, ESMAP, The United States Agency for International Development's (USAID) Power Africa programme, the International Renewable Energy Agency (IRENA), and the International Energy Agency (IEA); national policy and other government documents; civil society reports; and national and international media sources.

The structure of this chapter is as follows. Section 4.2 situates the emergence of mini-grids within the broader historical context of electricity governance and the relevant academic literatures. Section 4.3 explores how mini-grids as a rapidly evolving set of technological assemblages have been defined and become a term with multiple meanings and explains the growth of third-generation mini-grids as a key focus of this chapter. Section 4.4 explores mini-grid regulation in each case study country, within the national context of electricity governance. Section 4.5 concludes.

4.2 Governing Electricity: Of Monopolies, Mini-Grids, and Beyond

As a large-scale networked infrastructure and a complex, interconnected, and interactive system of artifacts and technologies (Hughes, 1983), electricity is not easily governed. Electricity is subject to vested interests and uncertainty in the adoption of new technologies and co-determined by factors such as the nature of domestic industrial, agricultural, and residential electricity demand; national varieties of capitalism; and national and subnational systems of governance (Baker et al., 2021).

In the first half of the twentieth century, the electricity sector, in countries where it was established, was generally a state-owned, vertically integrated monopoly. However, by the 1980s and 1990s, the "standard model" of power sector reform was established as a global blueprint, in keeping with the neo-liberal economic orthodoxy of the time. In developing countries, this model was promoted by the World Bank and related consultants and endorsed by other multilateral lending institutions as part

of loan and debt relief conditionalities under structural adjustment programs (Baker et al., 2021). The model was informed by the experiences of a small group of countries including the USA, the UK, Norway, and Chile and followed the assumption that state ownership was unable to meet the high levels of investment required by the electricity sector (Gratwick & Eberhard, 2008). The model therefore prescribed that state-owned utilities should be unbundled into private generation, distribution, and transmission companies, with a significant role for wholesale markets and ultimately, retail competition (Sen, 2014). The creation of a strong independent regulator to "regulate the monopoly prone parts" of the industry was to accompany this unbundling (Victor & Heller, 2007, p. 7).

Despite the apparent simplicity of the standard model, its practical application was more complex, resulting in various forms of failure, partial implementation, and stranded assets from surplus generation capacity (Foster & Rana, 2020). Given the role of the centralized electricity sector as a strategic source of "revenue, political power, and influence," these donor-driven power sector reforms have often faced resistance from various government departments (Godinho & Eberhard, 2019). The model has also been criticized for its generalized assumptions about the capacity of the state to implement it and attract investment (Sen, 2014). In addition, national regulators have rarely been as empowered as per the model's prescriptions, have faced significant political challenges, and struggled to negotiate the complex contractual and regulatory terms of power sector liberalization (Baker et al., 2021).

Many principles of electricity liberalization remain influential but other socio-technical dynamics have more recently come into play, not least the deployment of decentralized and off-grid renewable electricity, including mini-grids. This deployment has been accompanied by the emergence of new players and the reconfiguration of old ones; changes in national electricity policy, planning and regulation; and shifting trends in global investment and technological innovation. Debates over the governance of electricity have gone beyond the simplified dichotomy of state versus market to include competition and co-existence "between different scales and configurations of centralised and decentralised electricity" (Baker & Phillips, 2018). Significantly, developments in decentralized and off-grid renewable systems mean that electricity can now be generated and accessed without the centralized mediation of the transmission or distribution grid.

While research on the political economy of electricity has provided critical empirical insights into shifting models of electricity ownership, includ-

ing in various countries in SSA (Godinho & Eberhard, 2018; van den Bold, 2021), it has for the most part focused on reforms to the centralized system of generation, transmission, and distribution. Therefore, this research has yet to address the rapid and recent emergence of decentralized systems in any great depth. While new studies are emerging (Sareen et al., 2024; Sesan et al 2024; Ogeya & Lambe, 2025), an understanding of evolving regulation and the rapidly developing private sector investment in the sector in SSA is still limited.

With this in mind, our chapter adds to contributions from energy and development geography, which emphasize the need to understand the interactions between social, economic, political, and technological forces that influence and challenge the realization of sustainable energy access (Gollwitzer et al., 2018; Ulsrud et al., 2018). This understanding includes a focus on the significance of scale and spatial contexts, the formation of new "energy landscapes", and the "embeddedness" of the electricity system within specific national, local, and geographical contexts (Bridge et al., 2018; Castán-Broto & Baker, 2018; Rothfuß & Boamah, 2020). The concept of the "embeddedness" of electricity within "an evolving set of political relationships" is further developed by Balls and Fischer (2019, p. 474) and Ulsrud et al. (2018), who explore how factors such as population density, settlement patterns, and socio-economic conditions, as well as the significance of political ideologies on the role of the state, markets, and institutions, all condition electricity supply and demand in important ways.

This literature has further explored how large-scale, grid-connected electricity is often seen as a symbol of modernity and development, has been key to the formation of the state in many postcolonial countries, as well as being of immense significance to politics, citizenship, and democracy (Ahlborg, 2018; Balls & Fischer, 2019). For instance, in many contexts, a connection to the centralized electric grid as opposed to an off-grid or decentralized alternative can also be an indicator of socio-economic status and class and is therefore closely connected to political patronage and voter loyalty (Rothfuß & Boamah, 2020). Moreover, given the potential of electricity for revenue generation, there is a significant relationship between the control of large-scale and increasingly small-scale electricity systems, and political and economic power by both the state and/or private actors (McDonald, 2009; Silver, 2016). Despite the promise of minigrids, such dynamics are important considerations in the various types of resistance.

4.3 Mini-Grids in Context: Between Energy Access and Productive Use

Mini-grids were the earliest form of electrification for most industrializing economies and former colonies during the late nineteenth and early twentieth centuries (ESMAP, 2019, p. 12). In Tanzania, for example, hydro-powered mini-grids were set up in the 1950s and 1960s by large industrial and agricultural companies as well as missionaries (Jaglin & Guillou, 2020). Recent years have seen the rapid growth of solar-powered or so-called "third-generation" mini-grids, particularly in SSA, which are starting to replace diesel-generated systems and, in some cases, provide a more cost-effective and efficient alternative to the extension of the transmission and distribution grid. A second new development is the evolution of regulatory and financial arrangements aimed at the scale up of renewable energy mini-grid deployment, as well as the formation of new actors and institutions in the sector (IEA et al., 2025). Such regulation, however, has often taken place in the wake of mini-grid development rather than in advance of it and/or may have limited implementation despite having been well-written (SEforAll et al., 2024).

There is no universally agreed definition of a mini-grid in terms of size, scale, technical features, ownership structure, service area, and customer base. It is therefore a term with multiple meanings, purposes, and functions, and one through which the often-competing objectives of productive use, energy access, and rural electrification are conflated. ESMAP has defined a mini-grid to mean an electric power generation asset (e.g., hydro turbine, solar panel, battery, inverter) and distribution system (wires, poles, etc.) that can "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" (ESMAP, 2019, p. 3). Following this definition, a mini-grid has to serve multiple customers. Therefore, a decentralized electricity system that serves a single entity such as a hospital, university campus, mine, military base, or industrial facility does not qualify. A mini-grid is therefore defined separately from an "on-site solar" or captive power project for commercial and industrial (C&I) users, particularly mining and manufacturing, in which the electricity generated is directly consumed by the host and in contrast to a mini-grid, less beholden to national regulations and tariffs. The C&I sector has increased significantly across SSA since 2019 with cumulative installations now estimated at 1.7 GW, with the largest markets in Nigeria, South Africa, Kenya, Ghana, and Côte d'Ivoire (Solar Financed, 2024).

The installed capacity of a mini-grid can also vary considerably depending on the context and the country, but typically falls within a range of 10 kW to

10 MW (Muchunku et al., 2018, p. 7). This, as compared to that of a micro-grid, which is usually between 1 and 10 kW (Muchunku et al., 2018). Mini-grids can also be differentiated from SHSs, which are based on direct current (DC) and largely deployed for the provision of energy access such as lighting, radio, and mobile telephone charging using mobile payment technology. For further perspective, while SHSs sit under tiers one to three of the UN SEforAll categories (see Table 4.1), mini-grids generally sit from tiers three to five (PWC, 2016, p. 9) and can be converted to alternate current (AC). Mini-grids are therefore perceived as better able to support productive use in addition to energy access (Bhattacharyya & Palit, 2016; Peters et al., 2019).

While a small-scale mini-grid may be aimed at village-level rural electrification and comparable to a SHS, a large-scale mini-grid is often sited either in an urban or a peri-urban area where it can depend on a large number of medium- to large-scale electricity users with greater ability to pay (Peters et al., 2019, p. 28). Or, if in a rural area it is usually situated near to a large consuming "anchor client" with a long payback period in the interests of predictable demand and revenue (Pedersen, 2016, p. 16; Knuckles, 2016). Though mini-grids have recently become cheaper and quicker to install than utility-scale projects in many parts of SSA, in order to be financially viable, they generally depend on a high number of medium- to large-scale electricity consumers who can afford the tariff, such as users of refrigerators, freezers, electrical machinery, and tools, e.g., for grinding, cutting, drilling, welding, and milling. While mini-grid tariffs may be cheaper than the cost of power generation from diesel generators, in many countries they are still more expensive than tariffs from the centralized grid (Muchunku et al., 2018, p. 8), as we discuss below.

Third-generation mini-grids, which have started to emerge in very recent years, are typically solar PV or solar PV hybrids and have been enabled by geospatial analysis and digital technologies and have been designed to incorporate smart meters and remote monitoring systems. This, in addition to the economies of scale, decreased costs and the development of technological capabilities created by utility-scale solar PV and lithium-ion batteries in electric vehicles. Alongside SHSs, third-generation mini-grids are being promoted as a low-cost option to meet SEforAll's universal energy access commitment by 2030, connecting dispersed or rural communities in low-income settings, where the cost of extending the main grid is considered too expensive (IEA et al., 2025). Third-generation mini-grids have characteristics of both electricity utilities and SHSs, which presents both challenge and opportunity. Like utilities they have the potential to provide a constant supply of electricity and support productive loads such as

Table 4.1: Multi-Tier Energy Access Framework

	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Indicated minimum technology or system	*Pico-products, e.g., solar lamp and lantern; nano-grid; micro-grids; entry-level SHS*	*Basic capacity SHS to medium capacity SHS*	*Medium to high capacity SHSs, with lead-acid or lithium-ion battery; micro-grids*	*High capacity SHS; mini-grids*	*Mini-grids, or central grid*
Power capacity ratings in Watt	*Min 3 W*	*Min 50 W*	*Min 200 W*	*Min 800 W*	*Min 2 kW–10 MW*
Power capacity ratings in daily Watt hours	*Min 12 Wh*	*200 Wh*	*Min 1.0 kWh*	*Min 3.4 kWh*	*Min 8.2 kWh*
Availability hours per day	*Min 4 hours*	*Min 4 hours*	*Min 8 hours*	*Min 16 hours*	*Min 23 hours*
Availability hours per evening	*Min 1 hour*	*Min 2 hours*	*Min 3 hours*	*Min 4 hours*	*Min 4 hours*
Examples of appliances connected	*Two lights, mobile phone charging*	*Four lights, mobile phone, radio*	*Four lights, phone, radio, TV, sewing machine, fridge, fan, computer*	*Washing machine, hair dryer, microwave*	*Water heater, electric cooker*

Source: Adapted from Lighting Global et al. (2020, p. 268 and vii) and PWC (2016, p. 9).

agricultural milling and water irrigation pumps, as well as to operate as a rural distribution network. But like utilities, they also have large sunk capital costs (ESMAP, 2019, p. 13). Like SHSs, mini-grids share the potential for rapid expansion under the appropriate market conditions, but unlike SHSs mini-grids have been subject to greater regulatory oversight and tariff structures. It is perhaps for this reason that SHSs have had greater traction than mini-grids. Meanwhile, the growing interconnection of multiple SHSs is anticipated to contribute to the growth of mini-grids.

Third-generation mini-grids are generally owned and operated by private, international companies or consortiums whose interest is to generate large-scale investment portfolios rather than develop one-off projects. Recent years have seen the considerable growth of these companies operating in SSA. Key players include PowerGen, PowerHive, and Engie Energy Access. The mini-grid value chain, including technology supply, is for the most part internationally owned. Mini-grid financing is also evolving in parallel, with various modes of development and climate finance now coming from a combination of multilateral and bilateral donors. This, in addition to blended finance, which plays an increasingly important role in securing impact investment, including from Rockefeller, Acumen, and Ceniarth; commercial financiers such as CrossBoundary Energy Access and SunFunder; and strategic investors such as Sumitomo Corporation and Toyota (SEforAll & BNEF (2019), p. 90). Results-based financing, under which developers receive a grant from host governments once they can prove that their mini-grid is operational and supplying electricity to end users,[1] has also become an increasingly popular mechanism with commercial financiers. However, the negative impacts on project development of the restrictive requirements and limited timeframes of RBF have more recently been acknowledged (SEforAll et al., 2024, p. 13).

The institutions involved in third-generation mini-grids are increasingly organized, as illustrated by the formation of the African Minigrid Developers Association (AMDA) in 2018. Supported by donors such as the UK's FCDO, USAID, and Germany's KfW, AMDA has played an advocacy role in pushing for policies and regulations that favor private sector investment in various countries. Another example is that of the Mini-Grids Partnership, a consortium of over 250 institutions including investors, development banks, bilateral donors, industry, and other renewable energy networks, founded in 2014 under the auspices of SEforAll. With this in mind, we now explore how the mini-grid sector has evolved in the case study countries of Kenya, Tanzania, Nigeria, and Senegal.

[1] The grant is often paid for with assistance from development finance.

4.4 Country Case Studies

In this section, we undertake an analysis of electricity governance in each country, the key institutions involved, and the state of play regarding mini-grid regulation, as summarized in Tables 4.2 and 4.3.

Table 4.2: Comparative Statistics Kenya, Tanzania, Nigeria, and Senegal (2024)

	Kenya	**Tanzania**	**Nigeria**	**Senegal**
Population (2024)	*56 million*	*68 million*	*232 million*	*18 million*
GDP per capita (2024)	*$2,206*	*$1,185*	*$807*	*$1,744*
GDP overall (2024)	*$124.5 billion*	*$78.8 billion*	*$187.8 billion*	*$32.3 billion*
People without electricity access (2023 figures)	*13.1 million*	*34.9 million*	*86.9 million*	*4.6 million*
Total percentage of population with electricity access (2023)	*75%*	*38%*	*66%*	*74%*
Urban population as a percentage of the total population (2024)	*30%*	*38%*	*55%*	*50%*
Percentage of **urban** *population with electricity connectivity access (2023)*	*96%*	*82.5%*	*85.0%*	*96%*
Percentage or **rural** *population with electricity connectivity access (2023)*	*68%*	*28%*	*33%*	*56.5%*
Installed capacity (2023 figures)	*3.37 GW*	*2GW*	*14.3 GW*	*1.6 GW*

Sources: WB data, ESMAP (2024), Ember (2024).

Table 4.3: Institutions and Processes of Electricity Governance and Regulation (2022)

Country	*Utility*	*Transmission*	*Distribution*	*Generation*	*Regulator*	*Rural Electrification Agency*	*Renewable Energy Agency*	*Responsibility for Electricity Policy*	*Key Plans, Policies, and Legislation*	*Capacity Threshold for Licensing Exemption*	*Tariff*
Kenya	*KPLC*	*KPLC and KETRACO (est 2008)*	*KPLC (license to distribute power to whole country)*	*KenGen Ltd and 12 IPPs*	*ERC: Energy Regulatory Commission (est. 2007) succeeded by Energy and Petroleum Regulatory Authority (EPRA) in 2019*	*Rural Electrification Authority (REA), established 2006. Replaced in 2019 by Rural Electrification and Renewable Energy Corporation (REREC)*	*REREC*	*Ministry of Energy and Petroleum (MoEP)*	*Electric Power Act (1997); Energy Act (2012); Energy Act (2019); Kenya National Electrification Strategy (KNES) (2018). Least Cost Power Development Plan (LCPDP) (2021–2030)*	*100 KW*	*Uniform tariff for all customers. Customers linked to mini-grids pay the same as electricity consumers from the main grid. Some recent flexibility for private investors.*
Tanzania	*TANESCO*	*TANESCO*	*TANESCO*	*TANESCO*	*EWURA: Energy and Water Utilities Regulatory Authority*	*Rural energy agency (REA), established 2005. Rural Energy Fund (provides grants to co-finance the hardware)*	*Tanzania Renewable Energy Association*	*Ministry for Energy*	*Rural Energy Act (2005); Electricity Act (2008); Small Power Producers Framework (SPP) (2008, revised 2015); Scaling Up Renewable Energy Program (SREP) (2013); TEDAP (2011); Electricity Supply Industry Reform Strategy (2014–2025)*		*Determined by EWURA*

Country	Utility	Transmission	Distribution	Generation	Regulator	Rural Electrification Agency	Renewable Energy Agency	Responsibility for Electricity Policy	Key Plans, Policies, and Legislation	Capacity Threshold for Licensing Exemption	Tariff
Nigeria	Unbundled since 2013. Formerly PHCN	PHCN	Eleven distribution companies (disco)	Six private generation companies	NERC: Nigerian Electricity Regulatory Commission (est. 2007)	REA (Rural Electrification Agency)	REA (Rural Electrification Agency)	Ministry of Energy; Federal Ministry of Power	Electric Power Sector Reform Act (2005); REMP (2006), updated (2011); Nigeria Electrification Project; Regulatory framework for mini-grids (2018); National Electric Power Policy (NEPP); National Renewable Energy and Energy Efficiency Policy (NREEEP)	1 MW	
Senegal	Sénélec (Société Nationale d'électricité du Sénégal)	Sénélec	Private concessionary companies and Sénélec	Sénélec (just under 50%) and IPPs	CRSE: Electricity Sector Regulatory Commission, established 1998	ASER (L'agence Sénégalaise d'électrification rurale), created 1999	ANER (L'Agence Nationale d'Energies Renouvelables), established 2013	Ministry of Petrol and Energy	Renewable Energy Law (2010); Programme Nationale D'Electrification Rurale du Sénégal; Lettre de Politique de Développement du Secteur de l'Energie, LPDSE (2019–2023)	50 KW	

4.4.1 Kenya

Kenya has the highest levels of electricity access and one of the most ambitious power sectors in East Africa, as reflected in its "Kenya Vision 2030" plan. Launched in 2008, the plan aimed to achieve 100% electricity access by 2022 and a target that was later postponed to 2030. Kenya's electricity connectivity rate has since risen from 20% of the population in 2013 to almost 79% in 2023 (see Table 4.2). The percentage of the urban and rural population with electricity access now stands at approximately 96% and 68%, respectively. This increase has been achieved largely through donor-supported, government-run rapid grid extension programs, and to a lesser extent through the introduction of SHSs (IEA, 2019). One example of such a program is the Last Mile Programme, launched in 2015 and implemented by the state utility, the KPLC with support from the World Bank and African Development Bank. However, given that this program only targets residential consumers situated within a 600-meter radius of existing transformer stations, many households in more peripheral areas have been excluded from it (Boamah, 2020; Ulsrud, 2020).

Total generation capacity in Kenya stands at 3.37 GW, of which 860 MW is from hydroelectricity, 940 MW from geothermal, 570 MW from other fossils, 440 MW from the rapidly developing onshore wind sector, 370 MW of solar and 190 MW from bioenergy (Ember, 2024). While the country is one of the world's leading markets for off-grid solar PV (Ockwell & Byrne, 2016) and a global leader in pay-as-you-go (PAYGO) mobile payment schemes for SHSs alongside Tanzania (Onsongo, 2019; Onsongo & Schot, 2017), its mini-grid sector has followed a slower path despite some recent and significant regulatory developments (Pedersen & Nygaard, 2018).

Despite recent progress, in 2023, 13.1 million people in Kenya lacked access to electricity (see Table 4.2), of which there is a wide disparity reflecting the dispersed settlement patterns between and within the country's 47 counties (Boamah, 2020, p. 151). The transmission and distribution grid are unreliable in many parts of the country even where installations are new, partly because the costs of grid maintenance in poor rural areas are far higher than the revenue collected from low-income users (Ulsrud, 2020, p. 59). Until recently rural electrification efforts had largely prioritized industrial and productive sectors, with demand from low-income rural households considered too low to be financially viable (Pedersen & Nygaard, 2018). However, under the 2018 Kenya National Electrification Strategy (KNES), which was replaced by the Integrated National Electrification

Plan (INEP), the government reaffirmed its intention to achieve universal electricity access by 2022, including through the strategic use of on-grid, off-grid, and small-scale solutions to bring power to remote rural and/or underserved peri-urban locations (World Bank, 2018).

Following power sector reforms initiated in 1990s, Kenya's state-owned electricity sector was partially privatized. The Kenya Power Company, originally founded in 1945, was split into: KenGen PLC, which is responsible for the majority of the country's hydroelectricity generation; the KPLC, which owns the transmission grid, is the single buyer of electricity, and remains the sole distributor and retailer of electricity; and KETRACO, the state-owned transmission company, which shares transmission ownership and operations with KPLC. Both KenGen PLC and KPLC are listed on the Nairobi Securities Exchange with the former owned 70% by the Kenyan government and 30% by private investors, while KPLC is 50.1% government-owned and the remaining shareholding with private investors (Godinho & Eberhard, 2019).

The 2019 Energy Act introduced further reforms of the sector, including the updating of a renewable energy feed-in tariff, and paving the way for the introduction of mini-grid regulations, which had been drawn up by the regulator, in 2021 (EPRA, 2021a). However, the 2017–2037 Least Cost Power Development Plan (LCPDP), which is the central planning document for Kenya's electricity sector and was updated in 2021, has given limited consideration to mini-grids (Day & Kurdziel, 2019; EPRA, 2021b), meaning that there is some inconsistency of regulation.

Kenya's Ministry of Energy and Petroleum (MoEP) is responsible for setting sector policies and overseeing the country's utilities. The Energy Regulatory Commission (ERC), established in 2007, was responsible for regulation until the 2019 Energy Act replaced it with the Energy and Petroleum Regulatory Authority (EPRA). The regulator has faced various challenges over the years (Godinho & Eberhard, 2019), including tensions with KPLC. According to Pedersen and Nygaard, despite the regulator's apparent independence, it is in reality "dependent on being given clear policy frameworks by the MoEP in order to make cases that create precedents regarding regulatory issues" (Pedersen & Nygaard, 2018, p. 214). Meanwhile, the MoEP has been reluctant to stand up to KPLC and lacks political support (Pedersen & Nygaard, 2018).

Kenya's Rural Electrification Agency (REA) was established in 2007 to take over the implementation of rural electrification projects from KPLC as part of what Foster and Rana have described as a "second wave" of

more successful home-grown power sector reform (Foster & Rana, 2020, p. 83). REA was mandated to establish 25 mini-grids in small towns to be handed back to KPLC after commissioning (Godinho & Eberhard, 2019). REA was changed to the Rural Electrification and Renewable Energy Corporation (REREC) following the 2019 Energy Act, in a move which brought together rural electrification and renewable energy under one authority (Day & Kurdziel, 2019, p. 10).

A key challenge to the introduction of mini-grid regulation in Kenya has been the resistance of KPLC to private and decentralized players in electricity, which it sees as a threat to the monopoly that it holds over the distribution sector. According to Ulsrud (2020), KPLC tends to act in the interests of its shareholders and revenue generation and has prioritized higher consuming urban and industrial customers. KPLC has also reportedly claimed that grid electricity is superior to that of decentralized systems on the basis of the costs, it would incur to upgrade the grid in order to accommodate mini-grids (Boamah, 2020; Pedersen & Nygaard, 2018; Ulsrud, 2020).

Despite KPLC's resistance, the regulator (formerly ERC, now EPRA) has been actively pursuing private sector-led mini-grids and hybrid public–private models. In 2017, with the support of German bi-lateral donor (*Deutsche Gesellschaft für Internationale Zusammenarbeit, GIZ*), ERC developed a draft framework for mini-grids of up to 1 MW, which established a government-regulated, uniform tariff for all customers, made possible by a high level of cross-subsidy from main grid to mini-grid customers (Pedersen & Nygaard, 2018). These draft regulations were updated in April 2021 in collaboration with industry stakeholders to include licensing requirements, operating guidelines, and performance and reporting requirements (EPRA, 2021a; ESI-Africa, 2021). Projects that do not sell power to Kenya's electricity grid do not require a generation permit or license from the regulator. However, projects with a capacity of 1 MW now require both a generation *permit* and *license*, at a cost of 10,000 Kenyan shillings (EPRAa, 2021).

Until recently NGOs and community organizations had been involved in the delivery of small-scale, village-level mini-grids. Meanwhile, government/KPLC and donor support to mini-grids had focused on urban or peri-urban areas, where demand is growing due to population growth and increasing productive activities (Pedersen, 2016, p. 16). But both of these models are shifting toward one in which private companies, including PowerGen Renewable Energy and PowerHive, are playing an increasingly important role in the form of portfolio investments (Herbert & Phimister, 2019). Diesel-fueled mini-grids belonging to KPLC are gradually being replaced by third-genera-

tion hybrid systems and allocated to independent power producers (IPPs) or independent power distributors (IPDs) (Jaglin & Guillou, 2020). However, in the case of the latter, there is still considerable regulatory uncertainty. For instance, if a mini-grid developer acquires a license for a restricted area, they will not be granted exclusive rights because KPLC still retains the right to construct facilities within the same area.

Uniform tariffs have been imposed on mini-grids larger than 1 MW, as well as on KPLC-operated diesel-fueled rural mini-grids, though in the case of the latter, the cost of diesel is often government subsidized. Given that such tariffs are often seen as too low to be attractive to private investors, the Kenyan government has granted the private sector some flexibility. For instance, the developer PowerHive was recently granted permission to charge its own rates (Herbet & Phimister, 2019).

Despite some positive moves therefore the implementation of mini-grid regulation in Kenya still lacks clarity and has faced considerable resistance by KPLC.

4.4.2 Tanzania

With one of the lowest electrification rates in East Africa, less than 40% of Tanzania's 68 million population had access to electricity in 2023 (see Table 4.2). Electricity supply is unstable, and the transmission grid only extends to certain parts of the country. There are large areas, particularly in the sparsely populated western and southern regions, where the grid does not reach. Electricity generation capacity stood at 2 GW in 2023 and is dominated by large hydroelectricity (600 MW) and natural gas (1.02 GW), though the former has been challenged by regular droughts (Power Africa, 2022a). Meanwhile there are significant plans for the scale up of coal-fired power (Power Africa, 2022a). Of those with electricity access, 25% are supplied by the grid or mini-grids and 8% from SHSs (IEA, 2019; URT, 2020). According to SEforAll and BNEF (2020, p. 140), by 2019 Tanzania had 209 known operational mini-grids, with a total installed capacity of 231.7 MW, accounting for approximately 15% of the country's total capacity. Of these projects, almost one-third are third generation and are dwarfed by older hydro and diesel projects in terms of installed capacity.

Despite previous attempts at privatization in the late 1990s, electricity generation, transmission, and distribution in Tanzania are still dominated by the vertically integrated, state-owned monopoly utility TANESCO (Tanzania Electric Supply Company Limited), governed under the Public

Corporations Act of 1992 and the Companies Act of 2002 (Godinho & Eberhard, 2018). However, various reforms along the lines of the standard model of power sector reform (discussed in Section 4.2) were implemented. These include the introduction of an independent regulator in 2007; the Energy and Water Utilities Regulatory Authority (EWURA), which sets electricity tariffs and oversees licensing; and following the 2008 Electricity Regulation Act, the formation of various IPPs and small power producers (SPP), including mini-grids, with whom TANESCO has power purchase agreements (Godinho & Eberhard, 2018).

Tanzania's 2014 to 2025 Electricity Supply Industry Reform Strategy sets out plans for the unbundling of the electricity sector, although key steps within this have already been delayed (Godinho & Eberhard, 2018). Similar to Senegal's Plan Sénégal Emergent (Section 4.4.4), and Kenya's Vision 2030 plan (Section 4.1), this reform strategy is driven by the Tanzanian Development Vision, which achieved lower middle-income status by 2020.

The most relevant government institutions responsible for electricity are the Ministry of Energy, until 2017 the Ministry of Energy and Minerals, which holds overall responsibility for energy policy and the governance of TANESCO; and the Rural Energy Agency (REA(T)), which was established in 2007 under the 2005 Rural Energy Act with a mandate to scale up rural electrification and electricity access. The REA(T) reports to the Ministry of Energy.

Despite the incomplete liberalization of its electricity sector, Tanzania's regulatory environment for the encouragement of decentralized renewable energy systems through private participation, including mini-grids, is considered relatively advanced. This regulation has been developed with significant support and technical assistance from development finance institutions (DFIs) and donors (Odarno et al., 2017, p. 43; Peters et al., 2019, p. 28). As in the case of Kenya, Tanzania has also been heralded as a success story for the deployment of SHSs (Odarno et al., 2017). The country's mini-grid regulation largely evolved out of its 2008 Electricity Regulation Act and related initiatives, including the SPP framework, introduced in 2008 and revised in 2015. The first iteration of the SPP framework saw a technology neutral fixed feed-in tariff under which 52 mini-grid projects with a combined capacity of 67 MW were commissioned (Odarno et al., 2017, p. 40). The majority of these projects were hydro and biomass mainly because of the technology neutrality of the SPP framework which discouraged mini-grids from solar PV and wind due to their higher upfront costs.

The SPP framework was revised in 2015 to reflect different technology costs, plant sizes, and site-specific characteristics (Odarno et al., 2017, p. 40). Feed-in tariffs have now been set for hydro, biomass, wind, and solar projects of 0.1 to 1 MW, while a competitive bidding process is required for wind and solar projects of 1 to 10 MW (Odarno et al., 2017, pp. 44–48). The current framework has also removed barriers for mini-grid projects of up to 10 MW: isolated mini-grids of up to 1 MW are not required to apply for a license, do not need regulatory approval and need only to register with the regulator (Pedersen, 2016, p. 14); and systems with a capacity of 0.1 to 10 MW are allowed to feed into the grid. The revisions further pegged tariffs to the US dollar, a move which may incentivize international developers with access to international debt finance but deter local developers seeking finance in Tanzanian shillings. This move may also mean that TANESCO ends up absorbing the additional cost of any currency depreciation of the shilling against the dollar for electricity supplied by IPPs and SPPs.

Other initiatives for the promotion of mini-grids in Tanzania include the off-grid component of the World Bank–funded Tanzania Energy Development and Access Project (TEDAP), launched in 2011 and managed by the REA with funding from the World Bank (Pedersen, 2016; SEforAll & BNEF (2019)); and the Scaling Up Renewable Energy Program (SREP), launched in 2013 to catalyze the large-scale development of renewable energy and mini-grids with commercial anchor clients.

Despite Tanzania's mini-grid regulations being considered relatively advanced, the sector's development has in recent years been hampered by an "overly complicated implementation process," government opposition, and the increasing insolvency of TANESCO (Odarno et al., 2017, p. 50). Moreover, "issues concerning implementation and enforcement, as well as elements within the regulations themselves, have recently restricted private-sector investment in mini grids" (ESMAP, 2019, p. 33). Since 2016 TANESCO has been unable to meet its financial obligations to IPPs and SPPs, partly because the government has not allowed the regulator to raise TANESCO's tariff. As a result, the government has bailed out TANESCO for several years.

The institutional governance of the Tanzanian power sector is such that the president and his appointees have significant political power over planning and operations in the sector, which, "unchecked by a disempowered technical and managerial staff, has also allowed for corruption in the sector on a grand scale" (Godinho & Eberhard, 2018, p. 7). There is also a long-standing national ideological suspicion of

private sector involvement and foreign interference (Godinho & Eberhard, 2018). According to Aly et al. (2019), in recent years, the government has grown increasingly obstructive and unpredictable, which has created uncertainty for infrastructure investors, such as InfraCo Africa; developers; and bilateral donors. Developers have become frustrated with a lack of regulatory coordination, including cases where the national power grid has been extended into a mini-grid area. As Jaglin and Guillou (2020, p. 60) explain "it is not unusual for [developers] to discover that the grid is about to arrive, just months after installing their equipment in a locality." High mini-grid tariffs have also led to wealthier users moving back to the national grid, while poorer users, who are not considered profitable for private sector developers, remain as captive clients. The Tanzanian regulator is working on regulations to deal with circumstances in which the grid is extended to the same distribution area as a mini-grid, which would mean that if the mini-grids meet national standards, they can either choose to become bulk distributors or negotiate selling their infrastructure to TANESCO.

For reasons discussed above, the UK's Department for International Development (DFID), now Foreign Commonwealth and Development Office (FCDO), closed its contribution to the Green Mini-Grid's Tanzania program in March 2019, although the program, which uses a form of Results-Based Financing and is led by the REA(T) and jointly funded with Sida, has continued (Hunt, 2019). The future of the mini-grid sector in Tanzania therefore remains uncertain.

4.4.3 Nigeria

With approximately 240 million people, Nigeria is predicted to become the world's third most populous country by 2050. Approximately 66% of the population has an electricity connection, of which 85% in urban areas and 33% in rural areas (see Table 4.2). Biomass and waste currently make up the majority of Nigeria's primary energy supply and only 15% of the population have access to clean cooking. The remainder rely on polluting and inefficient cookstoves (Sesan, 2021).

Nigeria has the second most unreliable electricity supply on the continent (Afrobarometer, 2022). Though its potential generation capacity stands at approximately 16,000 MW from existing plants, actual dispatchable output is only around 4,000 MW, of which the majority is from

gas and to a lesser extent hydroelectricity (Edomah et al., 2021; Power Africa, 2022c). The majority of the country's electricity consumers, therefore, depend on costly self-generation from small and medium-scale diesel generators. Reasons for the shortfall in generation capacity are complex and long-standing but include problems with gas and water supply, high technical losses, financial shortfalls within the utility, poorly maintained infrastructure, energy theft, and corruption throughout the electricity value chain (Edomah et al., 2021; Roche et al., 2020; Roy, 2020). Periodic increases in electricity tariffs are often met with resistance from the public and labor unions, partly reflecting the low purchasing power of the majority, but also public perceptions of the power sector as corrupt and untransparent (Edomah et al. 2021).

Nonetheless, Nigeria has been promoted as a "frontier" country in terms of the comprehensiveness of its mini-grid regulations, including licensing, retail tariff-setting, and arrangements for the arrival of the main grid (ESMAP, 2019, p. 9; SEforAll et al., 2024). By the end of 2023, the country's estimated installed mini-grid capacity was about 14 MW, with a total of 117 projects (SEforAll et al., 2024, p. 25). Solar with battery and solar diesel hybrid mini-grids, as well as SHSs have started to play a key role in replacing Nigeria's diesel generators (Roche et al., 2020). The majority of solar hybrid mini-grids installed thus far are being operated by private sector developers backed by DFIs and bilateral donors (SEforAll & BNEF (2019), pp. 146–147).

The Energy Commission of Nigeria is nominally responsible for overall energy policy, but, in recent years, the Federal Ministry of Power has become the dominant state actor over electricity policy. The electricity sector was previously dominated by the state-owned monopoly utility, the National Electric Power Authority (NEPA). However, after the 2005 Electric Power Sector Reform Act (EPSRA) introduced the relevant legal and regulatory arrangements for power sector liberalization, NEPA was transformed into the Power Holding Company of Nigeria (PHCN). By 2013, the PHCN had been unbundled into eleven private regional distribution companies (DisCos) and seven private generating companies (GenCos) and sold on (Edomah, 2015). The single transmission company remained in the hands of the federal government and was concessioned to the Canadian firm Manitoba Hydro. This concession expired in 2016, and the company's management is now back in the hands of the federal government, which is considering the outright privatization of company (Jeremiah, 2021; Oni, 2020).

Two other key institutions that were established out of the EPSRA were the Nigerian Electricity Regulatory Commission (NERC) in October 2007, and the Rural Electrification Agency (REA) in 2006 (Edomah, 2015). NERC is responsible for issuing licenses and permits to private companies in the electricity sector and ensuring compliance with rules and regulatory guidelines. An implementing agency of the Federal Ministry of Power, REA has a core mandate to "promote, support and provide rural electrification through Public and Private Sector Participation and administer the rural electrification fund (REF)" (REA, n.d.).

The EPSRA also led to the introduction of various instruments for the promotion and development of mini-grids, which for the most part were designed with technical assistance from bilateral and multilateral donors. These instruments include, first, the Renewable Energy Master Plan (REMP), introduced in 2006 and updated in 2011, which seeks to increase the supply of renewable electricity to 23% of total electricity generation by 2025 and 36% by 2030 (IEA/IRENA, 2013). Second, in July 2016, the Rural Electrification Strategy and Implementation Plan (RESIP) was introduced, in which mini-grids are anticipated to play a significant role. In parallel, Nigeria's national climate plan has pledged to work toward installing 13 GW of solar power by 2030 (Federal Government of Nigeria, 2015).

Third, NERC introduced a regulatory framework in 2017 under which mini-grids of 1 MW or below may either be isolated, to be deployed in an area within a DisCo's network, where there is no existing distribution system, or interconnected to a DisCo's network in an underserved area (SEforAll & BNEF (2019), p. 146). In the case of the latter, operators must enter a tripartite contract with the community and the DisCo and gain NERC's approval (Aigbomian, 2019; NERC, 2018). There are different requirements for different sizes of mini-grids, as follows:

- Projects below 100 kW are only required to obtain a simple registration with NERC but may still choose to obtain a permit voluntarily because this will qualify the project for exit compensation should the distribution grid arrive (ESMAP, 2019, pp. 33–34).
- Projects between 100 kW and 1 MW must obtain a permit and adhere to minimum network, technical, and safety standards. Should the main distribution grid arrive and displace the mini-grid's operations, the permit holder will then be entitled to compensation equivalent to

the depreciated value of the mini-grid's network investment, plus one year's worth of revenue (NERC, 2018).

Generation projects larger than 1 MW are governed by the provisions of the EPSRA.

Fourth, the National Electrification Project (NEP) was introduced in 2018 alongside grid expansion plans (Edomah et al., 2021). One of its four core components is for "solar hybrid mini-grids for rural economic development" (Aigbomian, 2019; NERC, 2018; REA, 2019). The component is being implemented by REA on behalf of the federal government and aims to leverage large-scale private sector investments for electricity access for off-grid households, and micro, small, and medium enterprises (O'Sullivan, 2018, p. 7). It is the largest mini-grid program in Africa, with a target of 850 projects and an approximate capacity of 3,000 MW by 2025 across 250 sites in four states: Niger, Sokoto, Ogun, and Cross River (ESMAP, 2019, p. 37; REA, 2019). A loan for this component, prepared with support from ESMAP and approved in 2019, consists of $150 million from the International Development Association (IDA, the World Bank's low-income lending arm) and $200 million from the African Development Bank. The loan is anticipated to leverage $220 million in private sector investment through a performance-based grant and minimum subsidy tender for renewable energy mini-grid developers (GMP, 2019).

However, notwithstanding the apparent comprehensiveness of the much-lauded NERC regulations and other measures, mini-grid progress has thus far been hampered by various factors, including insufficient policy and limited government follow-up on existing policies, conflicts between DisCos and potential developers (Akinyele et al., 2019; Arowolo et al., 2019), a long-standing inability on the part of NERC to agree appropriate tariff structures with small-scale developers (Kemabonta et al., 2019), high investment costs which have been exacerbated by the lack of long-term patient capital and domestic commercial financing, and challenges to the creation of national technological capabilities. Tenders for isolated and interconnected mini-grids that are in the process of being issued have also experienced delays, in no small part due to COVID-related interruptions.

Moreover, mini-grid projects in Nigeria tend to be self-selecting in that they are typically implemented in areas where prior demand has been established; specifically, communities where people are accustomed to

using paraffin and/or diesel generators to meet their energy needs. While these communities invariably experience significant reductions in their energy expenses by switching to solar or hybrid mini-grids, they still pay much more for electricity than do grid-connected communities. The resolution of the tariff issue could therefore prove critical to the ability of mini-grids to scale up beyond a small number of communities.

Consequently, and as Akinyele et al. (2019) and Arowolo et al. (2019) argue, more proactive government support and involvement could help the existing mini-grid regulations to translate into substantial improvements in electricity access. Measures to achieve this could include bottom-up strategies such as engaging communities in the design of mini-grid projects, and more top-down approaches such as strengthening the capacity of state and market actors to implement the projects.

4.4.4 Senegal

Prior to 2012, Senegal experienced regular and prolonged electricity blackouts and load-shedding, accompanied by rising electricity tariffs. However, in recent decades, electricity security and access have improved in line with the government's commitment to achieve universal access to electricity by 2025 and increase the country's installed capacity to 2,500 MW by 2030 (Get.Invest, 2020). Installed capacity increased from 590 MW in 2010 to 1.56 GW in 2023 (Ember, 2024). By 2023, the electricity connectivity rate was at 74% of the population (see Table 4.2). While the country's electricity generation is still heavily dependent on fossil fuel generation, renewable energy is becoming an increasingly established niche sector.

As in the case of Kenya and Tanzania, infrastructure development, power sector reform, the reduction of electricity tariffs, and the overhaul of the generation mix are key components of Senegal's former national economic development strategy, the Plan Sénégal Emergent (PSE),[2] which aimed to achieve middle-income country status by 2035 (Gouvernement de la République du Sénégal, 2014). The deployment of solar PV was at the core of the PSE, which includes a target for renewables to meet 20% of all power production by 2017 (Ministère de l'Energie et du Développe-

[2] Replaced by the Vision Senegal 2050 in October 2024.

ment des Energies Renouvelables and ECREEE, 2015, p. 8). This target was eventually achieved at the end of 2019.[3]

However, despite such progress, there is considerable disparity between an urban and rural electrification rate of 96% and 56%, respectively, which reflects more general inequalities in the country (Table 4.2). While the national grid, owned and managed by the state power utility Société Nationale l'Électricité du Sénégal (Sénélec), reaches most of the country's urban centers and large rural habitations, the energy poor in the hardest to reach areas are still largely dependent on biomass such as wood fuel, crop residue, and animal dung. Senegal has the highest electricity tariffs in West Africa (GPP, 2025).

Senegal's electricity sector is now partially liberalized and overseen by the Ministère du Pétrole et des Energies (MPE), which holds overall responsibility for strategy and policy. Sénélec holds the monopoly on transmission and distribution and just under half of generation, with the remainder coming from IPPs that sell exclusively to the utility (IDA, 2016). The process of power sector liberalization began in 1998 with the passing of the Electricity Law No. 98-29 (CRSE, 1998) and has included:

A strategy to increase private sector engagement in the sector;
The creation of the energy regulator, La Commission de Régulation du Secteur de l'Électricité (CRSE), which is responsible for setting tariffs and licensing standards;
The updating of the governing policy of the energy sector, La Lettre de Politique de Développement du Secteur de l'Energie (LPDSE), to include key objectives for private participation and institutional reform[4]; and
The creation in 2013 of an autonomous agency within the MPE to promote rural electrification and grant technical and financial assistance to enterprises working in the sector, L'Agence Sénégalaise d'électrification rurale (ASER; Senegalese Agency for Rural Electrification) (Ministère du Pétrole et des Energies, 2020).

As part of the liberalization process, in 1998 the government also divided the country's rural regions into ten large concession areas for electrification, called Programmes Prioritaires d'Électrification Rurale (PPER;

[3] https://www.aner.sn/solutions/energie-solaire/.

[4] The LPDSE was released in 1997 and subsequently updated in 2002, 2008, 2012, and for the period 2019 to 2023 (Ba, 2018).

priority rural electrification programs), managed by ASER (RECP, n.d.). Under a bidding program supported by DFIs and bilateral donors, international developers operating in partnership with Senegalese companies have bid for concessions to construct a mix of grid extension and off-grid electrification for supply to local populations using a variety of technologies, including mini-grids, under a 25-year mandate. However, there were various challenges to the implementation of these programs including bureaucratic issues and a lack of capacity in key agencies, as a result of which there were significant delays in awarding the concessions (Ba, 2018; SEforAll and BNEF (2019), p. 78). Four out of the ten concessions were not allocated to private sector companies and are now under the management of Sénélec (Get.Invest, 2020). Second, the tariffs for this electrification have been capped at below cost and vary across concessions, which has deterred private investors, despite the fact that government has offered to cover up to 70% of capital expenditure through subsidies.

In parallel to the concessionary system, the Electrification Rurale d'Initiative Locale (ERIL; Locally Initiated Rural Electrification), also managed by ASER, allows private micro-utilities to supply electricity to local communities through the implementation and operation of stand-alone third-generation mini-grids. These systems must either be situated outside of the ten larger regional concessions discussed above and/or in communities in which there are no plans for grid-based electrification for the next three years (SEforAll and BNEF (2019), p. 78). Under the ERIL scheme, 80% of the mini-grid investment cost is financed by the German bilateral donor GIZ, 10% by customers, and 10% by the private operator (RECP, n.d.). As with the concession scheme, however, only a small number of mini-grids were developed under the ERIL scheme. In a potentially progressive move, in March 2019, ASER signed a contract with the German company GAUFF Engineering to install an additional 300 mini-grids, and in January 2020, ASER invited bids for the construction of mini-grids in an additional 133 villages (Get.Invest, 2021).

In 2004, a renewable energy procurement program for IPPs was implemented, with which Sénélec is now forced to compete. This partial privatization process was met with significant opposition, including a major strike by the trade union Syndicat Unique des Travailleurs de l'Électricité and the imprisonment of its leader (Havard, 2018, p. 94). Despite this opposition, the country adopted its Renewable Energy Law in 2010, the objectives of which include increasing renewable energy generation to 20% of total installed capacity by 2017, reducing the cost of electricity

generation and the tariff for households and companies, and increasing the share of renewables in the energy mix in order to improve the national energy security (ECREE, 2018). A further step was the creation of a dedicated renewable energy department (ANER) within Sénélec (ECREE, 2018). Various other agencies for rural electrification also emerged after 2010, including the National Ecovillage Agency. However, following Jaglin and Guillou (2020), there has been mission overlap and a lack of coordination and accountability between these multiple agencies.

A more recent outcome of the liberalization process that has been considered more successful has been a program for the procurement of utility-scale renewable energy from IPPs, including with support from the IFC's Scaling Solar. According to IRENA (2021), by the end of 2020, there was 246 MW of renewable energy generating capacity installed in the country with more in the pipeline. Of this, an estimated 171 MW is from utility-scale solar PV of between 20 and 30 MW, and 50 MW from wind (CAMCO Clean Energy, 2020).

Reforms to clarify the complex regulation that currently exists for renewable energy at both the utility and decentralized scales are under consideration. For instance, legislation was passed in December 2018 to subsidize concessionaires and allow them to bring rates down to the state-owned utility Sénélec's grid retail tariffs, a measure which would in principle increase the share of the rural population able to pay the high tariffs for mini-grid-generated electricity (SEforAll and BNEF (2019), p. 78). While Senegal lacks detailed regulations regarding grid arrival in the vicinity of established mini-grids, in practice, compensation for developers has been carried out across the board. Below 50 kW, mini-grid developers do not require a license (SEforAll and BNEF (2019), p. 84).

Until recently, diesel-generated mini-grids in Senegal were largely government-owned and operated by Sénélec. However, since the government introduced regulation to allow for private sector participation, private companies have become more involved in the sector. According to SEforAll and BNEF (2020, p. 46), as of 2019 Senegal had 272 mini-grids installed of which 63 projects had been built under the rural electrification component of the Energizing Development (EnDev) program, which has run since 2005 and is funded by GIZ and other donors. However, it is not clear how many of these grids are currently operational. A further 1,217 mini-grids are planned, which are anticipated to be largely solar PV generated (ESMAP, 2019, p. 48).

Finally, despite recent developments, existing bilateral support and the fact that mini-grids are anticipated to play a key role in meeting the government's targets for universal access and renewable energy, numerous challenges remain. These include hesitancy on the part of the private sector to invest and the lack of a clear and targeted regulatory framework. According to Ulsrud, the government has been reluctant to allow tariff-setting regulations that could enable solar mini-grid developers to be economically sustainable in areas where the national grid is not yet established: "New regulations for uniform tariffs and cross-subsidization to companies operating in remote areas were suggested by government officials but were not likely to be finished soon" (Ulsrud, 2020, p. 59). Private investment has therefore been discouraged by the government's position that everyone should pay the same tariff, whether they receive electricity from the national grid, mini-grids, or other off-grid provision (Ulsrud et al., 2018, p. 38). Investors have further been discouraged by the current legal requirement that mini-grid operators should withdraw under all circumstances once a locality is connected to the national grid given the ERIL's requirement that systems cut the supply once a daily quota is exceeded (Jaglin & Guillou, 2020).

4.5 Conclusion

As this chapter has discussed, the positive narrative behind third-generation mini-grids has led to them being seen as a game changer for the realization of the goal of universal access of SEforAll and SDG7. Because of their technological versatility mini-grids have been championed, particularly by the private sector and DFIs, as a way to bypass failing, often indebted, crisis-ridden, large-scale, capital-intensive monopoly utilities in many LMICs. However, as the case studies have illustrated, despite the potential of mini-grids they are not necessarily the panacea for energy access that they are often promoted as. Thus far, many citizens on a low-income are still excluded from both the centralized grid and/or decentralized alternatives. Moreover, the deployment of these new technological configurations is far from straightforward, and they have faced a variety of technical, economic, political, and social challenges. While some of these challenges are specific to the countries in question, others are common across contexts. With this in mind, we offer the following five conclusions.

First, in examining the case of mini-grids in the four case study countries, this chapter has identified evident tensions between state and private sector ownership of the electricity sector, centralized and decentralized systems, and priorities for energy access and productive use. In the case of Kenya, Tanzania, and Senegal, in particular, and perhaps less so Nigeria, there has been an ambiguity and/or a resistance by some government institutions, in particular state-owned utilities, toward mini-grid development. On the one hand, national regulatory frameworks and policies for mini-grids and the participation of private actors are being put in place by government institutions responsible for energy, particularly the regulator. On the other hand, there is still a strong national political discourse regarding the extension of the electric grid and support for the centralized utility. This internal conflict appears particularly strong in the case of Tanzania. Such tensions are enhanced by multiple and at times bewildering overlapping processes and institutions, at once for power sector liberalization and the introduction of mini-grid regulation, and between whom coordination is not entirely clear. This confusion has contributed to the regulatory uncertainty, which appears to have discouraged investors in the case study countries.

A second conclusion relates to the extent to which mini-grid regulation is nationally owned and in whose best interests these regulatory frameworks are being introduced. Such a question relates back to the standard model of power sector reform discussed in Section 4.2, a process which has been far from straightforward and in many instances has resulted in an incomplete liberalization process. This question may also relate to the fact that in Kenya, Tanzania, and Senegal, the reform of the power sector and the introduction of renewable energy forms part of a wider national goal to attain middle-income country status. As the case studies have illustrated, the development of third-generation mini-grids has been largely backed by an international private sector with a portfolio-based approach to investment and ownership. Indeed, the mini-grid value chain, including technology supply, is for the most part internationally owned. This private sector has in turn been supported by technical assistance and financial leverage from DFIs and bilateral donors, who have played a key role in supporting national regulators with the design of the relevant regulation. However, as discussed in Section 4.2, national regulators do not seem to have had the necessary bargaining power anticipated by the standard model. In all four countries, regulators have had less power and influence over the implementation of mini-grid regulation than institu-

tions that prioritize the continuation of the centralized grid. A key example of this is ERC/EPRA and KPLC in the case of Kenya.

Third, the electricity system in its centralized form is now subject to significant challenge from decentralized technological systems, which, if successfully scaled up, have the potential to disrupt the network architecture and structure of a centralized monopoly. However, as we have discussed, the shift toward private participation in mini-grids has faced its own challenges, one of which is the absence of a tariff structure that is deemed acceptable at once to investors, developers, the government, and consumers. For instance, as discussed in the case of Senegal, government has been reluctant to allow tariffs that could enable third-generation mini-grids to be economically sustainable in areas where the national grid is not yet established. A related challenge is that the extension of the centralized grid to areas in which mini-grids have recently been installed is generally seen as an investment risk for developers rather than an opportunity (Muchunku et al., 2018). A key reason for this, as Kenya, Tanzania, and Senegal illustrate, is limited clarity on the status of mini-grids which have been installed in areas where the centralized grid may later arrive. Moreover, predictions regarding the assumed future cost competitiveness of mini-grids with conventional grid-based generation may need to consider that thus far, rural electrification efforts have for the most part been heavily dependent on some kind of public subsidy.

Finally, this research puts forward two key areas for further research. First, while various parallels and comparisons can be drawn across the case studies, for instance regarding experiences of power sector reform, the introduction of mini-grid regulation and the influence of international trends and state priorities, there are also significant differences in national circumstances. For instance, in terms of levels of rural/urban energy access, population size as well as political, economic, and socio-cultural dynamics. There is therefore a danger of assuming that lessons can be transferred from one country to another, and in order to avoid such assumptions, in-depth interrogation of these important geographical specificities is needed.

Second, and to conclude, this study puts forward important theoretical implications regarding how the changing social, political, economic and technological configurations of electricity, its governance and ownership, should be accounted for. Growing contributions from energy geography and development studies provide useful insights into conceptualizing the evolving governance of decentralized electricity. Despite assumptions by some that the decentralization of electricity may also be accompanied by

the democratization of accompanying structures and institutions, technological disruption is not necessarily aligned with political or socio-economic disruption. And decentralization does not necessarily make electricity more affordable for the poorest users. A deeper political economy and critical governance focus could therefore be brought to bear in order to understand the messy politics of electricity sector reform under rapid technological changes for decentralization.

References

Afrobarometer. (2022, April 8). *Countries with the least reliable supply of electricity in Africa in 2019/2021 [Graph]*. Statista. https://www.afrobarometer.org/wp-content/uploads/2022/04/ad514-pap10-still_lacking_reliable_electricity_from_the_grid-many_africans_turn_to_alternative_sources-afrobarometer-10april22.pdf

Ahlborg, H. (2018). Changing energy geographies: The political effects of a small-scale electrification project. *Geoforum*, *97*, 268–280.

Aigbomian, F. M. (2019, February 18). *Nigeria: The NERC mini-grid regulations and the Nigerian mini-grid market: Opportunity for investment*. Mondaq. https://www.mondaq.com/nigeria/renewables/781960/the-nerc-mini-grid-regulations-and-the-nigerian-minigrid-market-opportunity-for-investment

Akinyele, D., Belikov, J., & Levron, Y. (2019). Challenges of microgrids in remote communities: A STEEP model application. *Energies*, *1*(2), 432.

Aly, A., Moner-Girona, M., Szabó, S., Pedersen, A. B., & Jensen, S. S. (2019). Barriers to large-scale solar power in Tanzania. *Energy for Sustainable Development*, *48*, 43–58.

Arowolo, W., Blechinger, P., Cader, C., & Perez, Y. (2019). Seeking workable solutions to the electrification challenge in Nigeria: Minigrid, reverse auctions and institutional adaptation. *Energy Strategy Reviews*, *23*, 114–141.

Ba, A. S. (2018). *The energy policy of the Republic of Senegal: Evaluation and perspectives*. https://hal.archives-ouvertes.fr/hal-01956187/document

Baker, L., Hook, A., & Sovacool, B. (2021). Power struggles: Governing renewable electricity in a time of technological disruption. *Geoforum, 118*, 93–105.

Baker, L., & Phillips, J. (2018). Tensions in the transition: The politics of electricity distribution in South Africa. *Environment and Planning C: Politics and Space*, *37*(1), 177–196.

Balls, J. N., & Fischer, H. W. (2019). Electricity-centered clientelism and the contradictions of private solar microgrids in India. *Annals of the American Association of Geographers*, *109*(2), 465–475.

Bhattacharyya, S. C., & Palit, D. (2016). Mini-grid based off-grid electrification to enhance electricity access in developing countries: What policies may be required? *Energy Policy*, *94*, 166–178.

Boamah, F. (2020). Emerging low-carbon energy landscapes and energy innovation dilemmas in the Kenyan periphery. *Annals of the American Association of Geographers*, *110*(1), 145–165.

Boamah, F., & Rothfuß, E. (2020). From technical innovations towards social practices and socio-technical transition? Re-thinking the transition to decentralised solar PV electrification in Africa. *Energy Research & Social Science*, *42*, 1–10.

Bridge, G., Bouzarovski, S., Bradshaw, M., & Eyre, N. (2018). Geographies of energy transition: Space, place and the low-carbon economy. *Energy Policy*, *53*, 331–340.

CAMCO Clean Energy. (2020). *Senergy 2: Project summary*.

Castán Broto, V., & Baker, L. (2018). Spatial adventures in energy studies: An introduction to the special issue. *Energy Research and Social Science*, *36*, 1–10.

CRSE. (1998). *Loi n° 98-29 du 14 avril 1998 relative au secteur de l'électricité*.

Day, T., & Kurdziel, M.-J. (2019). *The role of renewable energy mini grids in Kenya's electricity sector: Evidence of a cost-competitive option for rural electrification and sustainable development*. New Climate Institute. https://newclimate.org/sites/default/files/2019/11/The-role-of-renewable-energy-mini-grids-in-Kenya%E2%80%99s-electricity-sector.pdf

Edomah, N. (2015). Historical drivers of energy infrastructure change in Nigeria (1800–2015). In *Energy management for sustainable development* (pp. 23–45). IntechOpen. https://www.intechopen.com/chapter/pdf-download/59325

Edomah, N., Ndulue, G., & Lemaire, X. (2021). A review of stakeholders and interventions in Nigeria's electricity sector. *Heliyon*, *7*(9).

Ember. (2024). *Electricity data explorer: Installed capacity*. https://ember-energy.org/data/electricity-data-explorer/?data=capacity

EPRA. (2021a). *The Draft Energy (Mini-Grid) Regulations, 2021*. https://www.epra.go.ke/wp-content/uploads/2021/05/MINIGRID-REGULATIONS-REGULATORY-IMPACT-STATEMENT-FINAL-1.pdf

EPRA. (2021b). *Least Cost Power Development Plan, 2021–2030*. https://communications.bowmanslaw.com/REACTION/emsdocuments/LCPD%202021.pdf

ESI-Africa. (2021). *Interrogating Kenya's draft mini grid regulations*. https://www.esi-africa.com/industry-sectors/future-energy/interrogating-kenyas-draft-minigrid-regulations/

ESMAP. (2019). *Mini grids for half a billion people*.

ESMAP. (2022) Mini Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers. Energy Sector Management Assistance Program. Washington DC: World Bank.

ESMAP. (2024). *Tracking SDG 7, results worldwide*. https://trackingsdg7.esmap.org/

A. Fajardo, L.H. Baker, T. Sesan, S. Bhattacharyya, D. Kerr, M. Katyega, A. Barnett,(2025) 'Business models and access to finance for mini grid development in sub-Saharan Africa, Energy for Sustainable Development', (85)

Federal Government of Nigeria. (2015). *Nigeria's Intended Nationally Determined Contribution*. https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Nigeria%20First/Approved%20Nigeria's%20INDC_271115.pdf

Foster, V., & Rana, A. (2020). *Rethinking power sector reform in the developing world*. Sustainable Infrastructure Series. World Bank.

Gaiya, A. B. S., Okoroafor, G. P., Fagorite, V. I., Chuan Ho, P. W., & Sarimuthu, C. R. (2025). *A whole-of-state approach to renewable energy mini-grid development in Africa*. https://ssrn.com/abstract=5173300

Get.Invest. (2020). *Senegal: Energy Sector*. https://www.get-invest.eu/market-information/senegal/energy-sector/

Get.Invest. (2021). *Senegal: Market segments*. https://www.get-invest.eu/market-information/senegal/market-segments/

Godinho, C., & Eberhard A. (2018). *Chapter 7: Power sector reform and regulation in Tanzania*. Oxford Policy Management. https://edi.opml.co.uk/wpcms/wp-content/uploads/2018/09/07-TID_Power-sector.pdf

Godinho, C., & Eberhard, A. (2019). *Learning from power sector reform experiences: The case of Kenya*. Policy Research Working Paper 8819, World Bank Group, Energy and Extractives Global Practice.

https://openknowledge.worldbank.org/bitstream/handle/10986/31561/WPS8819.pdf?sequence=4&isAllowed=y

Gollwitzer, L., Ockwell, D., Muok, B., Ely, A., & Ahlborg, H. (2018). Rethinking the sustainability and institutional governance of electricity access and mini grids: Electricity as a common pool resource. *Energy Research & Social Science*, *39*, 152–161.

Gouvernement de la République du Sénégal. (2014). *Plan Sénégal Emergent (PSE)*.

GPP. (2025, March 10). *Household electricity prices in Africa as of June 2024, by country (in U.S. dollars per kilowatt hour)*. Statista. https://www-statista-com.libezproxy.open.ac.uk/statistics/1277594/household-electricity-prices-in-africa-by-country/

Gratwick, K. N., & Eberhard, A. (2008). Demise of the standard model for power sector reform and the emergence of hybrid power markets. *Energy Policy*, *36*(10), 3948–3960.

GMP (Green Mini Grids Partnership). (2019, April 9). *Update on UK DFID support to the Green Mini grids sector in Africa*. https://minigrids.org/update-on-uk-dfid-support-to-the-green-mini-grids-sector-in-africa/

Herbert, C., & Phimister, E. (2019). Private sector-owned mini grids and rural electrification: A case study of wind-power in Kenya's tea industry. *Energy Policy*, *132*, 1288–1297.

Hunt, S. (2019, April 9). *Update on UK DFID support to the green mini grids sector in Africa*. https://minigrids.org/update-on-uk-dfid-support-to-the-green-mini grids-sector-in-africa/

IDA (International Development Associate). (2016, July 7). *Project paper on a proposed additional credit in the amount of Euro 62.8 million (US$70 million equivalent) to the Republic of Senegal for the electricity sector support project*. https://documents1.worldbank.org/curated/en/593131470244330855/txt/PAD1815-PJPR-P158655-OUO-9-IDA-R2016-0184-1.txt

IEA. (2019). *Report extract: Access to electricity*. https://www.iea.org/reports/sdg7-data-and-projections/access-to-electricity

IEA, IRENA, UNSD, World Bank, WHO. (2025). Chapter 1, access to electricity. In *Tracking SDG 7: The Energy Progress Report*. World Bank. https://trackingsdg7.esmap.org/downloads

IEA/IRENA. (2013, July 3). *Nigeria Renewable Energy Master Plan*. IEA/IRENA Renewables Policies Database. https://www.iea.org/policies/4974-nigeria-renewable-energy-master-plan

IRENA. (2021, September 29). *Energy profile, Senegal*. https://www.irena.org/IRENADocuments/Statistical_Profiles/Africa/Senegal_Africa_RE_SP.pdf

Jaglin, S., & Guillou, E. (2020). Decentralized electricity solutions: Innovation in essential services is no substitute for policy. *Field Actions Science Reports*, Special Issue 22. http://journals.openedition.org/factsreports/6326

Jeremiah, K. (2021, May 28). Fresh concerns greet planned privatization of TCN. *The Guardian Nigeria*. https://guardian.ng/business-services/fresh-concerns-greet-planned-privatization-of-tcn/

Kemabonta, T., Geoffrey, A. O., & Uzzle, S. (2019). What went wrong and how can we fix it: Renewable energy and mini-grid policies in Nigeria. In *2019 IEEE PES/IAS PowerAfrica* (pp. 76–80). IEEE.

Knuckles, J. (2016). Business models for mini-grid electricity in base of the pyramid markets. *Energy for Sustainable Development*, *31*, 67–82.

Lighting Global, GOGLA and ESMAP. (2020). *Off-grid solar market trends report*. https://www.lightingglobal.org/wp-content/uploads/2020/03/VIVID%20OCA_2020_Off_Grid_Solar_Market_Trends_Report_Full_High.pdf

McDonald, D. (2009). Electric capitalism: Conceptualising electricity and capital accumulation in (South) Africa. In D. McDonald (Ed.), *Electric capitalism: Recolonising Africa on the power grid*. HSRC Press.

Ministère de l'Energie et du Développement des Energies Renouvelables and ECREEE. (2015). *Plan d'Actions National des Energies Renouvelables (PANER) SENEGAL Période [2015-2020/2030]*. https://www.se4all-africa.org/fileadmin/uploads/se4all/Documents/Country_PANER/Senegal_Plan_d_Actions_National_des_Energies_Renouvelables_pdf

Ministère du Pétrole et des Energies. (2020). *L'Agence Sénégalaise d'Electrification rurale (ASER)*. https://energie.gouv.sn/les-agences/

Muchunku, C., Ulsrud, K., Palit, D., & Jonker-Klunne, W. (2018). Diffusion of solar PV in East Africa: What can be learned from private sector delivery models? *Wires Energy and Environment*, *7*(3), e282.

NERC. (2018). *Nigerian Electricity Regulatory Commission: Regulation for mini grids 2016*.

Odarno, L., Sawe, E., Swai, M., Katyega, M. J. J., & Lee, A. (2017). *Accelerating mini-grid deployment in sub-Saharan Africa: Lessons from Tanzania*. World Resources Institute. https://files.wri.org/d8/s3fs-public/accelerating-mini-grid-deployment-sub-saharan-africa_1.pdf

Ogeya, M., & Lambe, F. (2025). The political economy of mini-grid electricity development and innovation in Kenya. *Renewable and Sustainable Energy Transition*, *6*.

Ojong, N. (2022). Energy justice and off-grid solar electrification in Africa: Trends, narratives and contestations. In N. Ojong (Ed.), *Off-grid solar electrification in Africa: A critical perspective*. Palgrave MacMillan.

Ockwell, D., & Byrne, R. (2016). Sustainable Energy for All: Innovation, technology and pro-poor green transformations (1st ed.). Routledge. https://doi.org/10.4324/9781315621623

Oni, A. (2020, February 25). *The Nigerian transmission network system conundrum*. Bloomfield Law. https://www.lexology.com/library/detail.aspx?g=a3558625-fbd6-4c77-ac70-629d91829338

Onsongo, E. K. and Schot, J. (2017). Inclusive innovation and multi-regime dynamics: The Case of Mobile Money in Kenya". SPRU Working Paper Series (SWPS), 2017-07: 1-28. ISSN 2057-6668.

Onsongo E. (2019). Institutional entrepreneurship and social innovation at the base of the pyramid: the case of M-Pesa in Kenya. Industry and Innovation, 26(4), 369–390. *Industry and Innovation*, *26*(4).

O'Sullivan, K. (2018). *Project Information Document-Integrated Safeguards Data Sheet - Nigeria Electrification Project - P161885 (English)*. World Bank Group. http://documents.worldbank.org/curated/en/493201525197708435/Project-Information-Document-Integrated-Safeguards-Data-Sheet-Nigeria-Electrification-Project-P161885

Pedersen, M. B. (2016). Deconstructing the concept of renewable energy-based mini grids for rural electrification in East Africa. *Wiley Interdisciplinary Reviews: Energy and Environment*, *5*(5), 570–587.

Pedersen, M. B., & Nygaard, I. (2018). System building in the Kenyan electrification regime: The case of private solar mini-grid development. *Energy Research and Social Science*, *42*, 211–223.

Peters, J., Sievert, M., & Toman, M. A. (2019). Rural electrification through mini grids: Challenges ahead. *Energy Policy*, *132*, 27–31.

Power Africa. (2022a). *Kenya Power Africa Fact Sheet*. Retrieved February 2022, from https://www.usaid.gov/powerafrica/kenya

Power Africa. (2022c). *Nigeria Power Africa Fact Shee*t. Retrieved April 2022, from https://www.usaid.gov/powerafrica/nigeria

Power Africa. (2022d). *Senegal Power Africa Fact Sheet*. Retrieved April 2022.

PWC. (2016). *Electricity beyond the grid: Accelerating access to sustainable power for all*. https://www.pwc.com/gx/en/energy-utilities-mining/pdf/electricity-beyond-grid.pdf

REA (Rural Electrification Agency). (n.d.). *About us*. https://rea.gov.ng/aboutus.html

REA (Rural Electrification Agency). (2019). *Nigeria Electrification Project (NEP): Solar hybrid mini grids component*.

RECP et al. (2014), Mini-grid policy toolkit, Africa EU Energy Cooperation Programme, https://www.ren21.net/wp-content/uploads/2019/06/MinigridPolicyToolkit_Sep2014_EN.pdf

Roche, M. Y., Verolmeb, H., Agbaegbu, C., Binnington, T., Fischedick, M., & Oladipo, E. O. (2020). Achieving Sustainable Development Goals in Nigeria's power sector: Assessment of transition pathways. *Climate Policy*, *20*(7), 846–865.

Rothfuß, E., & Boamah, F. (2020). Politics and (self)-organisation of electricity system transitions in a Global North–South perspective. *Politics and Governance*, *8*(3), 162–172.

Roy, P. (2020). *The potential of small and medium enterprises: Off-grid solutions to corruption in Nigeria's electricity sector*. Anti-Corruption Evidence Research Consortium, 010. https://ace.soas.ac.uk/wp-content/uploads/2022/05/ACE-BriefingPaper010-200629.pdf

SEforAllandBNEF.(2020).*Stateoftheglobalminigridsmarketreport2020*. https://www.seforall.org/publications/state-of-the-global-mini-grids-market-report-2020

SEforAll, UKAID, TEA. (2024). *State of the global mini grids market report*. https://www.seforall.org/system/files/2024-08/SOTM%20Report%202024_EN_vFc.pdf

Sen, A. (2014). Divergent paths to a common goal? An overview of challenges to electricity sector reform in developing versus developed countries, Oxford Institute for Energy Studies, Working paper

Sareen, S., Dodge, A., Nakakaawa-Jjunju, C., and Nabaasa, B. (2024) 'Scales of accountability: Solar mini-grids and clean energy for all in Uganda' , Energy Research & Social Science, (118)

Sesan, T. (2021). Clean energy: Game-changer for Nigeria? *International Trade Forum*, *4*, 26–27. https://doi.org/10.18356/15645304-2020-4-12

Sesan, T., Raman, S., Clifford, M., & Forbes, I. (2013). Corporate-led sustainable development and energy poverty alleviation at the bottom of the pyramid: The case of the CleanCook in Nigeria. *World Development*, *45*, 137–146.

Sesan, T., Fajardo, A. Baker, L.H. Uduka, U., Kausya, M., Kerr, D. Onsongo, E. Ugwu, O., Eleri, E. and Bhattacharyya, S (2024) 'Strengthening commercial viability through greater inclusiveness in rural mini-grid deployment: Insights from Nigeria and Kenya', Energy for Sustainable Development (83)

Silver, J. (2016). Disrupted infrastructures: An urban political ecology of interrupted electricity in Accra. *International Journal of Urban and Regional Research*, *39*(5), 984–1003.

Solar Financed. (2024, December 16). *The State of C&I Solar in Africa: Five years*. https://solarfinanced.africa/insights/the-state-of-c-i-solar-in-africa-five-years

Tenenbaum, B., Greacen, C., Siyambalapitiya, T., & Knuckles, J. (2014). *From the bottom up: how small power producers and mini grids can deliver electrification and renewable energy in Africa*. World Bank.

Ulsrud, K. (2020). Access to electricity for all and the role of decentralized solar power in sub-Saharan Africa. *Norsk Geografisk Tidsskrift - Norwegian Journal of Geography*, *74*(1), 54–63.

Ulsrud, K., Rohracher, H., Winther, T., Muchunku, C., & Palit, D. (2018). Pathways to electricity for all: What makes village-scale solar power successful? *Energy Research and Social Science*, *44*, 32–40.

van den Bold, M. (2021). In pursuit of diverse energy futures: The political economy of electricity in Senegal. *Environment and Planning E: Nature and Space*, *5*(4), 1–13.

Victor, D., & Heller, T. C. (Eds.). (2007). *The political economy of power sector reform*. Cambridge University Press.

World Bank. (2018). *Kenya National Electrification Strategy: Key highlights*.

Zimmerer, K. (2011). New geographies of energy: Introduction to the special issue. *Annals of the Association of American Geographers*, *101*(4), 705–711.

CHAPTER 5

Are Mini-Grids Socially Inclusive? A Literature Review

Elsie Onsongo,[1] Beryl Onjala,[1] Mourice Kausya,[1] Lucy H. Baker,[2] Temilade Sesan [3] and Subhes C. Bhattacharyya [4]

[1]Nuvoni Centre for Innovation Research, Nairobi, Kenya
[2]Geography and Geography and Environment Studies, The Open University, UK
[3]Center for Petroleum, Energy Economics and Law, University of Ibadan, Ibadan, Nigeria
[4]De Montfort University, Leicester, UK

Abstract

This study explores the potential of mini-grids as tools for inclusive innovation to address energy poverty in the Global South. We adopt the concept of inclusive innovation—which emphasizes the use of innovation to mitigate social exclusion and improve the well-being of marginalized populations—to systematically assess the literature on mini-grids in the Global South. We explore the extent of inclusiveness in the aspiration, design, procurement, deployment and impact of mini-grids. Our findings reveal that mini-grids have played a transformative role in bringing electricity to off-grid, marginalized communities in the Global South, offering the potential for income generation, a platform for local decision-making and ownership, and opportunities for capacity building and skill development, thus empowering individuals and communities. However, the inclusivity of mini-grids is not universal and often masks underlying socio-economic disparities. The community's role in the design, financing, procurement, and deployment of mini-grids is found to be minimal, highlighting the need for more democratic ownership and governance models. Further, mini-grids often privilege middle- and upper-income households, mostly headed by men who possess the technical know-how and financial resources for effective mini-grid utilization. This leaves behind the poor, especially women, thereby exacerbating existing socio-economic divides. The structural and post-structural inclusivity of mini-grids is limited, with

traditional, top-down approaches still prevalent. To enhance inclusivity, policies should foster community ownership, equitable access, and capacity building among marginalized groups, encouraging exploration of alternative governance models aligned with energy justice principles. This shift toward participatory frameworks could make mini-grids truly inclusive innovations, empowering communities and contributing to sustainable development in the Global South.

Keywords: mini-grids, inclusiveness, consumption, impact, innovation process, structural inclusion, Global South

5.1 Introduction

Inclusive innovation is an approach by which to address the social and economic disparities within societies by focusing on the development, implementation, and distribution of innovations that are accessible, affordable, and adaptable to the needs of marginalized and vulnerable populations. When applied to energy systems in the Global South, inclusive innovation aims to bridge the energy access gap, foster sustainable development, and promote social equity.

One of the primary challenges in the Global South is energy poverty, characterized by a lack of access to modern, reliable, and affordable energy services. This challenge disproportionately affects rural and impoverished communities, and this curtails local economic development (Amin et al., 2020), adversely affects educational outcomes and compromises access to efficient health care services (Banerjee et al., 2021), exacerbates gender inequalities, e.g., by disproportionately burdening women (Moniruzzaman & Day, 2020), and fosters environmental degradation due to overreliance on biomass (Sovacool, 2012). Inclusive innovation, in this context, emphasizes the need for energy systems that cater to the specific needs and circumstances of marginalized communities, thus empowering them, and contributing to broader sustainable development objectives.

The discourse on inclusive innovation falls at the intersection between innovation, development and poverty (Arocena et al., 2018; Baud, 2016; Cozzens & Kaplinsky, 2009; Pansera & Martinez, 2017). Inclusive innovation has been described as an approach or strategy that aims to improve the social and economic well-being of marginalized or disenfranchised groups in society through the development and implementation of novel ideas, technologies, products, or services (George et al., 2012; Heeks et al., 2014). Inclusive innovation emphasizes affordability, accessibility, and

relevance to the socio-economic context of the target population. By fostering inclusivity, this approach attempts to ameliorate social inequalities and contribute to sustainable development. Recent framings of inclusive innovation emphasize its collaborative, participatory, multistakeholder approach that prioritizes the agency of marginalized groups, ensuring that solutions are not only beneficial but also culturally and contextually appropriate (Hoffecker, 2021; Onsongo & Knorringa, 2020; Pansera & Owen, 2017; Patnaik & Bhowmick, 2020; Smith et al., 2023).

Mini-grids, as a decentralized energy solution, have the potential to serve as an inclusive innovation in the context of energy systems in the Global South. By providing localized and reliable electricity access to communities that are often excluded from centralized grid systems, mini-grids can address the energy access gap, promote sustainable development, and foster social equity. However, it has not been entirely clear whether they actually deliver on these promises (Bhattacharyya & Palit, 2016; Gill-Wiehl et al., 2022; Joshi & Yenneti, 2020; Sharma, 2020). Mini-grid projects are diverse in terms of their technological choices, ownership models, management structures, and financing mechanisms. This diversity can lead to different outcomes in which some projects achieve inclusiveness while others may not. As a result, it is challenging to generalize the inclusiveness of mini-grids as a whole. To better understand and harness the inclusive potential of mini-grids, it is crucial to address these challenges through targeted research.

This article applies a justice-based framework for inclusive innovation in an in-depth literature review to assess the social sustainability of mini-grids in the Global South. We analyze whether and how mini-grids, as presented in empirical studies in our review, attain different levels of inclusiveness and interrogate the underlying implications for social justice.

5.2 Inclusive Innovation: An Analytical Framework

In recent years, the paradigm of "inclusive innovation" has sparked interest in the academic, policymaking, and developmental communities (Cozzens & Sutz, 2014; Heeks et al., 2014; IDRC, 2011; Kaplinsky, 2011; Paunov, 2013; UNCTAD, 2014). Initially, the term denoted specific products, services, or business models, but it has since evolved to encompass comprehensive initiatives and policies designed to mitigate social exclusion and inequality (Levidow & Papaioannou, 2018). Advocates suggest that the existing, resource-intensive model of innovation, predominant in

developed societies, may be ill-suited to lower-income environments grappling with socio-environmental issues (Chataway et al., 2014; Cozzens & Kaplinsky, 2009; Paunov, 2013). Thus, a different approach might serve to bridge the gap for communities affected by social exclusion.

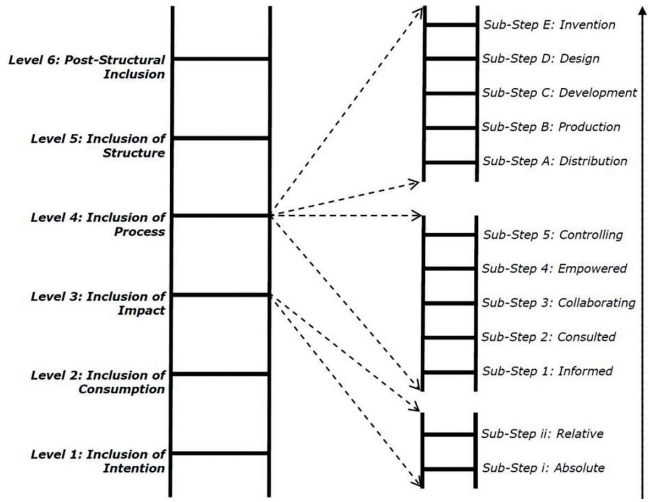
Inclusive innovation is a strategy designed to address social exclusion by ensuring that marginalized and poor communities are not only beneficiaries of innovation but also active participants in innovation processes (Hoffecker, 2021). The ultimate aim of inclusive innovation is to foster social inclusion by creating opportunities for these marginalized groups to partake in, and benefit from, innovative activities that improve their quality of life. The concept can be seen as multidimensional, with different authors emphasizing different aspects, such as the intention of the innovation, inclusivity in the process, the structural environment, and the outcomes or impacts of the innovation (e.g., Altenburg, 2008; Bortz & Thomas, 2017; Ciarli et al., 2018; Onsongo & Schot, 2017).

Informed by Sen's (2000) conceptualization of poverty as a deprivation of capabilities, social exclusion, in the context of inclusive innovation, frequently aligns with financial poverty (Cozzens & Sutz, 2014; Joseph, 2014). Yet, as Sen emphasizes, poverty and social exclusion are multidimensional, comprising economic, social, political, individual, spatial, and group elements. They can be both the root and the result of each other, which Joseph (2014) further elucidates within the domain of inclusive innovation.

There are two main stances within scholarly circles exploring alternative models of innovation suitable for lower-income contexts: the market-oriented liberal-individualist stance and the equity-centered social-collectivist stance (Levidow & Papaioannou, 2017). The former, supported by base of the pyramid (BOP) literature (Prahalad & Hammond, 2002), encourages affordable products and services via substantial corporate investments. Critics, however, contend that this approach often neglects the cultural and political factors engendering social exclusion (Arora & Romijn, 2012). Conversely, the social-collectivist stance stresses equitable participation and collective creativity, hallmarks of grassroots and informal setting innovation (Gupta et al., 2003; Pansera & Owen, 2015; Seyfang & Smith, 2007). Nevertheless, their scalability remains a challenge due to the localized nature and small-scale implementations (Smith et al., 2014). Despite differing

perspectives on leveraging innovation for social justice, both stances underscore social inclusion, thereby paving the way for further exploration of the nexus between innovation and development (Pansera & Owen, 2017).

Figure 5.1: The Ladder of Inclusive Innovation (LII) Depicting Different Levels (or gradations) of Inclusion



Source: Heeks et al. (2013).

The Ladder of Inclusive Innovation proposed by Heeks et al. (2014) provides a useful model to understand this linkage, outlining various degrees of inclusion based on the involvement of marginalized groups in the innovation process. The Ladder of Inclusive Innovation consists of six rungs, each signifying an increased level of participation by the excluded group in the innovation process (see *Fig. 5.1*). The lower rungs reflect a liberal-individualist stance, where the excluded group adopts an innovation created by others to address their needs (Levidow & Papaioannou, 2017). However, a more harmonized approach is feasible if the innovating entity is a community group or grassroots entrepreneur. Level 4, the mid-point of the ladder, hinges on the degree of ownership and control the excluded groups exert over the innovation process, with a shift toward a social-collectivist stance becoming evident if they dictate the process according to their norms and values. The pinnacle of the ladder—"Structure" and "Post-Structural" inclusion—demands systemic change and a significant

transition of control to marginalized communities (Fressoli et al., 2014). These top rungs of inclusion might entail social justice organizations and activists dictating the terms for innovative processes and outcomes. This approach resonates with the concept of "empowered citizens" posited in Arnstein's model (Heeks et al., 2014).

5.3 mini-grids as Inclusive Innovation

Mini-grids, as localized energy systems, can potentially represent inclusive innovations by offering a decentralized, sustainable, and cost-effective solution for energy access, especially in underserved or isolated areas (Bhattacharyya & Palit, 2016). They can address multiple dimensions of social exclusion by providing affordable energy, extending productive hours, and enabling community involvement in energy planning and management (Bhattacharyya, 2013; Chaurey et al., 2012; Kirubi et al., 2009).

In the context of the inclusive innovation model, mini-grids can embody both the liberal-individualist and the social-collectivist stances, depending on the degree of local participation and control (Levidow & Papaioannou, 2017). From a liberal-individualist perspective, mini-grids can be seen as market-driven solutions, in which the private sector develops and sells energy services to low-income consumers. From a social-collectivist stance, they can be grassroots innovations, developed and managed collectively by communities based on local needs and resources. These issues reflect the spectrum of inclusion as described in the Ladder of Inclusive Innovation by Heeks et al. (2013, 2014). At the lower levels of this ladder, external developers design and implement the mini-grid, and local communities adopt it. At higher levels, communities may own, control, and benefit from the mini-grid, indicating a significant shift in power and resource control.

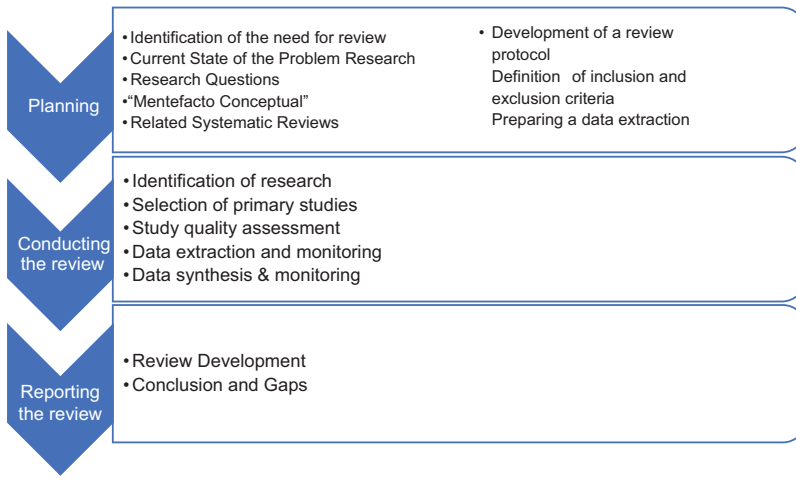
Thus, simply labeling mini-grids as inclusive innovations may oversimplify the complex dynamics and challenges involved in their development and implementation. The extent of their inclusiveness can vary widely depending on various factors. In this article, we conduct an in-depth analysis of the literature to establish whether and under what circumstances mini-grids can be truly considered as inclusive innovations. This analysis provides a more nuanced understanding of the role of mini-grids as inclusive innovations to guide the development of policies and strategies for their successful implementation.

5.4 Methodology

The approach of the study is to undertake a systematic review of the literature. Systematic literature reviews are, according to Tranfield et al. (2003), important tools for developing an evidence database toward further developing the knowledge base around a research topic. This method is most preferred in that it will allow for the assessment of progress in research on inclusivity of mini-grids and facilitate the formulation of recommendations for future areas of research (Fink, 2010).

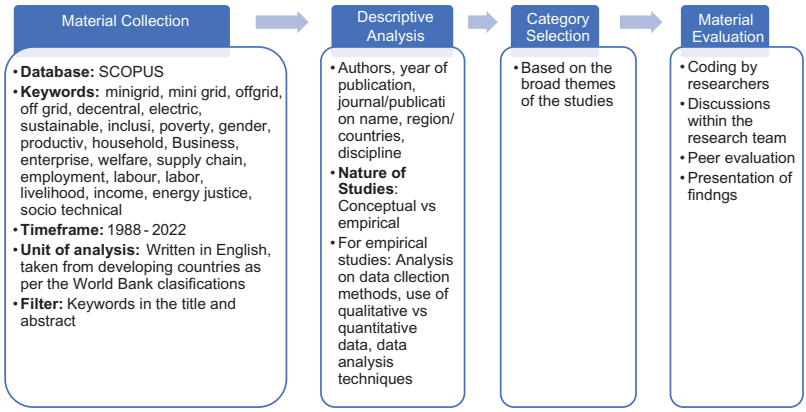
The systemic literature review (SLR) structure, proposed by Kitchenham (2004) and later adopted by (Bacca et al., 2014) along with other researchers, divides the process into three broad parts—the planning stage, conducting the review, and reporting the results of the review (*Fig. 5.2*).

Figure 5.2: Three-Stage Systematic Literature Review



Further breaking down the three-stage procedure, Mayring (2010) offers an alternative structure to SLRs, which comprehensively covers the collection of the material to the analysis of the contents. This includes material collection, descriptive analysis, category section, and material evaluation. This method outlines specifics of the search, including the databases used, keywords, time frame considered, the units of analysis, and filters applied. Our methodology employs a combination of the methods proposed by Kitchenham (2004) and Mayring (2010) to evolve a comprehensive system and review (see *Fig. 5.3*).

Figure 5.3: Methodology Adapted from Rosca et al. (2018).



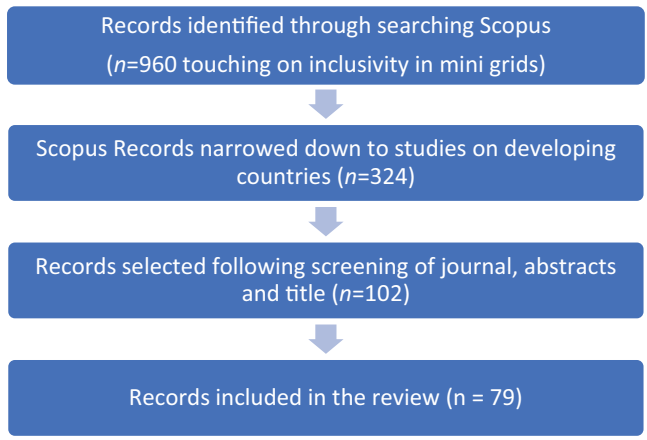
The SCOPUS platform provided by Elsevier, with its extensive database of peer-reviewed journals in energy, social sciences, and humanities, was the primary source of documents. Other sources, such as development partner web platforms and gray literature, were also consulted. SCOPUS was searched for documents containing the keywords mini-grids or off-grid solutions and for measures of inclusivity such as poverty, gender, business, and welfare, using the following broad search term: <"mini-grid" OR "mini grid" OR "offgrid" OR "off grid" OR "decentral" AND "electric" AND "sustainable" OR "inclusive" OR "poverty" OR "gender" OR "productiv" OR "household" OR "business" OR "enterprise" OR "welfare" OR "supply chain" OR "employment" OR "labour" OR "labor" OR "livelihood" OR "income" OR "energy justice" OR "socio technical">. These key words were selected based on a literature review and team discussions and quotation marks used to eliminate cases of grammatical coincidence within the results. This search yielded a total of 960 documents written between 1988 and 2021.

Other types of articles from the search include conference papers, book chapters, business articles, reviews, editorials and news reports. A vast majority of articles were from five major fields, including environmental science, energy, engineering, medicine, and social sciences. Although occurring less frequently, there were articles from other fields, including agricultural and biological sciences, economics, econometrics and finance, computer science, chemical engineering, and earth and planetary science, among others.

To obtain articles relevant to low- and middle-income countries, we used the World Bank's analytical classifications in the World Development

Indicators (WDI) to filter results by geographic origin. The WDI Database includes 218 countries categorized into four income groups (Low, Lower Middle, Upper Middle, and High Income) between 1987 and 2018. We selected source countries that were classified as low or middle-income within the past decade, resulting in 123 selected countries. The filter was applied to each of the three databases, reducing the number of articles on SCOPUS to 324. The materials were organized on Mendeley, and we screened titles and abstracts to select relevant articles for the study. We were left with a total of 79 documents. *Figure 5.4* summarizes the short-listing process.

Figure 5.4: Literature Shortlisting Process



5.5 Characteristics of Selected Articles

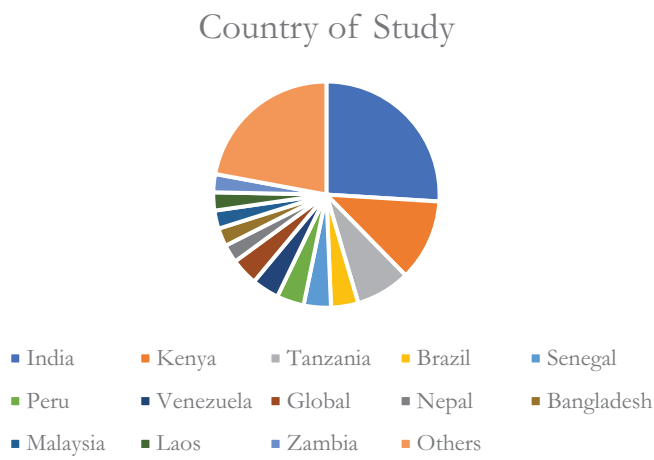
Our review indicates that the selected articles were published between 2009 and 2021 and that none were published in 2013 (*Fig. 5.5*). However, there is a significant and drastic increase in the number of published articles since 2018, peaking in 2020. This clearly suggests that there is an increasing research interest in this field, a trend that is likely to grow in future.

Figure 5.5: Year-Wise Distribution of Papers Published from 2008 to 2021



These articles on mini-grids were intentionally collected from the Global South, where there has been growing research interest in the subject. The studies mainly focus on developing economies in sub-Saharan Africa, Latin America, and South Asia. India has the highest number of studies (26%), followed by Kenya (12%), Tanzania (7%), and several other countries accounting for smaller percentages (*Fig. 5.6*). Only one article covered developed countries such as the USA, UK, and Sweden. The concentration of studies in India can be attributed to the country's efforts to electrify its large rural population through mini-grid development projects.

Figure 5.6: Articles by Country of Study



The majority (94%) of the selected articles had an empirical component (qualitative or quantitative). The remaining (6%) were theoretical or conceptual. Among the empirical studies, 67% used mixed-method approaches, 24% used qualitative approaches, and 9% used quantitative approaches (*Fig. 5.7*). About half of the analyzed articles focused on one mini-grid, while the rest studied multiple mini-grids (*Fig. 5.8*). Most of the studies (74%) were conducted in a single country, suggesting a lack of attention to cross-country comparisons in the existing literature (*Figs. 5.9 and 5.10*). Articles studying one mini-grid mainly evaluated the challenges and benefits of mini-grids, their sustainability, and their impact compared to pre-grid electrification. Some also compared the impact of mini-grids in electrified and unelectrified areas.

Figure 5.7: Article Types and Empirical Approach Used

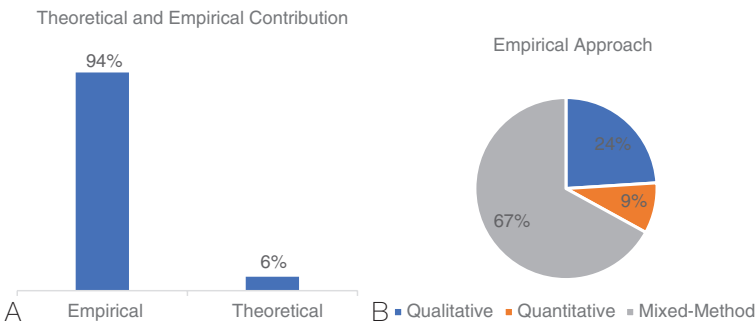
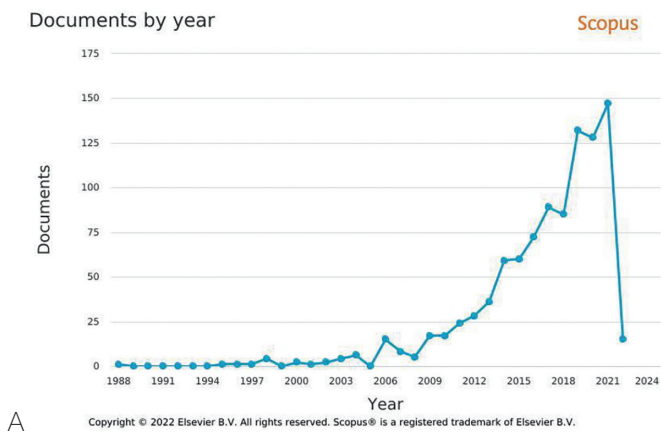
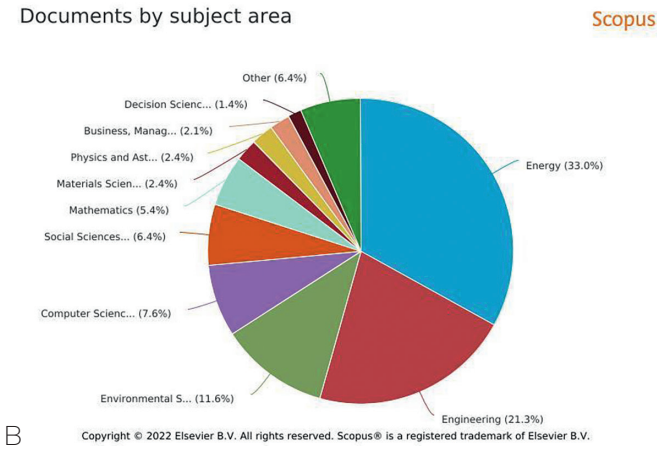


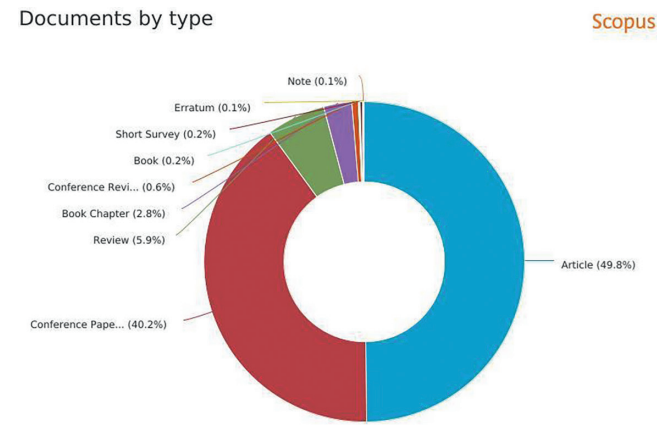
Figure 5.8: Year of Publications Overall Publications vs Publications with the Exclusion Criteria



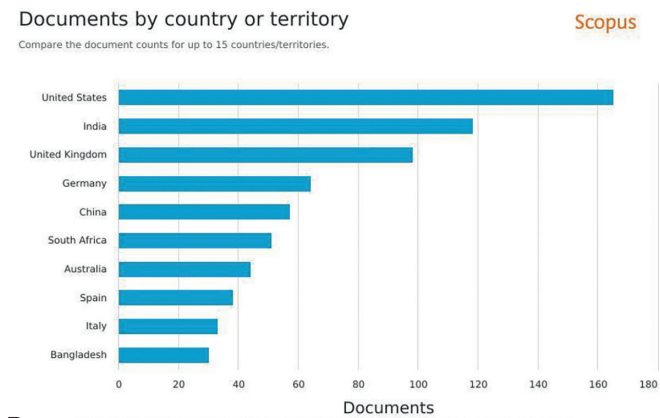


B

Figure 5.9: Document Type and Country Focus

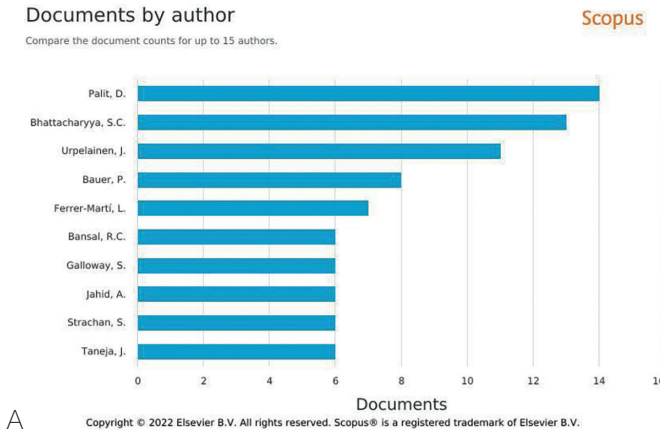


A

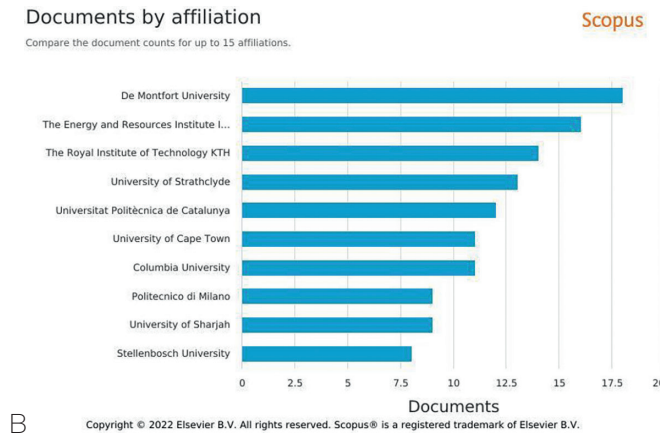


B

Figure 5.10: Authorship and Affiliation



A



B

5.6 Findings

5.6.1 Defining Social Inclusivity

Sustainable electricity services are typically assessed based on technical, economic, institutional, governance, environmental, and social and cultural considerations (Katre et al., 2019; Katre & Tozzi, 2018; Urmee & Md, 2016). Katre et al. (2019) also emphasize that the social sustainability of projects involves enhancing the lives of the community, including benefits to households, businesses, institutions, community connectedness, and operations. However, López-González et al. (2018) expand on this by including concepts of community empowerment, inclusion, and governance in assessing social sustainability. This involves considering

issues such as community participation, improving health and education outcomes, promoting equity in energy access, and strengthening institutions (Wiese, 2020). The economic angle also plays a crucial role, encompassing energy equity, energy poverty, and productive growth. Energy equity refers to the ability to pay for quality electricity service and ensure sustainable access, while energy poverty can be measured using indicators such as the minimal standard (MIS), Low-income, High-cost (LIHC), and the Ten-Percent Rule (TPR) (Boardman, 1991, 2009; Hills, 2012; Moore, 2012). Productive growth pertains to the capacity to increase incomes through electricity use.

5.6.2 Inclusion of Intention: The Case for Mini-Grids

Mini-grids have emerged as a popular solution to provide electricity access in remote and geographically isolated areas where extending the central grid is either technically or financially challenging (Ahlborg, 2018; Lukuyu et al., 2021; Muchunku et al., 2018; Uamusse et al., 2020; van Gevelt et al., 2020). The development of mini-grids is driven by a variety of factors, including geographical barriers, high connection and operating costs, high renewable energy potential, household income levels, specific institutional needs, and policy restrictions.

Countries like the Philippines face significant geographical barriers due to their archipelagic nature, making grid extension difficult and expensive (Duran & Sahinyazan, 2021; IRENA, 2017). This has led to the increased adoption of mini-grids powered by local renewable resources to provide electricity in remote areas (Almeshqab & Ustun, 2019). In countries like India and Brazil, extending the central grid to remote areas is similarly challenging due to wide rivers, creeks, and the vastness of the Amazon rainforest (Almeshqab & Ustunb, 2019; Mazzone, 2019; Moharil & Kulkarni, 2007).

The high connection and operating costs associated with extending the central grid have prompted the installation of decentralized photovoltaic (PV) power plants with microgrids in remote villages in countries like India and Brazil (Aklin et al., 2017; Bahaj et al., 2019; Duran & Sahinyazan, 2020; Kandpal, 2013; Lukuyu et al., 2021; Moharil & Kulkarni, 2007; Muchunku et al., 2018; Pedersen et al., 2020; Sharma, 2020; van Els et al., 2012; Yadoo & Cruickshank, 2012). In some cases, households in these countries may find it more economical to pay for microgrid

connection instead of using expensive alternatives like kerosene (Kobayakawa & Kandpal, 2014).

Regions with high renewable energy potential, such as areas with small waterfalls, wind, and solar energy, have also seen mini-grid development (Lillo et al., 2015; Terrapon-Pfaff et al., 2014). Household income levels play a role in the type of connection, with higher income households in countries like India having a higher capacity to pay electricity tariffs and initial connection charges (Kobayakawa & Kandpal, 2014; Schnitzer et al., 2014).

Energy demand plays a crucial role in driving the development of mini-grids, as the presence of economic and agricultural activities in an area reduces the risk of non-payment, making mini-grid projects more financially viable (Pedersen et al., 2020). By providing electricity access to small businesses and households with significant electricity demand, mini-grids can promote economic growth and improve the quality of life in remote and rural communities (Kirubi et al., 2008; Pedersen et al., 2020).

Mini-grids have been developed in some countries to specifically power institutions in remote areas that require electricity in order to function efficiently—hospitals, schools, and vocational centers in Kenya and Tanzania (Kirubi et al., 2008; Klunne & Michael, 2010; Ngowi et al., 2019). Policy restrictions also play a role in mini-grid development, with regulations in India, for example, prohibiting grid extension through reserve forests and leading to the establishment of mini-grids in isolated regions with no future expectation of grid connection (Sharma & Palit, 2020).

5.6.3 Inclusion of Consumption and Impact

Our analysis of the literature shows that many grades are used by a wide variety of population groups in a community. However, the levels of consumption of energy differ among men, women and children, and even among different income groups and age groups. Consumption and impact are interrelated and so population groups with higher utilization of the mini-grid energy tend to experience higher positive and/or negative impacts. In what follows, we highlight consumption patterns and impacts of electrification on domestic lighting, drudgery reduction, communication and entertainment, health and education outcomes, security, water and sanitation, and productive uses. Despite the many advantages, some challenges and disparities remain, emphasizing the importance of continued research and development in this field.

Domestic lighting: Access to lighting is a significant benefit for households, as highlighted in many reviewed articles (e.g., Aklin et al., 2017; Bhattacharyya & Palit, 2016; Johnson et al., 2019; Kirubi et al., 2009; Kobayakawa & Kandpal, 2014; Luukkanen et al., 2012; Pueyo & DeMartino, 2018; Terrapon-Pfaff et al., 2014; Uamusse et al., 2020; Urmee & Md, 2016; Wiese, 2020; Yadoo & Cruickshank, 2012). These studies report the social and emotional value that communities place on this new resource. A notable outcome that beneficiaries appreciate is the potential for improved futures for their children, who can "live in the light." This is a reasonable expectation, given the benefits such as increased study time and entertainment opportunities. Study time is a common metric used to measure household social welfare improvement. Many articles report that access to lighting allows children to study for longer hours after sunset. The additional study time ranges from just under an hour to 3.2 hours per day (Asuamah et al., 2021; Bhattacharyya & Palit, 2016; Kirubi et al., 2009; Wiese, 2020; Yadoo, 2012; Yadoo & Cruickshank, 2012). Wiese (2020) suggests that longer study hours are more feasible due to the lower cost and reduced health risks of electric lighting. Further, improved learning outcomes have been linked to better illumination (Kirubi et al., 2009), which estimates a gain of approximately two years of educational achievement for children in electrified households compared to those without electricity. However, the authors also note that outcomes may vary depending on the size of the systems, as larger systems provide better lighting for study. Urmee and Md (2016) note that families often base their choice of systems on their children's education. However, there are also gender disparities in extra study time in that boys generally have more time to study than girls (Wiese, 2020). The extra study time has been shown to improve children's performance, with instructors noting improved quality of education and homework for those with access to electricity at home (Yadoo & Cruickshank, 2012).

Domestic Drudgery: Numerous studies (Chandra et al., 2020; Ganguly et al., 2020; Johnson et al., 2019; Katre et al., 2019; Kirubi et al., 2009; Moharil & Kulkarni, 2009; Terrapon-Pfaff et al., 2014, 2018; Uamusse et al., 2020; Wiese, 2020; Yadoo, 2012; Yadoo & Cruickshank, 2012) have found a positive link between mini-grid electrification and easing household chores. For example, Kirubi et al. (2009) observed that power installations led to more women visiting local health clinics for prenatal care due to time savings and reduced manual labor. Yadoo (2012) and Yadoo and Cruickshank (2012) noted how traditional agro-processing

techniques were modernized, easing tasks previously performed manually by women.

Wiese (2020) reported that electrified households saw improved efficiency in chores like cooking, while Muhoza and Johnson (2018) found that women could perform tasks more easily in well-lit houses and communal spaces. Millinger et al. (2012) observed later evening cooking times after electrification, and Terrapon-Pfaff et al. (2018) highlighted gendered impacts of sustainable energy, including reduced time for women gathering firewood. Ganguly et al. (2020) emphasized the importance of improved lighting for household productivity, and Katre et al. (2019) observed reduced drudgery for women in electrified households who now have more time to care for children.

However, Wiese (2020) and Muhoza and Johnson (2018) both found that despite electricity making chores easier, it did not significantly impact women's overall working time or substantially reduce the burden of their chores.

Entertainment and communication: Electricity access through mini-grids has significantly improved communication, connectivity, and information access for beneficiary communities (e.g., Aklin et al., 2017; Ahlborg, 2018; Asuamah et al., 2021; Chandra et al., 2020; Groth, 2019; Kirubi et al., 2009; Kobayakawa & Kandpal, 2014; Millinger et al., 2012; Ngowi et al., 2019; Pueyo & DeMartino, 2018; Roche & Blanchard, 2018; Uamusse et al., 2020; Urmee & Md, 2016; Wiese, 2020). Access to television has been shown to improve access to information (Kobayakawa & Kandpal, 2014; Moharil & Kulkarni, 2009; Ngowi et al., 2019; Uamusse et al., 2020), and the proliferation of mobile phones has facilitated communication and connectivity due to easier and more affordable phone charging (Ahlborg, 2018; Bhattacharyya & Palit, 2016; Johnson et al., 2019; Kirubi et al., 2009; Luukkanen et al., 2012; Urmee & Md, 2016). Katre et al. (2019) observed that communities with mini-grid electricity felt more connected to the outside world due to the availability of phones and televisions. López-González et al. (2018) found that electricity increased basic and secondary education rates, improving information access and telecommunication. Yadoo and Cruickshank (2012) reported improved communication and access to information in a community with mini-grid electricity, as teachers noted that students seemed more informed due to increased television and radio access at home. Bhattacharyya and Palit (2016) highlighted better communication opportunities and higher profits for businesses providing communication services in electrified communities.

One of the major benefits of mini-grid electrification highlighted in the literature is access to electronic entertainment and leisure activities such as watching television and listening to the radio, using the internet and reading after sunset (Ahlborg, 2018; Bhattacharyya & Palit, 2016; Ferrer-Martı´ et al., 2012; Johnson et al., 2019; Kirubi et al., 2009; Millinger et al., 2012; Moharil & Kulkarni, 2009; Muhoza & Johnson, 2018; Ngowi et al., 2019; Uamusse et al., 2020; Urmee & Md, 2016; Wiese, 2020; Yadoo, 2012). Ahlborg (2018) found that electronic entertainment positively affected people's sense of well-being, as people "stopped having thoughts" or "thinking too much until you go mad." Luukkanen et al. (2012) reports a similar case where watching television, among other benefits, is said to be a relaxing entertainment activity as it is good for mental health and reduces loneliness after a hard day of work. Kirubi et al. (2009) found that electricity enables professionals working in rural settings access entertainment services enjoyed by their counterparts in the urban regions. This article further emphasized the importance of television for women's education and access to health and family planning information. Groth (2019) suggested that electrified households with television access had higher levels of information and knowledge, impacting their earnings and education. Various authors also showcase how rural mini-grids enhanced socialization at the community level, by creating well-lit communal areas, allowing villagers to watch television or listen to the radio together or have social gatherings while having a cold refrigerated drink (Johnson et al., 2019; Muhoza & Johnson, 2018; Urmee & Md, 2016).

Health outcomes: Health outcomes in communities are influenced by multiple factors such as household activities, community involvement, and healthcare facilities. The relationship between these factors and access to electricity has been extensively discussed in the literature (Bahaj et al., 2019; Bhattacharyya & Palit, 2016; Butchers et al., 2020; Ferrer-Martí et al., 2012; Johnson et al., 2019; Katre et al., 2019; Kirubi et al., 2009; López-González et al., 2018, 2020; Luukkanen et al., 2012; Moharil & Kulkarni, 2009; Muhoza & Johnson, 2018; Ngowi et al., 2019; Terrapon-Pfaff et al., 2014, 2018; Uamusse et al., 2020; Wiese, 2020; Yadoo, 2012; Yadoo & Cruickshank, 2012). Another way health outcomes have been improved is through access to educational content on TV and radio within households (Uamusse et al., 2020). Consuming educational content about diseases like HIV and malaria leads to a reduction in their prevalence, as viewers gain knowledge on prevention, management, and

treatment (Kirubi et al., 2009; Uamusse et al., 2020). Awareness initiatives about family planning and hygiene are also beneficial (Wiese, 2020).

Mini-grids electrification has resulted in an overall improvement in community nutrition. Bahaj et al. (2019) reported a 30 to 55% increase in fruit consumption within two Kenyan communities following electrification, along with a significant increase in food supply due to higher incomes. Terrapon-Pfaff et al. (2014) also noted improved nutrition, with increased availability of cooked food and boiled water. Additionally, using refrigerators to store food can prevent infectious diseases by reducing contamination in items like bottles and infant food, thereby lowering infant mortality rates (López-González et al., 2018, 2020). Refrigeration also prevents the growth of pathogens, especially in indigenous communities in high-temperature areas with diets consisting mainly of meat and fish (López-González et al., 2018).

Access to electricity can directly reduce injuries and overall bodily harm caused by using other fuels. The use of kerosene and firewood for cooking has been linked to negative impacts on lung function and a higher incidence of ailments like asthma and tuberculosis. Reduced kerosene emissions from lighting in homes, schools, and other areas lead to a decrease in respiratory illnesses, eye infections, and cancer in both children and adults (López-González et al., 2018, 2020; Wiese, 2020). This is due to less indoor smoke from kerosene and candles (Ferrer-Martí et al., 2012; Terrapon-Pfaff et al., 2014). Terrapon-Pfaff et al. (2014) also reported improvements in space heating within electrified communities, potentially contributing to better respiratory health outcomes. However, some studies have noted that the continued use of firewood for cooking after installing electricity can negate improvements in indoor air quality (Katre et al., 2019). Despite this, rural households that continue using firewood for cooking after gaining access to electricity experience a decrease in related accidents, as electric lighting simplifies cooking tasks (Wiese, 2020).

Mini-grid electrification has also led to significant improvements in healthcare services within institutions and at the community level. Hospitals connected to electricity can provide a wider range of services, thanks to extended operating hours made possible by electrical lighting (Ferrer-Martí et al., 2012; Uamusse et al., 2020). Electrification of rural hospitals in Mozambique has facilitated better illumination across various departments, such as delivery rooms, consultation rooms, and administrative areas (Johnson et al., 2019). Reliable artificial lighting has allowed some hospitals to offer 24-hour services to their communities. It also makes medical examinations, such as those by ENT specialists, easier

and improves the experience of nighttime deliveries (Yadoo, 2012; Yadoo & Cruickshank, 2012). In one case, a community mini-grid in Kenya enabled nighttime deliveries without the use of a torch or lantern (Bahaj et al., 2019). The availability of electricity also contributes to increased prenatal visits at local health clinics (Kirubi et al., 2009). Improved health services due to electricity have been linked to a reduction in maternal and infant mortality rates (Cecelski, 2004).

Electrification has also improved healthcare by powering diagnostic machines, sterilizers, and refrigerators for storing medications (Johnson et al., 2019; Muhoza & Johnson, 2018). Laboratory testing has improved, with one study reporting a rise in daily tests from 20 to 50 after electrification (Bahaj et al., 2019). Additionally, consistent refrigeration of medications and vaccines has made them more accessible to local communities, eliminating the need to travel long distances for these essentials (Bahaj et al., 2019). Furthermore, electrification can attract and retain healthcare professionals from other regions, as access to electricity is often a significant factor in their decision to work in a particular community (Bahaj et al., 2019).

Education outcomes: The literature highlights the connection between mini-grid electricity access and improved learning outcomes as a measure of social inclusivity (Aklin et al., 2017; Bahaj et al., 2019; Bhattacharyya & Palit, 2016; Butchers et al., 2020; Ferrer-Martí et al., 2012; Ganguly et al., 2020; Groth, 2019; Johnson et al., 2019; Joshi & Yenneti, 2020; Katre et al., 2019; Kirubi et al., 2009; Kobayakawa & Kandpal, 2014; López-González et al., 2018, 2020; Luukkanen et al., 2012; Millinger et al., 2012; Moharil & Kulkarni, 2009; Muhoza & Johnson, 2018; Uamusse et al., 2020; Urmee & Md, 2016; Wiese, 2020; Yadoo & Cruickshank, 2012). Introducing electricity to a community can lead to the establishment of new learning institutions, the enhancement of existing ones, and other positive externalities such as increased migration and human resources. Access to electricity enables longer study sessions (Johnson et al., 2019) and attracts teachers to rural education facilities, ultimately improving the quality of education (Uamusse et al., 2020).

Electrification allows schools to utilize resources such as science laboratories and computer studies, exposing students to diverse opportunities (Ferrer-Martí et al., 2012; Kirubi et al., 2009; Yadoo & Cruickshank, 2012). Electricity-based resources like computers, projectors, and photocopy machines improve the efficiency of school administration and instruction (Kirubi et al., 2009; Yadoo & Cruick-

shank, 2012). Additionally, electrification supports innovative instructional materials, such as cassette players for language classes, DVD players and TVs for educational videos, and computers with electronic encyclopedias (Ferrer-Martí et al., 2012; Yadoo, 2012; Yadoo & Cruickshank, 2012).

Studies have reported higher educational achievement among children from electrified households compared to non-electrified ones (Kirubi et al., 2009). Factors contributing to this improvement include better access to water, improved hygiene, and reduced absenteeism (Bahaj et al., 2019; López-González et al., 2018). Schools with access to electricity can also extend their school days, providing more time for learning (Bahaj et al., 2019). However, the extent of benefits for learning institutions and learners depends on available resources and the institution's capacity to implement new strategies. Some schools may not fully utilize electrification benefits due to financial constraints, lack of instructors, or insufficient demand for services like evening classes (Wiese, 2020).

Security: Several studies have highlighted the overall community benefits of street and outdoor lighting in terms of increased security for residents (Ahlborg, 2018; Bhattacharyya & Palit, 2016; Joshi & Yenneti, 2020; Katre et al., 2019; Luukkanen et al., 2012; Moharil & Kulkarni, 2009; Yadoo & Cruickshank, 2012). Johnson et al. (2019) suggested that improved lighting within communities facilitates social cohesion, as streetlights in public places make residents, particularly women and children, feel safe to move around and socialize at night (Uamusse et al., 2020). Terrapon-Pfaff et al. (2014) noted that nighttime street lighting enhances the safety of women and girls, allowing them to attend school and participate in community events after dark. Yadoo and Cruickshank (2012) also emphasized that street lighting makes women feel more secure when visiting neighbors at night. Moreover, improved security through street lighting has contributed to better medical service provision, higher quality education, and the creation of new businesses (Muhoza & Johnson, 2018).

Water and sanitation: The importance of mini-grid electricity in providing access to clean, reliable water and sanitation for beneficiaries has been well documented in numerous studies (Bhattacharyya & Palit, 2016; Chandra et al., 2020; Asuamah et al. (2021); Kirubi et al., 2009; Moharil & Kulkarni, 2009; Sharma & Palit, 2014; Uamusse et al., 2020; Yadoo, 2012). Moharil and Kulkarni (2009) describe an innovative approach that integrates water pumps into mini-grid systems, enabling communities

to access clean and safe drinking water from deep underground sources. Uamusse et al. (2020) and Kirubi et al. (2009) report on developments involving the installation of water pumps that allow community members to access clean drinking water and sanitation facilities without having to travel long distances, significantly improving their lives. Asuamah et al. 2021 and Dagoumas (2021) discuss the benefits of using mini-grid powered water pumping for agricultural purposes.

Productive uses: The importance of electricity in income generation has been extensively discussed in the literature on inclusivity and social sustainability, emphasizing the advantages for households and small and medium enterprises (SMEs) (Ahlborg, 2018; Bahaj et al., 2019; Bhattacharyya & Palit, 2016; Ferrer-Martí et al., 2012; Ganguly et al., 2020; Kirubi et al., 2009; Lillo et al., 2015; Luukkanen et al., 2012; Muhoza & Johnson, 2018; Yadoo, 2012; Yadoo & Cruickshank, 2012). Productive electricity use benefits entrepreneurs and communities, creating value through cottage industries, particularly those that use electric appliances, tools and equipment, including barbershops and salons, phone charging services, welding, carpentry, and ice-block provision (Kirubi et al., 2009; Muhoza & Johnson, 2018; Ngowi et al., 2019; Terrapon-Pfaff et al., 2018; Wiese, 2020; Yadoo, 2012).

Increased income is attributed to direct and indirect uses of electricity, such as extending opening hours and supporting marketing techniques (Johnson et al., 2019) (Johnson, 2018b). Ferrer-Martí et al. (2012) found that beneficiaries use energy to provide services to nearby unelectrified communities and expand or start small businesses. In the agricultural sector, farmers and SMEs benefit from electricity through improved storage for perishable goods, leading to better trade opportunities (Kirubi et al., 2009b; López-González et al., 2020b; van Gevelt et al., 2020; Yadoo, 2012). Cold storage facilities and electric tools enable local farmers to trade in larger volumes and create linkages between agriculture and SMEs (Kirubi et al., 2009b). Improved farming techniques, facilitated by better access to information and tools, also contribute to increased income (Yadoo, 2012). Indirect income generation effects are also highlighted in literature on the role of electricity access in improving education and household income (Kirubi et al., 2009b).

One notable outcome is increased competition within communities due to expanded access to electricity (Pedersen et al., 2020). This can lead to both positive and negative effects, as well as conflicts of interest between entities promoting household connections to the mini-grid. Millinger et

al. (2012) reported that, while women engaged in various small-scale activities after electrification, the impact on productivity was minimal.

It is worth noting that the inclusiveness of consumption increases when tariff subsidy programs are implemented (Lukuyu et al., 2021), as otherwise, mini-grid tariffs are generally very high for low-income households.

5.6.4 Inclusion of Process: Social Inclusion in Mini-Grid Development Processes

Effective and inclusive community participation and ownership can make low-carbon energy projects socially acceptable and enhance their long-term sustainability (Wiese, 2020). Numerous studies showcase how upfront involvement in the mini-grid design and implementation process empowers the community to become active stakeholders in the project (Katre et al., 2019; Palit & Chaurey, 2011; Pedersen et al., 2020; Uamusse et al., 2020). Community participation is thought to increase the sense of belonging and ownership structure as a key factor in the success of power systems (Urmee & Md, 2016). Further, community participation in the process is widely accepted as a prerequisite for ensuring equity and sustainability of electrification efforts in rural areas (Palit & Chaurey, 2011) and enhances collective empowerment as it increases the community's confidence, resulting in seeking more mini-grid projects (Lillo et al., 2015). Similarly, Uamusse et al. (2020) emphasizes the importance of involving local stakeholders such as households and small-scale industry at an early stage.

In the following sections, we explore inclusivity in mini-grid development processes and the related dynamics.

5.6.5 Feasibility, Site Acquisition, Approval

The initial step in mini-grid project development involves conducting a technical feasibility assessment of proposed sites (Wiese, 2020). The process differs in different countries, which affects the extent to which the process is inclusive. In India, for instance, state agencies secure funding for mini-grid projects and identify target areas (Ulsrud et al., 2011). Meetings are held with local leaders to discuss the project and outline community contributions. Surveys ascertain interest in electricity and village demand, while the tendering process for equipment, installation, and operators occurs later. In Peru, a non-governmental organization identi-

fies electrification projects and communities through a quantitative-based socio-economic and resource analysis (Lillo et al., 2015). Technical design, management models, and community-requested projects are prioritized to ensure high community motivation. Villagers receive training in efficient energy use, maintenance, and system operation. Community involvement is promoted to foster collective empowerment, leading to the pursuit of additional projects. Once the system is operational and the community deemed capable, it is handed over for management and operation (Lillo et al., 2015). Similarly, López-González et al. (2018) describe a government-developed hybrid microgrid program that began by estimating daily power consumption based on historical census data. Surveys in rural areas profiled houses and inhabitants, and socio-demographic evaluations determined the distribution of non-electrified rural households.

After site identification and approval, developers consult with community leaders to discuss various aspects of the project, including responsibilities, expectations, and ownership structures. Public village meetings inform the broader community about the project, e.g., issues around connection fees, bill payment methods, and connection procedures, and to create awareness of electricity's benefits (Ulsrud et al., 2011). Communal meetings allow for public participation, enabling community members to voice their opinions and ask questions, and are seen as a way to prevent misinformation (Pedersen et al., 2020). Another strategy is door-to-door visits that addressed individual user issues and provided training, while open-air meetings served as a platform to share information about the company. However, the decision-making process is mainly focused on technical implementation, with limited community participation.

Several articles highlight cases of community and specific individuals being excluded from mini-grid development processes. Wiese (2020) reports that in some cases, only men were included in consultative meetings and that women were informed about the project at a later stage. Technical issues raised by villagers were sometimes ignored, leading to conflicts and disappointments. Van Gevelt et al. (2020). describe a Malaysian community that was completely excluded from a wind turbine project, unaware of its initiation, funding, or why it was never completed. In another solar–diesel hybrid mini-grid project, only male community leaders attended consultation meetings, leaving the rest of the community uninformed about the project and technology. Maintenance concerns were also raised since no one was designated to maintain the system.

The literature also highlights instances of social exclusion during feasibility and site acquisition processes. Wiese (2020) reports that some consultations only included men, with women being informed about the project at later stages.

5.6.6 Financing

Mini-grid projects require considerable capital for development, and the choice of funding instrument and financier depends on the project type and stage of development (Moharil & Kulkarni, 2007). Most mini-grid projects rely on subsidies and grants from various sources, such as governments, international development agencies, local governments, foundations, and private individuals (Moharil & Kulkarni, 2007; Pedersen et al., 2020; Pigaht & Van der Plas, 2009; Ulsrud et al., 2018). Funding also originates from venture capital investors, debt capital providers, civil society organizations (CSOs), and self-help groups (IRENA, 2017; Joshi & Yenneti, 2020; Katre & Tozzi, 2018). The inclusiveness of the financing process depends on the extent of local community involvement, government engagement, and collaboration between stakeholders, such as the private sector and CSOs.

Debt and equity: Funding mechanisms often involve grants and subsidies for earlier, riskier stages of mini-grid development, while advanced and less risky projects rely on debt financing (Schnitzer et al., 2014; Pedersen et al., 2020; Pigaht & van der Plas, 2009). Pigaht and Van der Plas (2009) describe a project in Rwanda that sourced local equity and debt capital, combined with a subsidy of 30 to 50% for project costs, to develop micro-hydro projects with local distribution grids. The involvement of local investors fostered a sense of ownership and shared responsibility among stakeholders, which can promote greater community engagement and participation. This engagement can help ensure that the mini-grid project addresses the community's needs and expectations, fostering greater inclusiveness in the project. Chandra et al. (2020) propose a mini-grid development process in which external investors fund the setup costs and gradually recoup their investment through monthly installments. The system would be owned by the financiers and leased to a community operating committee for utilization.

CSOs are pivotal in financing mini-grids in remote and unelectrified regions, engaging communities in the development and governance of these projects (Katre & Tozzi, 2018). For example, self-help groups, espe-

cially those led by local women in poverty-stricken regions, have been successful in owning and operating renewable energy systems (Joshi & Yenneti, 2020). This involvement has led to more inclusive institutional arrangements that can better adapt to local realities and respond to challenges (Katre & Tozzi, 2018). However, when CSOs finance mini-grids, there are sometimes mixed project outcomes and high levels of failures (Katre et al., 2019; Katre & Tozzi, 2018). CSOs may have limited capacity and resources to adequately finance and support the development of mini-grids in remote and unelectrified regions. This can lead to underfunded projects and inadequate infrastructure, potentially hampering the effectiveness of the mini-grid in providing reliable energy access to communities. In addition, CSOs may lack the long-term capacity to maintain and manage mini-grid systems, leading to sustainability issues in the future.

While benefiting communities may not be significantly involved in the direct financing of mini-grids, there are instances where they contribute in other ways, e.g., by contributing labor (Butchers et al., 2020; Wiese, 2020). Some mini-grid cooperatives are structured so that users' initial labor and financial contributions grant them a share in the project. This demonstrates that communities can participate and contribute to mini-grid projects through non-financial means, fostering a sense of ownership and engagement in the project's success.

Donor funding through grants, often provided by international development agencies, has been instrumental in financing mini-grids, especially in regions where private sector engagement is limited (Blum et al., 2015). Studies have found mixed outcomes in relation to inclusivity of donor-funded projects. On the one hand, donor-funded projects offer flexibility to include community financial contributions to projects, e.g., in a mini-grid in Malaysia, whereby the developer alongside the local community, through their local leaders and the local leader's daughter, sought funding from UNDP. The community further donated land and labor for the project (van Gevelt et al., 2020). There are also donor-funded projects with special purpose vehicles (SPVs) operating on a commercial basis, albeit with subsidies on investment and interest rates (Pedersen et al., 2020).

On the other hand, the process may not be very inclusive. For example, in Laos, donor-funded mini-grid pilots, which have been installed and supported by international development agencies, faced challenges due to an unfavorable national investment environment and high levels of corruption. These factors deterred international private

investors from investing in rural Laos, limiting private sector engagement in mini-grid development (Blum et al., 2015). In Tanzania, a donor-funded NGO pilot project introduced an "Energy Service Platform" and microgrid to supply electricity to villagers. However, the NGO failed to maintain service delivery, highlighting the challenges in ensuring the sustainability of donor-funded mini-grids (Ahlborg, 2018). Thus, to ensure a more inclusive process, donors should focus on actively involving communities, supporting capacity building, and promoting collaboration between different stakeholders, including the government, private sector, and CSOs.

Government subsidies are another significant source of financing for mini-grids (Blum et al., 2015; IRENA, 2017; Joshi & Yenneti, 2020; Millinger & Ahlgren, 2012). Governments can fully or partially finance mini-grid projects, either directly or by partnering with other financiers like NGOs and communities (van Gevelt et al., 2020; Yadoo, 2012). In India, an established federal policy framework supports mini-grid co-financing with other actors, with up to 55% of financial costs provided by local state governments (Ulsrud et al., 2018).

When governments finance mini-grids, several issues can arise, such as inconsistency in policy and technological preferences, lack of clear guidance, and limited coordination with other stakeholders. Governments can sometimes act opportunistically, accepting financial support for various electrification concepts from international donors, and this can result in a lack of a clear technology strategy and discontinuity in the guidance of the search (Blum et al., 2015). Inclusiveness in the process depends on the level of coordination between governments, communities, and other stakeholders. Governments can facilitate inclusive processes by engaging communities in decision-making and ensuring that diverse regions and populations are represented in electrification plans. However, limited coordination and inconsistent guidance can negatively affect the inclusiveness of the process. In Peru, a 40 kW micro-hydro mini-grid was installed in Tamborapa Pueblo, whose capital costs were covered by national and local government bodies (Yadoo, 2012). The community contributed unpaid labor, highlighting an example of exploitation in the process. Similarly, in Sarawak, Malaysia, the state and federal governments set an ambitious target to provide access to reliable and affordable electricity for all rural households by 2025 (van Gevelt et al., 2020). However, the project was funded by the federal Ministry of Science, Technology and Innovation, rather than state funding, indicating potential coordination

challenges. Overall, the inclusiveness of the process when governments finance mini-grids is contingent on effective coordination between different stakeholders, consistent policy guidance, and active community engagement.

Our analysis shows that many mini-grid projects, in fact, adopt hybrid financing models, i.e., a combination of multiple financing sources and instruments to fund the development, implementation, and operation of mini-grid projects. Hybrid financing models enable project developers to leverage various funding sources, such as public, private, and donor financing, to improve project viability and sustainability.

5.6.7 Engineering, Procurement, and Construction

A notable gap exists in the literature that specifically addresses the aspect of inclusiveness within the engineering and procurement stages. This lack is particularly evident in regard to the limited role of local communities within these crucial processes.

In the engineering phase, the interaction between the project developers and the local community is often confined to the collection of data for needs assessment or feasibility analysis. Although this information is vital, the role of the community is typically passive, providing the necessary details but not participating in the analytical process or the subsequent technical design of the mini-grid. Van Gelvet et al. (2020) describe a Malaysian community that was entirely excluded from a wind turbine project's design and implementation. This approach may be attributed to the prevailing assumption that community members lack the requisite technical expertise. However, such an assumption could potentially overlook valuable local insights and knowledge, thereby undermining the inclusivity and possibly the effectiveness of the mini-grid system.

Similarly, in the procurement stage, local communities frequently play a minimal role, if any. The process primarily revolves around the importation of equipment, an activity typically managed almost exclusively by the mini-grid developer. This exclusion of community participation from procurement not only impedes the potential for capacity building within the community but also limits opportunities for fostering a sense of ownership and investment in the mini-grid project.

Although community members are often involved in the construction phase, their roles are largely confined to providing manual labor rather than to decision-making or skill-building activities. Wiese (2020) highlights that

community members provided raw materials such as sand and stones for project construction. Furthermore, they considered unpaid labor as a form of participation in the project implementation. Similarly, Butchers et al. (2020) note that local beneficiaries were often expected to contribute labor for repairs when needed. Exclusion in the design process may lead to the deployment of mini-grids that do not account for the local context and a lack of legitimacy. In a micro-hydropower grid in Ethiopia, villagers' complaints about technical issues during construction were not addressed, leading to conflicts and disappointment due to misinformation about the system's capacity and boundaries (Wiese, 2020). A Malaysian community was unaware of the project's origin, funding, and reasons for noncompletion (van Gevelt et al., 2020). In another case involving a solar–diesel hybrid mini-grid, community engagement was insufficient, as only male kampong leaders attended consultation meetings. Other community members were uninformed about the project and technology used (van Gevelt et al., 2020).

5.6.8 Operation and Maintenance

Mini-grid ownership and management models differ from project to project, with common models including private sector management, local community management, utility-based management, and hybrid ownership (Lillo et al., 2015). It has been observed that the majority of government and donor-funded projects are eventually transferred to the communities. These communities assume responsibility for the operation and maintenance of the project, either immediately on installation or after a certain period, once functionality has been ensured (Joshi & Yenneti, 2020; López-González et al., 2018; Schnitzer et al., 2014). Such management models are varied. For instance, a management model in Venezuela was formed by the Ministry of Energy, which included the local community council among other stakeholders (López-González et al., 2018). Another management model in India involves the local community, civil society, and the industry (Joshi & Yenneti, 2020; Pandey & Sharma, 2021). Joshi and Yenneti (2020) highlight a solar module manufacturing unit owned and operated by local tribal women and supported by academics and philanthropic partners. Community-based management models empower locals and foster a sense of project ownership (Yadoo, 2012). In some cases, a mini-grid developer or any other entity with the technical know-how provides technical assistance to the community to maintain the mini-grid (Sharma & Palit, 2020).

Some communities form local micro-enterprises or cooperatives to operate, maintain, and administer the mini-grid systems, including revenue collection, mini-grid extension, and tariff-setting (Joshi & Yenneti, 2020; López-González et al., 2018; Millinger & Ahlgren, 2012). (Bahaj et al., 2019; Butchers et al., 2020; Ferrer-Martí et al., 2012; Johnson et al., 2019; Kulkarni, 2007; Schnitzer et al., 2014; Ulsrud et al., 2011; Yadoo, 2012; Yadoo & Cruickshank, 2012). In some cases, mini-grids are managed by pre-existing cooperatives that are gender-balanced and democratically elected (Yadoo & Cruickshank, 2012). Wiese (2020) highlights that, in Ethiopia, women's inclusion in management committees was mandated by laws and achieved through an elective process. These committees were expected to remain independent from political and personal interests to ensure efficiency. Additionally, the revenues collected in some other cases is used to provide members with micro-loans repayable in a given period of time.

Successful mini-grid projects often involve training community and/or committee members to operate and maintain the systems (Van Gelvet et al., 2020). Technical issues beyond the capabilities of these technicians are handled at a secondary level, e.g., in a Kenyan case, through videoconference calls from the manager to the project team, and if not resolved, an engineer on day call out fee is sent to the project from Nairobi (Bahaj et al., 2019). Klunne and Michael (2010) point out that involvement of local technical skills in maintaining the mini-grid system enabled the community to solve technical problems on their own, bringing trust to the users over service delivery, a factor identified as vital in willingness to pay for the services.

Institutional mini-grid projects, such as those installed for hospitals or schools, can be maintained and operated by the institutions themselves, or in collaboration with local community committees (Klunne & Michael, 2010; Ngowi et al., 2019). For instance, Ngowi et al. (2019) describe a hospital-owned mini-grid in Tanzania where the hospital management worked with local communities to manage and control power supply.

Overall, community inclusivity and involvement in the operation and maintenance of mini-grids can lead to more sustainable and successful projects. This can be achieved through various management models, such as local community management, cooperatives, and partnerships with institutions.

In sum, mini-grid developers adopt different approaches to the implementation of what they consider as an inclusive development process. For instance, two Kenyan private firms prioritized connecting nearly every

household in the mini-grid's vicinity, considering both the commercial and social welfare logic. The firms believed that building good relationships with communities and gaining their acceptance are essential for success, thus implementing a "connect all" strategy (Pedersen et al., 2020). Developers also take formal steps to increase community influence over projects by establishing project committees with balanced gender representation and setting up complaint procedures to enhance accountability and consumer rights (Pedersen et al., 2020). It is assumed that collective buy-in is crucial for accessing cost-effective options and ensuring that no one is left behind, as excluding community members could create opposition. Effective communication strategies, such as open-air meetings and door-to-door visits, are employed by private mini-grid developers in Kenya to reach customers, address individual user issues, and provide training (Pedersen et al., 2020). Communal meetings are used for participatory decision-making processes, fostering ownership, and addressing concerns like mini-grid system placement.

Nevertheless, mini-grid developers often face community resistance. Van Gelvet et al. (2020) mention a Malaysian solar project that faced opposition due to the community's belief that solar technology was unsuitable for their area, which received sunlight only 30% of the time. They also felt excluded from the decision-making process. Soshinskaya et al. (2014) document similar instances of resistance due to past disappointments and vested interests. In some cases, community engagement levels vary, with some members showing little interest or ownership in the project, even when acknowledging its importance (Butchers et al., 2020). Non-participation is also seen as a way for communities to exercise their agency, especially when they do not accept predefined roles and identities as set by elite actors (Pandey & Sharma, 2021). Economic situations affecting the ability to pay and reduced power from minihydro plants also contribute to reduced community interest (Butchers et al., 2020).

5.7 Inclusion of Structure

The discourse surrounding the inclusivity of mini-grids, particularly within the context of energy systems in the Global South, reveals a complex landscape, where the structural and inherent inclusivity of these systems is not a given but rather a goal that requires deliberate effort and design (Almeshqab & Ustun, 2019; Bhattacharyya & Palit, 2016; Kitenge & Siringi, 2019; López-González et al., 2019).

Mini-grids, heralded for their potential to democratize energy access and foster socio-economic development, face challenges in realizing truly inclusive innovation. The evidence presented in the literature indicates that while mini-grids offer transformative potential for marginalized communities by providing access to electricity, the extent of their inclusivity, especially in the design, procurement, deployment, and governance stages, remains limited. The community involvement in these crucial stages is often minimal, focusing primarily on rubber-stamping participation, rather than meaningful participation in technical design or decision-making processes (Gill-Wiehl et al., 2022; Kitenge & Siringi, 2019; Pandey & Sharma, 2021). Moreover, the procurement and deployment activities are predominantly managed by developers, while community contributions are largely confined to providing labor or local materials, rather than engaging in substantive decisions that shape the project's direction and outcomes.

The structural barriers to inclusivity within mini-grid projects are further compounded by socio-economic disparities and gender dynamics (Aklin et al., 2017; Hills, 2012; Klunne & Michael, 2010; Van Els et al., 2012). Despite the potential benefits of mini-grids in terms of income generation and reduction of domestic drudgery, the actual advantages tend to accrue to those already possessing technical know-how, financial resources, or decision-making power, typically middle- and upper-income males. Women and individuals from lower-income households frequently remain on the periphery, not because of a lack of interest or need but due to the absence of democratic structures of ownership, governance, and inclusive decision-making mechanisms that acknowledge and bridge these gaps (Johnson et al., 2019; Wiese, 2020). This scenario highlights a critical mismatch between the potential of mini-grids to act as vehicles for inclusive innovation and the reality of their implementation, which often perpetuates existing inequalities rather than dismantling them. To move toward genuinely inclusive mini-grid projects, there is a pressing need for policies and practices that prioritize community engagement, equitable participation, and the distribution of benefits across all segments of society, ensuring that the innovation process within energy systems becomes inherently inclusive.

5.8 Post-Structural Inclusion

The analysis of the literature reveals a critical gap between the potential of mini-grids as vehicles for inclusive innovation and the reality of their development and implementation in the Global South. This gap exists primarily due to the predominant reliance on traditional engineering and economic paradigms, rather than embracing alternative, more democratic frameworks for energy infrastructure development.

The literature highlights instances where the design and deployment of mini-grids are not fully democratized or inclusive of community inputs. For example, as already seen, community involvement is often limited to data collection for feasibility studies, without meaningful participation in the technical design or decision-making processes. This approach reflects a significant reliance on the expertise of engineers and economists, who prioritize technical efficiency and financial viability over the diverse needs and aspirations of the communities they aim to serve (Brix et al., 2020; Chaurey et al., 2004; Moore, 2012; Roche & Blanchard, 2018). The result is a system that may not fully align with the socio-cultural dynamics of the target communities, thereby limiting its inclusiveness and potential impact on energy poverty alleviation (Johnson et al., 2019; Urmee & Md, 2016).

Analysis of the literature underscores a significant oversight in considering alternative governance models of post-structural inclusion, as argued by Smith et al. (2023), such as public ownership, co-operative governance, or conceptualizing energy infrastructure as a commons. These models have the potential to foster a more equitable distribution of energy resources and ensure that the interests of all stakeholders, especially marginalized communities, are taken into account (Korkovelos et al., 2020). However, the current approach to mini-grid development often treats inclusiveness instrumentally, focusing on making the systems appealing to customers rather than integrating the systems sociologically around the community's inputs, knowledge, and aspirations.

5.9 The Dark Side of mini-grids: Exclusions and Environmental Effects

The introduction of mini-grids and electricity in communities can provide numerous benefits, such as improved access to information, entertainment, and communication. However, these advancements can also lead to unintended negative consequences on social cohesion within communities. One such effect is the potential for reduced community engagement,

as highlighted by van Gevelt et al. (2020). The availability of electricity may lead to a shift in social dynamics within the community. As people gain access to new forms of entertainment and communication, such as television, radio, and the internet, they may be less likely to engage in traditional community gatherings and events. This can result in a weakening of social ties and a decline in the sense of community that is often vital to the well-being and cohesion of rural populations.

Community participation is generally considered an essential component of successful mini-grid development, as it helps to ensure that projects are tailored to the needs and preferences of local communities. However, if not managed appropriately, community participation can also have negative effects on the project, as mentioned by Gill-Wiehl et al. (2022). These negative effects can manifest in technical, economic, and social issues, which can hinder the overall success and sustainability of the mini-grid. Negative end-user perceptions due to poorly implemented projects can have long-lasting consequences, leading to skepticism about the technology's appropriateness, economic cost, and suitability (van Gevelt et al., 2020). Further, inadequate training for community members responsible for the operation and maintenance of the mini-grid can lead to improper handling, neglect, or misuse of equipment (Gill-Wiehl et al., 2022). This can result in reduced output, decreased reliability, and poor performance of the mini-grid system. A lack of respect for all parties involved in the mini-grid project can lead to social tensions and conflicts within the community. Disagreements over the planning, implementation, or operation of the project may arise if community members feel their opinions or concerns are not being taken into account. Moreover, miscommunication or lack of transparency can result in distrust and dissatisfaction among community members, which can negatively impact the overall social cohesion and acceptance of the project.

In a case in Cambodia, the mini-grid was installed only along the road, resulting in houses situated more than 50 meters from the road being excluded from access to electricity (Luukkanen et al., 2012). Social segregation arising from such disparities can manifest in various ways. First, households with access to electricity may enjoy improved living standards, increased productivity, and opportunities for economic development, while those without access remain at a disadvantage. This imbalance can create a sense of inequality and frustration among the unconnected households, as they might feel excluded from the benefits of the mini-grid project. Unconnected households may struggle to participate in new

economic opportunities, educational advancements, or social activities that require access to electricity. The division in access to electricity can exacerbate existing social or economic divides within the community, reinforcing existing power dynamics or widening gaps between different groups. This separation may lead to increased tensions and a breakdown in social cohesion, as community members perceive the uneven distribution of resources as unjust.

Gender disparities in mini-grids are evident in various aspects, including access to education, work distribution, and the ability to benefit from electricity. Johnson et al. (2019) emphasize the triple role of women within the household and community, which encompasses reproductive, productive, and community work. These roles often result in women bearing a higher burden of responsibilities compared to men. Wiese (2020) highlights the differences between boys and girls in terms of study time, with girls having less study time after dark due to their expected engagement in domestic work, unlike boys who are not obligated to perform similar activities. This disparity is evident in the fact that all the males in the study completed primary/basic school, while 5 out of 12 women were illiterate. Additionally, Wiese (2020) raises the possibility that the arrival of electricity could lead to higher dropout rates among boys as they may feel obligated to take up productive work to support their families financially.

Gender disparities are also observed in the way men and women spend their time post electrification. Wiese (2020) points out that men, especially those in higher income groups, can spend more time engaging in recreational activities, reading, or conducting business activities after dark. In contrast, women often find that electric lighting extends their working time as they continue to perform household chores such as cooking with less-than-efficient fuels, taking care of children, and feeding animals. Although mini-grid electricity can make some chores easier, the overall reduction in the burden of domestic work for women may be limited (Muhoza & Johnson, 2018; Wiese, 2020). Many households may be unable to afford or may choose not to invest in labor-saving appliances, such as washing machines, electric cookers, or refrigerators. In some societies, women may still be expected to perform a majority of domestic work, regardless of the availability of electricity or labor-saving appliances. In some cases, electricity may enable new income-generating activities for women. While this can have positive economic impacts, it may also result in additional responsibilities, maintaining or even increasing the overall workload of women, rather than reducing it.

Mini-grids can have unintended negative consequences on the environment and the community at large. Rahmann et al. (2016) highlight two such effects: environmental problems arising from fossil-fueled backup generation and the impact on residents' quality of life due to noise and visual disturbances. Fossil-fueled generation units, which are sometimes used as backup power sources when renewable energies are not available, can contribute to greenhouse gas emissions and air pollution, and these emissions can have adverse effects on the health of community members. The visual impact of the mini-grid infrastructure, including power lines, solar panels, and wind turbines, can alter the community's landscape and affect the aesthetic appeal of the area (Rahmann et al., 2016). In addition, the noise generated by certain components of the mini-grid system, such as generators or inverters, can be disruptive to residents, particularly if they are located close to residential areas. The introduction of electronic devices and appliances can also lead to increased noise pollution within the community. As people play loud music on their stereos or watch television at high volumes, it can disrupt the peace and tranquility that was once prevalent in the community. This can be particularly concerning for older residents or those who value quiet and calm environments and may lead to tensions and conflicts between neighbors.

5.10 Discussion and Conclusion

The aspiration behind mini-grid development can be considered as promoting social inclusion, as it aims to provide electricity access to remote and geographically isolated areas where extending the central grid is challenging (Ahlborg, 2018; Lukuyu et al., 2021; Muchunku et al., 2018; Uamusse et al., 2020; van Gevelt et al., 2020). By offering more economical alternatives to expensive energy sources, mini-grids help households with different income levels gain access to electricity (Kobayakawa & Kandpal, 2014; Schnitzer et al., 2014). Furthermore, mini-grids support economic growth, improve the quality of life in remote and rural communities (Kirubi et al., 2008; Pedersen et al., 2020), and power essential institutions such as hospitals, schools, and vocational centers (Kirubi et al., 2008; Klunne & Michael, 2010; Leary et al., 2012; Ngowi et al., 2019). Overall, mini-grid development contributes to social inclusion by promoting economic development, enhancing living standards, and ensuring the efficient functioning of vital institutions in remote areas. The analysis of the literature on mini-grids within the context of the Global

South reveals nuanced insights into their role as inclusive innovations. By examining mini-grids through the lens of the six levels of inclusiveness, we can discern their strengths, limitations, and the pathways needed to harness their full potential for marginalized communities.

When considering the first level, inclusion of intention, the aspiration behind mini-grid development can be considered as promoting social inclusion, as mini-grid projects often articulate a commitment to addressing energy poverty among marginalized groups, suggesting a recognition of the need to serve these populations (Ahlborg, 2018; Lukuyu et al., 2021; Muchunku et al., 2018; Uamusse et al., 2020; van Gevelt et al., 2020). By offering more economical alternatives to expensive energy sources, mini-grids help households with different income levels gain access to electricity (Kobayakawa & Kandpal, 2014; Schnitzer et al., 2014). Furthermore, mini-grids support economic growth, improve the quality of life in remote and rural communities (Kirubi et al., 2008; Pedersen et al., 2020), and power essential institutions such as hospitals, schools, and vocational centers (Kirubi et al., 2008; Klunne & Michael, 2010; Leary et al., 2012; Ngowi et al., 2019). Overall, mini-grid development contributes to social inclusion by promoting economic development, enhancing living standards, and ensuring the efficient functioning of vital institutions in remote areas.

There is substantial evidence that there is inclusion of consumption, as mini-grids adapt novel product-services with clear usage by marginalized groups in domestic and community lighting, alleviating drudgery, productive uses and even at the institutional level (Asuamah et al., 2021; Bahaj et al., 2019; Chandra et al., 2020; Chaurey et al., 2004; Joshi & Yenneti, 2020; Mazzone, 2019; Roche & Blanchard, 2018). These services undoubtedly improve the quality of life, showcasing mini-grids' ability to adapt to the consumption needs of marginalized communities. Inclusion of impact is similarly well documented, and while some studies indicate that mini-grids have a positive impact on the well-being of marginalized groups, others show some negative outcomes of mini-grids in household and community dynamics (Gill-Wiehl et al., 2022; Rahmann et al., 2016; Wiese, 2020).

From the market-oriented liberal-individualist perspective captured by these first rungs of the ladder of inclusivity (Levidow & Papaioannou, 2017), these findings show that mini-grids exemplify a promising avenue for providing affordable energy solutions to underserved populations. This stance, echoing the principles of BOP strategies (Prahalad & Ham-

mond, 2002), suggests that mini-grids can be scaled through significant investments, potentially by large corporations, to extend electricity access to remote and marginalized communities efficiently. This approach views mini-grids as market opportunities that, with the right business models, could attract substantial private investments to address energy poverty. However, as the findings on impact already show, this perspective may not fully account for the complex socio-political and cultural dimensions of energy access. There are clear disparities in regard to how different population groups access mini-grid energy and the extent of usage, with a clear disadvantage that affects women (Cecelski, 2004; Johnson et al., 2019; Pandey & Sharma, 2021; Sharma, 2020; Urmee & Md, 2016; Wiese, 2020). As in the inclusiveness of consumption, the impact's distribution appears uneven, often favoring those within the community who already possess certain socio-economic advantages, such as higher income or technical know-how (Pandey & Sharma, 2021; Wiese, 2020). Thus, market-driven mini-grid projects could prioritize profitability and operational efficiency over addressing deeper issues of social exclusion and equity, potentially neglecting the specific needs, preferences, and contributions of local communities.

Inclusion of process presents some nuances in the extent to which marginalized groups influence developments. While there are instances of community engagement in the development and deployment of mini-grids, participation tends to be limited to initial consultations or provision of labor, rather than deep, meaningful involvement in decision-making processes (Gill-Wiehl et al., 2022; Kitenge & Siringi, 2019; Pandey & Sharma, 2021). This indicates a moderate level of process inclusion but highlights the need for more robust mechanisms that allow for genuine influence by marginalized groups over project development.

Structural and post-structural inclusiveness remain elusive in the practice of mini-grid development in the Global South. The structural inclusiveness of mini-grid innovation remains limited, as evidenced by the absence of democratized ownership and governance models in many projects (Kitenge & Siringi, 2019; Pandey & Sharma, 2021). Although mini-grids have the potential to be developed within frameworks that make it easy and desirable for excluded groups to become involved, the literature suggests that this potential is not fully realized, with traditional, top-down approaches still prevalent. Similarly, there is scant evidence to suggest that mini-grids are developed within a post-structurally inclusive framework informed by the experience, knowledge, and discourse of marginal-

ized groups who set the agenda and terms for development, deployment, and operation. These observations suggest that for mini-grids to become post-structurally inclusive, there needs to be a paradigm shift in how they are conceived, designed, and implemented. This shift should involve moving away from top-down, techno-economic approaches toward more participatory, sociologically oriented frameworks that prioritize community engagement, co-creation, and shared governance (Smith et al., 2023). By doing so, mini-grids could better anticipate and explore the potential of inclusive energy systems, aligning user interests with system interests and fostering more sustainable, equitable energy access in the Global South.

The latter three rungs of the ladder of inclusivity exemplify the social-collectivist stance that emphasizes the importance of equitable participation; community empowerment; and localized, grassroots innovations in mini-grid development (Levidow & Papaioannou, 2017). From this perspective, mini-grids designed and implemented with a focus on collective creativity and community governance can foster social inclusion and empowerment. Mini-grid projects that align with this stance would involve communities in decision-making processes from planning and design to operation and maintenance, ensuring that the energy systems are tailored to local contexts and needs (Pansera & Owen, 2015; Smith et al., 2023). This approach would not only address the immediate energy needs but also build local capacity and support socio-economic development through community ownership and governance structures (Fressoli et al., 2014). However, scalability and financial sustainability may pose significant challenges under this model, as projects may rely heavily on grants, subsidies, or community contributions, which may not always be readily available or sufficient for expansion.

In conclusion, the inclusiveness of mini-grids can be better understood through the interplay between these two stances. A balanced approach that incorporates the market efficiency and scalability of the liberal-individualist perspective with the social equity and community empowerment focus of the social-collectivist stance may offer the most sustainable and inclusive pathway for mini-grid development. Policies should aim to foster community ownership and governance of mini-grid projects, ensure equitable access to the benefits of electrification, and support capacity building among marginalized groups to actively participate in and influence energy projects. Furthermore, policies should encourage the exploration of alternative, multistakeholder governance models and financing mechanisms that align with the principles of energy justice and inclusive-

ness (Korkovelos et al., 2020). By doing so, mini-grids can move closer to realizing their potential as truly inclusive innovations that empower marginalized communities and contribute to sustainable development in the Global South.

References

Adrian Smith, Gerardo A. Torres Contreras, Marie-Claire Brisbois, Max Lacey-Barnacle, Benjamin K. Sovacool, Inclusive innovation in just transitions: The case of smart local energy systems in the UK, Environmental Innovation and Societal Transitions, Volume 47, 2023, 100719, ISSN 2210-4224, https://doi.org/10.1016/j.eist.2023.100719.

Adrian Smith, Mariano Fressoli, Hernán Thomas, Grassroots innovation movements: challenges and contributions, Journal of Cleaner Production, Volume 63, 2014, Pages 114-124, https://doi.org/10.1016/j.jclepro.2012.12.025.

Ahlborg, H. (2018). Changing energy geographies: The political effects of a small-scale electrification project. *Geoforum*, *97*, 268–280. https://doi.org/10.1016/j.geoforum.2018.09.016

A.K. Gupta, R. Sinha, D. Koradia, R. Patel, M. Parmar, P. Rohit, H. Patel, K. Patel, V.S. Chand, T.J. James, A. Chandan, M. Patel, T.N. Prakash, P. Vivekanandan, Mobilizing grassroots' technological innovations and traditional knowledge, values and institutions: articulating social and ethical capital, Futures, Volume 35, Issue 9, 2003, Pages 975-987, https://doi.org/10.1016/S0016-3287(03)00053-3.

Akanksha Chaurey, P.R. Krithika, Debajit Palit, Smita Rakesh, Benjamin K. Sovacool, New partnerships and business models for facilitating energy access, Energy Policy, Volume 47, Supplement 1, 2012, Pages 48-55, https://doi.org/10.1016/j.enpol.2012.03.031.

Aklin, M., Bayer, P., Harish, S. P., & Urpelainen, J. (2017). Does basic energy access generate socioeconomic benefits? A field experiment with off-grid solar power in India. *Science Advances*, *3*(5), 1–8. https://doi.org/10.1126/sciadv.1602153

Almeshqab, F., & Ustun, T. S. (2019). Lessons learned from rural electrification initiatives in developing countries: Insights for technical, social, financial and public policy aspects. *Renewable and Sustainable Energy Reviews*, *102*, 35–53. https://doi.org/10.1016/j.rser.2018.11.035

Amin A, Liu Y, Yu J, Chandio AA, Rasool SF, Luo J, Zaman S. How does energy poverty affect economic development? A panel data analysis of

South Asian countries. Environ Sci Pollut Res Int. 2020 Sep;27(25):31623-31635. doi: 10.1007/s11356-020-09173-6. Epub 2020 Jun 4.

Arora, S., & Romijn, H. (2012). The empty rhetoric of poverty reduction at the base of the pyramid. *Organization*, 19(4), 481-505.

Arocena R, Goransson B and Sutz J (2019) Towards making more compatible research evaluation with developmental goals. Science and Public Policy 46(2): 210–218

Asuamah, E. Y., Gyamfi, S., & Dagoumas, A. (2021). Potential of meeting electricity needs of off-grid community with mini-grid solar systems. *Scientific African*, *11*. https://doi.org/10.1016/j.sciaf.2020.e00675

Baud, I. 2016. Moving Towards inclusive development? Recent views on inequalities, frugal innovations, urban geo-technolo gies, gender and hybrid governance. The European Journal of Development Research, 28(2): 119–129.

Bahaj, A. B., Blunden, L., Kanani, C., James, P., Kiva, I., Matthews, Z., Price, H., Essendi, H., Falkingham, J., & George, G. (2019). The impact of an electrical mini-grid on the development of a rural community in Kenya. *Energies*, *12*(5), 1–21. https://doi.org/10.3390/en12050778

Benjamin K. Sovacool, The political economy of energy poverty: A review of key challenges, Energy for Sustainable Development, Volume 16, Issue 3, 2012, Pages 272-282, ISSN 0973-0826, https://doi.org/10.1016/j.esd.2012.05.006.

Bhattacharyya, S. C., & Palit, D. (2016). Mini-grid based off-grid electrification to enhance electricity access in developing countries: What policies may be required? *Energy Policy*, *94*, 166–178. https://doi.org/10.1016/j.enpol.2016.04.010

Boardman, B. (1991). *Fuel Poverty: From cold homes to affordable warmth*. Belhaven Press.

Bortz, G., & Thomas, H. (2017). Biotechnologies for inclusive development: scaling up, knowledge intensity and empowerment (the case of the probiotic yoghurt 'Yogurito' in Argentina). Innovation and Development, 7(1), 37–61. https://doi.org/10.1080/2157930X.2017.1281206

Boardman, B. (2009). *Fixing fuel poverty: Challenges and solutions* (1st ed.). Routledge.

Brix, M., Wehrmeyer, W., & Nygaard, I. (2020). Commercial yet social : The practices and logics of bringing mini-grid electricity to rural villages in Kenya. *Energy Research & Social Science*, *68*, 101588. https://doi.org/10.1016/j.erss.2020.101588

Butchers, J., Williamson, S., Booker, J., Tran, A., Karki, P. B., & Gautam, B. (2020). Understanding sustainable operation of micro-hydropower: A field study in Nepal. *Energy for Sustainable Development*, *57*, 12–21. https://doi.org/10.1016/j.esd.2020.04.007

Cozzens, S., & Sutz, J. (2014). Innovation in informal settings: reflections and proposals for a research agenda. *Innovation and Development, 4(1)*, 5–31. https://doi.org/10.1080/2157930X.2013.876803

Cecelski, E. (2004). *Re-thinking gender and energy: Old and new directions*. ENERGIA/EASE Discussion Paper, May, 681–700.

Chataway, J., Hanlin, R., & Kaplinsky, R. (2014). Inclusive innovation: an architecture for policy development. *Innovation and Development, 4(1)*, 33–54. https://doi.org/10.1080/2157930X.2013.876800

Chandra, R., Saha, J., Yen, S. J., Panda, S. K., Gandhi, O., & Luerssen, C. (2020). Electrifying lives with community empowerment. *IECON Proceedings (Industrial Electronics Conference)*, *2020*, 1797–1802. https://doi.org/10.1109/IECON43393.2020.9254864

Chaurey, A., Ranganathan, M., & Mohanty, P. (2004). Electricity access for geographically disadvantaged rural communities-technology and policy insights. *Energy Policy*, *32*(15), 1693–1705. https://doi.org/10.1016/S0301-4215(03)00160-5

Duran, A. S., & Sahinyazan, F. G. (2021). An analysis of renewable mini-grid projects for rural electrification. *Socio-Economic Planning Sciences*, *77*, 100999. https://doi.org/10.1016/j.seps.2020.100999

Emmanuel Yeboah Asuamah, Samuel Gyamfi, Athanasios Dagoumas, Potential of meeting electricity needs of off-grid community with mini-grid solar systems, Scientific African, Volume 11, 2021, e00675, https://doi.org/10.1016/j.sciaf.2020.e00675.

Elsie Onsongo & Johan Schot, 2017. "Inclusive Innovation and Rapid Sociotechnical Transitions: The Case of Mobile Money in Kenya," SPRU Working Paper Series 2017-07, SPRU - Science Policy Research Unit, University of Sussex Business School.

Elizabeth Hoffecker, Understanding inclusive innovation processes in agricultural systems: A middle-range conceptual model, World Development, Volume 140, 2021, 105382, https://doi.org/10.1016/j.worlddev.2020.105382.

Fink A, Grabner RH, Gebauer D, Reishofer G, Koschutnig K, Ebner F. Enhancing creativity by means of cognitive stimulation: evidence from an fMRI study. Neuroimage. 2010 Oct 1;52(4):1687-95. doi: 10.1016/j.neuroimage.2010.05.072. Epub 2010 Jun 2. PMID: 20561898.

Fressoli, M., Arond, E., Abrol, D., Smith, A., Ely, A., & Dias, R. (2014). When grassroots innovation movements encounter mainstream institutions: implications for models of inclusive innovation. Innovation and Development, 4(2), 277–292. https://doi.org/10.1080/21579 30X.2014.921354

Ferrer-Martí, L., Garwood, A., Chiroque, J., Ramirez, B., Marcelo, O., Garfí, M., & Velo, E. (2012). Evaluating and comparing three community small-scale wind electrification projects. *Renewable and Sustainable Energy Reviews*, *16*(7), 5379–5390. https://doi.org/10.1016/j.rser.2012.04.015

GEORGE, Gerard; McGahan, Anita M.; and Prabhu, Jaideep. Innovation for Inclusive Growth: Towards a Theoretical Framework and a Research Agenda. (2012). *Journal of Management Studies*. 49, (4), 661-683.

Gill-Wiehl, A., Miles, S., Wu, J., & Kammen, D. M. (2022). Beyond customer acquisition: A comprehensive review of community participation in mini grid projects. *Renewable and Sustainable Energy Reviews*, *153*. https://doi.org/10.1016/j.rser.2021.111778

Hills, J. (2012). Getting the measure of fuel poverty. *Final Report of the Fuel Poverty Review*, 19. https://assets.publishing.service.gov.uk/media/5a796f55e5274a2acd18ccde/4662-getting-measure-fuel-pov-final-hills-rpt.pdf

IDRC (2011) Innovation for Inclusive Development, IDRC, Ottawa

IRENA (2017), Accelerating renewable mini-grid deployment: A study on the Philippines, International Renewable Energy Agency, Abu Dhabi.

Jayshree Patnaik, Bhaskar Bhowmick, Promise of inclusive innovation: A Re-look into the opportunities at the grassroots, Journal of Cleaner Production, Volume 259, 2020, 121124, https://doi.org/10.1016/j.jclepro.2020.121124.

Jorge Bacca, Silvia Baldiris, Ramon Fabregat, Sabine Graf, & Kinshuk. (2014). Augmented Reality Trends in Education: A Systematic Review of Research and Applications. Journal of Educational Technology & Society, 17(4), 133–149. http://www.jstor.org/stable/jeductechsoci.17.4.133

Johnson, O. W., Gerber, V., & Muhoza, C. (2019). Gender, culture and energy transitions in rural Africa. *Energy Research and Social Science*, *49*, 169–179. https://doi.org/10.1016/j.erss.2018.11.004

Joshi, G., & Yenneti, K. (2020). Community solar energy initiatives in India: A pathway for addressing energy poverty and sustainability? *Energy and Buildings*, *210*. https://doi.org/10.1016/j.enbuild.2019.109736

Katre, A., & Tozzi, A. (2018). Assessing the sustainability of decentralized renewable energy systems: A comprehensive framework with analytical methods. *Sustainability (Switzerland)*, *10*(4). https://doi.org/10.3390/su10041058

Katre, A., Tozzi, A., & Bhattacharyya, S. (2019). Sustainability of community-owned mini-grids: Evidence from India. *Energy. Sustainability and Society*, *9*(1). https://doi.org/10.1186/s13705-018-0185-9

Kirubi C, Jacobson A, Kammen D, Mills A. Community-based electric micro-grids can contribute to rural development: evidence from Kenya. World Dev 2008;37(7): 1208–21

Kirubi, C., Jacobson, A., Kammen, D. M., & Mills, A. (2009). Community-based electric micro-grids can contribute to rural development: Evidence from Kenya. *World Development*, *37*(7), 1208–1221. https://doi.org/10.1016/j.worlddev.2008.11.005

Kitenge, D. K., & Siringi, P. E. (2019). *Community participation, policy framework and the performance of solar energy in Kenya: A case study of Kalobeyei Ward in Turkana West Sub-County*. *International Journal of Research and Innovation in Social Science*, *III*(X), 347–358.

Kitchenham, B., 2004. Procedures for Performing Systematic Reviews. Technical Report TR/SE0401, Keele University, and Technical Report 0400011T.1, National ICT Australia.

K.J. Joseph, 2014. "Exploring exclusion in innovation systems: case of plantation agriculture in India," Innovation and Development, vol. 4(1), pages 73-90, April.

Klunne, W. J., & Michael, E. G. (2010). Increasing sustainability of rural community electricity schemes-case study of small hydropower in Tanzania. *International Journal of Low-Carbon Technologies*, *5*(3), 144–147. https://doi.org/10.1093/ijlct/ctq019

Korkovelos, A., Zerri, H., Howells, M., Bazilian, M., Rogner, H. H., & Nerini, F. F. (2020). A retrospective analysis of energy access with a focus on the role of mini-grids. *Sustainability (Switzerland)*, *12*(5), 1–29. https://doi.org/10.3390/su12051793

Levidow, L., & Papaioannou, T. (2018). Which inclusive innovation? Competing normative assumptions around social justice. Innovation and Development, 8(2), 209–226. https://doi.org/10.1080/2157930X.2017.1351605

Lillo, P., Ferrer-Martí, L., Boni, A., & Fernández-Baldor, Á. (2015). Assessing management models for off-grid renewable energy electrification projects using the Human Development approach: Case study in Peru. *Energy for Sustainable Development*, *25*, 17–26. https://doi.org/10.1016/j.esd.2014.11.003

López-González, A., Domenech, B., & Ferrer-Martí, L. (2018). Sustainability and design assessment of rural hybrid microgrids in Venezuela. *Energy*, *159*, 229–242. https://doi.org/10.1016/j.energy.2018.06.165

López-González, A., Ferrer-Martí, L., & Domenech, B. (2019). Long-term sustainability assessment of micro-hydro projects: Case studies from Venezuela. *Energy Policy*, *131*, 120–130. https://doi.org/10.1016/j.enpol.2019.04.030

Lukuyu, J., Fetter, R., Krishnapriya, P. P., Williams, N., & Taneja, J. (2021). Building the supply of demand: Experiments in mini-grid demand stimulation. *Development Engineering*, *6*. https://doi.org/10.1016/j.deveng.2020.100058

Luukkanen, J., Tuominen, V., & Vehmas, J. (2012). Scales and fields of electricity production: Sustainability discourses of electricity production in Cambodia and Laos. *Forum for Development Studies*, *39*(2), 209–230. https://doi.org/10.1080/08039410.2012.666671

Mario Pansera, Richard Owen, Framing inclusive innovation within the discourse of development: Insights from case studies in India, Research Policy, Volume 47, Issue 1, 2018, Pages 23-34, https://doi.org/10.1016/j.respol.2017.09.007.

Mario Pansera, Fabien Martinez. Innovation for development and poverty reduction: an integrative literature review. Journal of Management Development, 2017, 36 (1), pp.2-13. {10.1108/JMD-02-2015-0013}

Mayring, Ph. (2010). Design. In G. Mey & K. Mruck (Hrsg.), Handbuch qualitative Forschung in der Psychologie (S. 225 – 237). Wiesbaden: VS Verlag für Sozialwissenschaften.

Mariya Soshinskaya, Wina H.J. Crijns-Graus, Josep M. Guerrero, Juan C. Vasquez, Microgrids: Experiences, barriers and success factors, Renewable and Sustainable Energy Reviews, Volume 40, 2014, Pages 659-672, https://doi.org/10.1016/j.rser.2014.07.198.

Mazzone, A. (2019). Decentralised energy systems and sustainable livelihoods, what are the links? Evidence from two isolated villages of the Brazilian Amazon. *Energy and Buildings*, *186*, 138–146. https://doi.org/10.1016/j.enbuild.2019.01.027

Md Moniruzzaman, Rosie Day, Gendered energy poverty and energy justice in rural Bangladesh, Energy Policy, Volume 144, 2020, 111554, https://doi.org/10.1016/j.enpol.2020.111554.

Millinger, M., Mårlind, T., & Ahlgren, E. O. (2012). Evaluation of Indian rural solar electrification: A case study in Chhattisgarh. *Energy for Sustainable Development*, *16*(4), 486–492. https://doi.org/10.1016/j.esd.2012.08.005

Moore, R. (2012). Definitions of fuel poverty: Implications for policy. *Energy Policy*, *49*, 19–26. https://doi.org/10.1016/j.enpol.2012.01.057

Muchunku, C., Ulsrud, K., Palit, D., & Jonker-Klunne, W. (2018). Diffusion of solar PV in East Africa: What can be learned from private sector delivery models? *Wiley Interdisciplinary Reviews: Energy and Environment*, *7*(3), 1–15. https://doi.org/10.1002/wene.282

Onsongo, E. K., & Knorringa, P. (2020). Comparing frugality and inclusion in innovation for development: logic, process and outcome. *Innovation and Development, 15(3)*, 621–641. https://doi.org/10.1080/2157930X.2020.1811931.

Palit, D., & Chaurey, A. (2011). Off-grid rural electrification experiences from South Asia: Status and best practices. *Energy for Sustainable Development*, *15*(3), 266–276. https://doi.org/10.1016/j.esd.2011.07.004

Pansera, Mario & Owen, Richard, 2015. "Framing resource-constrained innovation at the 'bottom of the pyramid': Insights from an ethnographic case study in rural Bangladesh," Technological Forecasting and Social Change, vol. 92(C), pages 300-311.

Prahalad CK, Hammond A. Serving the world's poor, profitably. Harv Bus Rev. 2002 Sep;80(9):48-57, 124. PMID: 12227146.

Paunov, C., 2013, Innovation and Inclusive Development: A discussion of the main policy issues, STI Working Paper 2013/1, OECD, Paris.

Pandey, P., & Sharma, A. (2021). Knowledge politics, vulnerability and recognition-based justice: Public participation in renewable energy transitions in India. *Energy Research and Social Science*, *71*, 101824. https://doi.org/10.1016/j.erss.2020.101824

Pedersen, M. B., Wehrmeyer, W., Nygaard, I., Brix, M., Wehrmeyer, W., & Nygaard, I. (2020). Commercial yet social: The practices and logics of bringing mini-grid electricity to rural villages in Kenya. *Energy Research and Social Science*, *68*, 101588. https://doi.org/10.1016/j.erss.2020.101588

Pueyo, A., & DeMartino, S. (2018). The impact of solar mini-grids on Kenya's rural enterprises. *Energy for Sustainable Development*, 45, 28–37.

Pigaht, M., & van der Plas, R. J. (2009). Innovative private micro-hydro power development in Rwanda. *Energy Policy*, *37*(11), 4753–4760. https://doi.org/10.1016/j.enpol.2009.06.039

Rahmann, C., Núñez, O., Valencia, F., Arrechea, S., Sager, J., & Kammen, D. (2016). Methodology for monitoring sustainable development of isolated microgrids in rural communities. *Sustainability (Switzerland)*, *8*(11). https://doi.org/10.3390/su8111163

Raphael Kaplinsky, Schumacher meets Schumpeter: Appropriate technology below the radar, Research Policy, Volume 40, Issue 2, 2011, Pages 193-203, https://doi.org/10.1016/j.respol.2010.10.003.

Rajabrata Banerjee, Vinod Mishra, Admasu Asfaw Maruta, Energy poverty, health and education outcomes: Evidence from the developing world, Energy Economics, Volume 101, 2021, 105447, https://doi.org/10.1016/j.eneco.2021.105447.

Richard Heeks & Christopher Foster & Yanuar Nugroho, 2014. "New models of inclusive innovation for development," Innovation and Development, Taylor & Francis Journals, vol. 4(2), pages 175-185, October.

Roche, O. M., & Blanchard, R. E. (2018). Design of a solar energy centre for providing lighting and income-generating activities for off-grid rural communities in Kenya. *Renewable Energy*, *118*, 685–694. https://doi.org/10.1016/j.renene.2017.11.053

Subhes C. Bhattacharyya, Financing energy access and off-grid electrification: A review of status, options and challenges, Renewable and Sustainable Energy Reviews, Volume 20, 2013, Pages 462-472, https://doi.org/10.1016/j.rser.2012.12.008.

Schnitzer, D., Lounsbury, D. S., Carvallo, J. P., Deshmukh, R., Apt, J., & Kammen, D. M. (2014). Microgrids for Rural Electrification: A critical review of best practices based on seven case studies. *United Nations Foundation*, *122*.

Sen, A. (2000). A Decade of Human Development. Journal of Human Development, 1(1), 17–23. https://doi.org/10.1080/14649880050008746

Seyfang, G., & Smith, A. (2007). Grassroots innovations for sustainable development: Towards a new research and policy agenda. *Environmental Politics, 16(4)*, 584–603. https://doi.org/10.1080/09644010701419121

Sharma, R. K., & Palit, D. (2020). A coevolutionary perspective on decentralised electrification: A solar mini-grid project in India. *Inter-national Journal of Sustainable Society*, 12, 202–219. https://doi.org/10.1504/IJSSOC.2020.109773

Sharma, A. (2020). 'We Do Not Want Fake Energy': The social shaping of a solar micro-grid in Rural India. *Science, Technology and Society*, *25*(2), 308–324. https://doi.org/10.1177/0971721820903006

Susan E Cozzens & Raphael Kaplinsky, 2009. "Innovation, Poverty and Inequality: Cause, Coincidence, or Co-evolution?," Chapters, in: Bengt-Åke Lundvall & K. J. Joseph & Cristina Chaminade & Jan Vang (ed.), Handbook of Innovation Systems and Developing Countries, chapter 3, Edward Elgar Publishing

Tranfield, D., Denyer, D. and Smart, P. (2003), Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review. British Journal of Management, 14: 207-222. https://doi.org/10.1111/1467-8551.00375

Tilman Altenburg, Hubert Schmitz, Andreas Stamm, Breakthrough? China's and India's Transition from Production to Innovation, World Development, Volume 36, Issue 2, 2008, Pages 325-344, https://doi.org/10.1016/j.worlddev.2007.06.011.

Terrapon-Pfaff, Julia & Dienst, Carmen & König, Julian & Ortiz, Willington, 2014. "A cross-sectional review: Impacts and sustainability of small-scale renewable energy projects in developing countries," Renewable and Sustainable Energy Reviews, Elsevier, vol. 40(C), pages 1-10.

Tommaso Ciarli, Martin Kenney, Silvia Massini, Lucia Piscitello, Digital technologies, innovation, and skills: Emerging trajectories and challenges, Research Policy, Volume 50, Issue 7, 2021, 104289, https://doi.org/10.1016/j.respol.2021.104289.

Toru Kobayakawa, Tara C. Kandpal, A techno-economic optimization of decentralized renewable energy systems: Trade-off between financial viability and affordability—A case study of rural India, Energy for Sustainable Development, Volume 23, 2014, Pages 92-98, https://doi.org/10.1016/j.esd.2014.07.007.

Ulsrud, K., Winther, T., Palit, D., Rohracher, H., & Sandgren, J. (2011). The Solar Transitions research on solar mini-grids in India: Learning from local cases of innovative socio-technical systems. *Energy for Sustainable Development*, 15, 293–303.

Ulsrud, K., Rohracher, H., Winther, T., Muchunku, C., & Palit, D. (2018). Pathways to electricity for all: What makes village-scale solar power successful? *Energy Research and Social Science*, *44*, 32–40.

Uamusse, M. M., Tussupova, K., Persson, K. M., Bengtsson, L., & Berndtsson, R. (2020). Access to sustainable electrification: Possibilities for rural Mozambique. *Cogent Engineering*, *7*(1). https://doi.org/10.1080/23311916.2020.1765688

UNCTAD, 2014, UNCTAD Annual Report 2014, Putting Sustainable Development First, Delivering Results, United Nations, Geneva.

Urmee, T., & Md, A. (2016). Social, cultural and political dimensions of off-grid renewable energy programs in developing countries. *Renewable Energy*, *93*, 159–167. https://doi.org/10.1016/j.renene.2016.02.040

Van Els, R. H., De Souza Vianna, J. N., & Brasil, A. C. P. (2012). The Brazilian experience of rural electrification in the Amazon with decentralized generation - The need to change the paradigm from electrifica-

tion to development. *Renewable and Sustainable Energy Reviews*, *16*(3), 1450–1461. https://doi.org/10.1016/j.rser.2011.11.031

VAN GEVELT, Terry; ZAMAN, T.; GEORGE, F.; BENNETT, M.M; FAM, S.D.; and KIM, J.E.. End-user perceptions of success and failure: narratives from a natural laboratory of rural electrification projects in Malaysian Borneo. (2020). *Energy for Sustainable Development*. *59*, 189-198.

Wiese, K. (2020). Energy 4 all? Investigating gendered energy justice implications of community-based micro-hydropower cooperatives in Ethiopia. *Innovation: The European Journal of Social Science Research*, *33*(2), 194–217. https://doi.org/10.1080/13511610.2020.1745059

Yadoo, A. (2012). *Delivery models for decentralised rural electrification: case studies in Nepal, Peru and Kenya*. Available at https://www.iied.org/16032iied

Yadoo, A., & Cruickshank, H. (2012). The role for low carbon electrification technologies in poverty reduction and climate change strategies: A focus on renewable energy mini-grids with case studies in Nepal, Peru and Kenya. *Energy Policy*, *42*, 591–602. https://doi.org/10.1016/j.enpol.2011.12.029

Part 2

Fieldwork Reports

This part of the book contains details of the fieldwork undertaken in Nigeria, Kenya, and Tanzania as part of the research project, discusses the methodology used for the fieldwork, and provides main observations and reflections.

Chapter 6 presents the case of Kenya; Chapter 7 presents the Nigerian case, while Chapter 8 presents the Tanzanian case. The collaborating teams from these countries have undertaken the primary data collection activities and have prepared the reports. Ethical approval for the project came from the Ethics Committee of the Faculty of Technology, De Montfort University (DMU), at the start of the project, and subsequently, when the project lead moved to the University of Surrey, approval was obtained from the University of Surrey as well. The fieldwork adhered to the ethical conduct of research as outlined in the approval process.

CHAPTER 6

Kenya Fieldwork Report

Elsie Onsongo, Abigael Okoko, Beryl Onjala, Rosebella Nyumba and Mourice Kausya

Nuvoni Centre for Innovation Research, Nairobi, Kenya

Abstract

This chapter presents the details of the fieldwork undertaken in Kenya for the SIGMA project. The work involved questionnaire design, site identification, field visits, focus group meetings, and interviews with key stakeholders at various sites. Data was collected from 15 mini-grid sites covering a range of locations, technologies, ownership types and sizes. Researchers interviewed 110 connected households, 45 unconnected, 53 productive users, 13 institutions, 4 community leaders, 9 site agents/operators, and 7 county energy department representatives. For each site visited, the chapter provides a brief background of the mini-grid system and the challenges being faced by the mini-grid system. The chapter ends with some reflections around the fieldwork and a brief summary of lessons from the fieldwork.

Keywords: field visit, questionnaire, focus group discussions, mini-grid, challenges, lessons

6.1 Introduction and Background

ICFI Kenya Hub is part of a consortium implementing a 3-year research project titled "Sustainability, Inclusiveness and Governance of Mini-grids in Africa" (SIGMA) funded by UK Research and Innovation-Global Challenge Research Fund. This is a collaborative project involving partners from the United Kingdom (University of Sussex and DMU), TaTEDO in Tanzania, International Centre for Energy, Environment and Development in Nigeria, and the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE) in West Africa. The main objectives of the project are to:

Develop an evidence base on mini-grid performance in sub-Saharan Africa;
Develop a framework to analyze the political economy of energy access and the sustainability framework of mini-grids; and
Undertake in-depth case studies of mini-grid sustainability, inclusiveness, and governance in countries of sub-Saharan Africa (Kenya, Tanzania, Senegal, and Nigeria).

The ICFI Kenya Hub is to provide data for the "Sustainability, Inclusivity, and Governance of Mini-grids in Africa" work package, taking care of the Kenyan geographical context.

6.2 Methodology

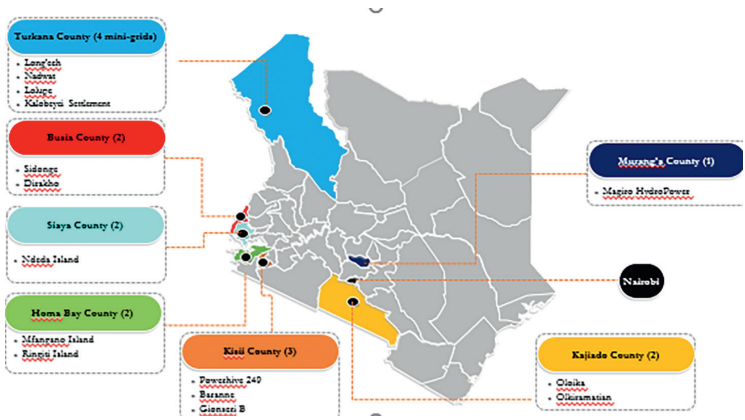
6.2.1 Research Design

The study adopted an embedded case study design, where we considered Kenya as a case study, with a focus on several embedded units, which informed the fieldwork exercise.

6.2.2 Research Area

The field visits were conducted in the counties of Kajiado, Siaya, Homa bay, Kisii, Busia, Turkana, and Murang'a (see Fig. 6.1).

Figure 6.1: Map of Kenya Indicating Counties Visited for Fieldwork



6.2.3 Data Collection

To achieve the objectives of the work package, data collection was necessary. A fieldwork protocol was developed outlining the data collection plan, as discussed in what follows.

6.2.3.1 Data Collection Plan

As per the fieldwork protocol, we targeted data collection from 20 mini-grids across selected counties. The selection of the mini-grids was based on the matrix presented in Table 6.1, according to technology and ownership type.

From these sites, we conducted focus group discussions (FGD) and interviews with key informants and households. Key informant interviews were conducted with mini-grid developers/operators, county government officials in charge of energy, and community leaders such as members of the management committee, e.g., the chairman and the secretary. Users of the mini-grids such as households, enterprises, and community facilities were interviewed using semistructured questionnaires. We interviewed ten (10) connected and five (5) unconnected households. Five (5) enterprises were also interviewed per mini-grid, focusing on different types of business (general shops, barbershops, salons, posho mills, video halls, guest houses, welding workshops, among others). Community facilities such as schools, health centers, vocational training colleges, and a community library were also interviewed where possible. FGD were conducted with the mini-grid users. The criteria for conducting the FGDs considered planned mini-grid/under development, in an existing mini-grid and in a decommissioned/nonoperational mini-grid.

6.2.3.2 Questionnaire

We developed semistructured questionnaires targeting households connected to the mini-grids and those not connected to the mini-grids, productive users such as business enterprises that were connected to the mini-grid, and institutions such as schools and health facilities. The aim was to collect their views on their energy use, expenditure, inclusivity and community participation, benefits derived from the connection for those who are connected, etc.

Table 6.1: Matrix of Targeted Mini-Grids in Each Country

		Ownership Model					
		Publicly Owned	*Privately Owned*	*Public–Private Partnership*	*Community Owned*	*Other (e.g., Faith-Based Organization)*	*Total*
Technology	*Hydro*	1		1	1	2	5
	Solar PV		3		3		6
	Fuel oil	2	2				4
	Geothermal						0
	Biomass		1				1
	Natural gas	1					1
	Wind		1				1
	Hybrid		2				2
	Total	4	9	1	4	2	20

The questionnaires development process was iterative. The development of the questionnaires considered different variables, including household demographics and income, energy use, energy cost, electricity connection cost, electricity stability, reliability, payment systems, and participation, during mini-grid development and during operation and communication channels. The software we used was the free version of the *Kobotoolbox* (*survey form building and data storage*) and ODK (*data collection app*). The form building was done in-house and the ODK app was downloaded from Google Play Store and configured to the *Kobotoolbox* server.

It is crucial to highlight that the data collection process adhered strictly to ethical guidelines, as outlined by both DMU and the University of Surrey. These ethical approvals from DMU and Surrey were taken, and the procedures outlined there were followed.

6.2.3.3 Lessons Learned During Questionnaire Development

The process of developing the survey questionnaires and building them on *Kobotoolbox* was smooth except for a few issues. First, the software (*Kobotoolbox*) had some technical shortcomings, which created some challenges as we were creating the questionnaire. This platform lacks some advanced options found in other sophisticated software such as SurveyCTO. Second, some survey questions were complex in nature, and, therefore, developing the survey forms proved to be challenging. To deal with this, the questions were simplified, yet the objective of the research was maintained. Third, late changes made to the questionnaires were also a source of delays and posed challenges to the form building process. Furthermore, software problems could lead to system hiccups in the middle of an interview, and it was a challenge moving forward with the interview.

In addition, during the fieldwork, the *Kobotoolbox* was to be continuously enhanced and updated in the field, and this led to too many changes, which led to some inconsistencies, as some submitted forms were slightly different from the others. Few coding errors and last-minute questionnaire modifications forced these changes. These hiccups led to delays in the start of the actual fieldwork in the field. Another problem faced in the field was the constant need to recharge the tablets once they ran out of power. We, however, solved this challenge by using power banks. Editing the forms once they had been uploaded into the system proved to be

challenging, and the problems arose from the platform itself. However, despite these challenges, data collection using the tablets was much more advantageous than using a paper questionnaire.

Tablets provide much needed anonymity and confidentiality in research.
Using tablets ensured that the data was safe from the possibility of data loss or damage even if the tablet was broken or lost. This is because some tablets were set in such a way that the forms were submitted automatically to the protected server.
They facilitated real-time data storage and access.
These tablets were easy and less cumbersome to carry around, and we had no worries of accounting for every questionnaire.
Use of tablets also saved us the cost of printing the paper questionnaires.
The use of tablets ensured efficiency in data collection since less time was used while collecting the data compared to writing responses on paper questionnaires.
Programming of questionnaires in *Kobotoolbox* can reduce or minimize errors in data collection. For instance, it can allow for setting limits, e.g., on age; determine whether a response has to be a numerical or alphabetical, selection of one or multiple options, ensuring all questions are responded to.

Every researcher on the team had a good knowledge of how to use the tablets and the K*obotoolbox*.

6.2.3.4. Recommendations

The advantages of using electronic data collection systems (tablets in our case) outweigh the disadvantages encountered. We recommend the following:

Building the questionnaire into the *Kobotoolbox* is an arduous and time-consuming task, which should be completed fully before the actual fieldwork begins.
A more advanced software (*form builder and server*) should be adopted to avoid the recurrence of the technical challenges outlined in the previous section.
Once the actual fieldwork has begun, no changes should be made on the questionnaire, as this proves to be time consuming and leads to inconsistencies.

It is important to have an internet connection during the fieldwork as it is the tablets have to be used for timely downloading and uploading of forms.
It is important to have a backup source of power for the tablets, i.e., extra tablets or power banks, as in our case.

6.2.3.5 Interview Guides

We developed interview guides targeting mini-grid operators, community leaders, and county energy department representatives in the respective counties visited. Other key informant interviews conducted were with government agencies such as the Ministry of Energy, Rural Electrification and Renewable Energy Corporation (REREC), mini-grid financiers. In addition, we developed an interview guide for use during the FGD sessions in selected sites.

6.2.3.6 Planning for the Key Informant Interviews

We made prior arrangements before conducting the interviews. After identifying the key informants, we sent them emails and phoned them to request for interviews and book appointments with the respective persons. In most cases, the interviews were successful. In some cases, we received no response, and, therefore, such interviews could not be conducted. For those who accepted our requests, we agreed on an appropriate date of the interview either in person or virtually.

6.2.3.7 Planning for FGD, How They Were Conducted, and Outcomes in General, Lessons

Planning for the FGD involved setting up a criterion for the selection of the participants, their mobilization, and eventually conducting the discussion. The criteria followed was to conduct an FGD in a site with an operating mini-grid, one with a mini-grid under development, and one that is decommissioned /nonoperational.

The composition of the discussants ensured representation from the different segments in the community, with the number ranging from 10 to 15 discussants. These included males, females, youth, and a community

leader. The discussants also included members who were either connected or not connected to the mini-grid. Mobilization of the discussants in most cases was done by the mini-grid operators. This may have led to a bias in the selection of the discussants against the criteria provided. However, in Mfangano Island and Baranne, the Area Chief did the mobilization. Generally, the discussions went on smoothly, with much of what was intended for the discussion covered.

At the end of the fieldwork, we managed to conduct four FGDs, three of which were in operational sites and one in a decommissioned site. These were conducted in Mfangano Island (Homa Bay County), Lolupe (Turkana County), Magiro Hydro mini grid (Murang'a County), and Baranne (Kisii County). However, there was no FGD conducted in a site under development. KUDURA Power East Africa has sites where they intend to install mini-grids. However, we could not conduct an FGD in those sites since the officers at KUDURA advised that this would lead to awakening/raising the expectations of the residents who have been waiting for the project for a long time.

6.2.3.8 Recommendation regarding FDGs

From our observations, it is important to engage a neutral person in the mobilization of FGD participants wherever possible to avoid a predetermined scenario or responses.

6.3 Field Visits

6.3.1 Planning for field visits

Before the commencement of the actual field visits, we made contact with the point persons at the respective mini-grids such as the mini-grid developers or operators. We explained the purpose of the study and our intention to visit their mini-grid sites and interview their clients. An appropriate date was set. Where the developers were not at their respective mini-grids, they provided us with alternative contact persons and their details. Once the dates were confirmed, we developed a fieldwork itinerary that we adopted as a guide to facilitate our travel to and within the respective counties. It also enabled us keep track of activities in the field to ensure that we covered all the activities as planned.

The aim of the field visits was to collect data in the sites where the mini-grids are located. This encompassed visiting the mini-grid sites, conducting interviews with the operators, households, businesses/productive users, institutions, local leaders, and the county energy departments in the respective counties.

6.3.2 Actual Fieldwork

The fieldwork actively began on February 2, 2022, and continued until May 2022. The details of the fieldwork are provided in Table 6.2.

As illustrated in Table 6.2, we visited seven (7) counties where we managed to visit 15 mini-grids. The mini-grids we visited were of varying characteristics (Table 6.3) such as the technology, number of connections, generation capacity, ownership, and status of the mini-grids at the time of

Table 6.2: Itinerary of Mini-Grid Sites Visited During the Study

Location	Date (2022)	Name of Mini-Grid/ Location	Mini-Grid Developer
Kajiado County	February 1 and 2	Oloika	University of Southampton
	February 3	Olkiramatian	Renewvia
	February 7	Kajiado County Energy Department	
Siaya	February 15	Siaya County Energy Department	
	February 15 and 16	Ndeda Island	Renewvia
Homabay	February 18	Mfangano	Kengen/KPLC
	February 20	Ringiti	Renewvia
Kisii	February 22	Powerhive team and Powerhive chicken slaughterhouse	
	February 23	Powerhive 249	Powerhive
	February 23	Kisii County Energy Department	
	February 24	Baranne	Powerhive
	February 24	Gionseri B	Powerhive

(Continued)

Location	Date (2022)	Name of Mini-Grid/ Location	Mini-Grid Developer
Busia	March 16	KUDURA Power East Africa Team	
	March 16	Sidonge	KUDURA Power East Africa
	March 17	Dirakho	KUDURA Power East Africa
	March 18	Busia County Energy Department	
Turkana	March 21	Longech	Nal Offgrid
	March 22	Lolupe	Nal Offgrid
	March 22	Nadwat	Nal Offgrid
	March 23	Kalobeyei Settlement	
	March 24	Turkana County Energy Department	
Murang'a	May 10–11	Magiro Hydro mini grid	Magiro
	May 11	Murang'a County Energy Department	

the visit. Collection of data from mini-grids with varying characteristics would aid in comparing different mini-grids from economic, technological, and technical perspectives, which are important parameters or dimensions for mini-grid sustainability.

We interviewed 110 connected households, 45 unconnected, 53 productive users, 13 institutions, 4 community leaders, 9 site agents/operators, and 7 county energy department representatives, as detailed in Table 6.4.

The productive users of electricity that we interviewed included those who operated general shops, guesthouses, posho mills, welding workshop, barbershops, salons, pubs, etc (Table 6.5). Common PUE across the different mini-grids were barbershops, salons, and general shops. The existence of PUE such as welding were not common. In some places such as Ndeda Island, a welder would come to the island occasionally when the need arose. Establishment of PUE that utilized electricity from the mini-grid for processing of gold was due to the availability of the raw material in the localities such as Nadwat and Lolupe. Longech area, being a fishing

Table 6.3: Characteristics of Mini-Grids Visited

Mini-Grid Name	Technology	Capacity KW	Status	Ownership	*Connections (Households, Institutions, Businesses)*
Oloika	Solar	13.5	Semioperational	Community	46
Olkiramatian	Solar	6.2	Fully operational	Private	70
Ndeda	Solar & Wind	9.6	Fully operational	Private	400
Ringiti	Solar	20.45	Fully operational	Private	290
Mfangano	Diesel & Solar	520.10	Fully operational	Public	5,000+
Powerhive 249	Solar	60	Fully operational	Private	169
Gionaseri B	Solar	60	Fully operational	Private	374
Baranne	Solar	50	Decommissioned	Private	80 (at the time of decommissioning)
Sidonge	Solar	7.3	Fully operational	Private	220
Dirakho	Solar	30	Fully operational	Private	524
Longech	Solar	45	Semioperational	Private	218
Lolupe	Solar	22	Fully operational	Private	136
Nadwat	Solar	44	Semioperational	Private	180
Kalobeyei settlement	Solar	60 extending to 504	Semioperational	Private	504, expected to serve 2,000+ after expansion work is completed
Magiro	Hydro	70	Fully operational	Private	1,500

Table 6.4: Number of Interviews or FGD Conducted per Mini-Grid

	HH-Connected	HH-Unconnected	PUE	Institutions	FGD	Community Leaders	Operator	County Energy Department
Oloika	10	5	5	2		1	1	1
Olkiramatian	10	5	5				1	
Ndeda	10	5	5	2		1	1	1
Ringiti	10	5	5	2			1	1
Mfangano			2	1	1		1	
Powerhive 249	10	5	3				1	1
Gionseri B	10	5	3				1	
Baranne					1		1	
Sidonge	10		5			1		1
Dirakho	10		5	1		1		
Longech	10	5	5	2			1	1
Lolupe					1			
Nadwat	10	5	5					
Kalobeyei Integrated Settlement	10	5	5	3				
Magiro Hydro					1			1

Table 6.5: Types of Productive Users, Institutions, and Community Leaders Interviewed at Mini-Grid

	Productive Users Interviewed	Institutions Interviewed	Community Leaders Interviewed
Oloika	*General shops, rental businesses,*	*Secondary school, dispensary,*	*Committee secretary*
Olkiramatian	*General shops*		
Ndeda	*Guesthouses, barbers, general shops, betting*	*Primary school,*	*Beach Management Unit*
Ringiti	*Salons, pubs*	*Primary school,*	
Mfangano	*Welding & fish farms,*	*School-boarding primary*	
Powerhive 249	*Posho mill,*		
Gionseri B	*Hotel, posho mill,*		
Baranne			
Sidonge	*General shops, barbers,*		*Rtd. Chief*
Dirakho		*Vocational training school*	*CBO chair*
Longech	*Ice processor, salons, barbers*	*Dispensary*	
Lolupe			
Nadwat	*Welder/garage, gold processor, salon & cosmetic*		
Kalobeyei settlement	*Carpenter/furniture shops, welding*		
Magiro			

community, necessitated the establishment of an ice processing plant for the purpose of fish preservation.

We conducted four (4) FGDs (Table 6.6), comprised of representatives of the respective community. The FGDs were composed of men, women, youths, and the elderly.

Table 6.6: FGDs Conducted

Site	MG Owner/Operator	Status
Baranne	Powerhive	Decommissioned
Lolupe	Nal Offgrid	Operational
Mfangano	KPLC	Operational
Magiro	Magiro/Hydroxox	Operational

6.4 Observations/Findings

6.4.1 Kajiado County

Kajiado County is located in the former Rift Valley region and borders Narok County to the west; Nakuru County, Kiambu County, and Nairobi County to the north; Machakos County, Makueni County, and Taita Taveta County to the east, and Tanzania to the south, constituting one of the counties that share a border with Tanzania. Kajiado County spans an area of 21,292.7 km². Its main tourist attraction is its wildlife.

In Kajiado County, we visited Oloika and Olkiramatian mini-grid sites both located in Kajiado West subcounty. The two mini-grids are also owned by Renewvia.

6.4.1.1 Oloika Mini-Grid

At Oloika mini-grid (Fig. 6.1), we conducted interviews with the site agent and the secretary general of the committee, who informed us that the consultation to start the project was done between the Oloika cooperative society, whose membership was drawn from the community, and the mini-grid developers, i.e., University of Southampton. The mini-grid was installed in 2015. Currently, the community through Oloika cooperative society manages the mini-grid after the developer handed it over to them.

The mini-grid generates electricity from solar energy. The mini-grid served 39 households, 1 dispensary, a secondary school and 5 shops. The connection fee was 3,000 Ksh.

Figure 6.1: Oloika Mini-Grid



Photo credits: Rosebella Nyumba.

The mini-grid is currently not functioning optimally, as reflected by the rundown of storage batteries that need replacement. The repair is yet to be done.

From the interviews conducted, community members stated that at the initial stages when the mini-grid was installed, the benefits were obvious, and the community was happy with the electrification. Businesses and households had the opportunity to have improved and extended hours of lighting. Shops with refrigerators realized good business due to increased sales. It is important to note that the extremely hot climate creates a conducive environment for sale of refrigerated drinks such as soda and water.

Challenges Faced at the Mini-Grid Include:

Rundown of the battery, and therefore, no power storage, which also means no electricity at night when it is mostly needed by the households

Overload on the system due to too many connections beyond the capacity of the mini-grid. Therefore, rationing is done even during the day, where some parts of the site do not get electricity even during the day.

Financial management challenges: the money collected from the community cannot be accounted for.

Lack of training for the site agent

There is no existing working relationship with the county government. So the mini-grid operator or site agent cannot get the technical assistance needed.

6.4.1.2 Olkiramatian Mini-Grid

The solar mini-grid at Olkiramatian (Fig. 6.2) was developed and installed by Renewvia in 2019. During the interviews that were conducted, it was learned that there were consultations with the local leadership of the community to initiate the process of the mini-grid installation. Afterward, a consultative meeting enjoined the project developers, the local leadership, and the community members. After they reached a consensus to start the project, the Olkiramatian group ranch leased out land to Renewvia to facilitate the construction of the mini-grid. Those who wanted the electricity connection paid 1,000 Ksh payable to Renewvia. All payments, including token purchase, are made to Renewvia through a mobile money payment system.

It has a capacity of 6.2 KW with a potential to serve 150 households. At the time of the field visit, the mini-grid was already serving 70 households with a reliable and constant 24-hour electricity supply. The mini-grid was also serving one private dispensary and other business premises. However, no public facility (schools, public hospitals, etc.) had been connected.

Figure 6.2: Olkiramatian Mini-Grid

A  B 

Photo credit: Abigael Okoko.

Challenges:

Technical challenges. Lack of technician on site. In case there is a need for technical assistance, the site agent relays the information to the mini-grid developer (Renewvia), who then sends a technician. The community, however, states that there are delays since the technician is in the capital city, Nairobi.

The mode of payment for the tariff relies on money agents, e.g., Mpesa. However, there is only one Mpesa agent who prefers one-way transactions, i.e., withdrawal of cash, since he gets commission on each

withdrawal unlike deposits, which do not attract commission from safaricom and therefore lack of enough float to transact the Mpesa agent.

6.4.2 County Energy Department of Kajiado County

On February 7, 2022, we had an interview with the County Director Energy of Kajiado County, in which we discussed regulatory and policy issues of mini-grids in the county.

From the interview, it was noted that the county is not so much involved in matters around mini-grids. The Ministry of Energy approves the mini-grid projects at the national government level. The county energy department is also not involved in the process of setting tariffs. The county is, however, involved in easing the approval and licensing process for investors, such as creating a conducive environment for the investors by linking them up with the community. The county also helps in matters that involve land, e.g., knowing where one can put up a mini-grid project. In some cases, the County energy office only gets reports/feedback when there is a problem in the community. However, the county has strategies in place to assist the communities where they face challenges by providing technical assistance when it comes to matters involving energy.

Some of the approvals required by investors include approvals by National Environment Management Authority (NEMA), land use approvals, i.e., the land should not be a public land, and the project should be located within an area where that kind of development is permitted. Land approvals are done by the Ministry of Lands and Housing at the county level, which includes the change of land use. The county lacks an energy policy. However, the process of developing the energy plans is underway. The County Integrated Development Plan (CIDP) has included mini-grids as one of the sources of energy among others in the county. There are plans by the county to electrify all public facilities such as schools and dispensaries. To improve the rate of electrification in Kajiado County, the county is putting in place measures that will encourage independent developers.

Challenges:

There is no budget allocated for electrification of the remote areas.

The county is not involved in mini-grid regulation and approval and feels left out.

The existing channel of communication between the country energy office and the community is through the ward administrators, which

the community is not aware of or not utilizing. From the interviews with the community, there has not been any working relationship with the county energy department.

6.4.3 Siaya County

Siaya County is one of the counties in the former Nyanza Province in the southwestern part of Kenya. It is bordered by Busia County to the north, Kakamega County and Vihiga Counties to the northeast and Kisumu County to the southeast. It shares a water border with Homa Bay County, which is located south of Siaya County. In Siaya County, we visited a mini-grid in Ndeda Island located in Bondo subcounty and also had an interview with the county director of energy in Siaya town.

6.4.3.1 Ndeda Island Mini-Grid

We accessed the Ndeda Island by driving for about 45 minutes on a murram road from Bondo town to Uyawi beach, from where we had a boat ride for about 30 minutes. The Island has a population of more than 4,000 inhabitants and was served by a primary school and a health facility as the main public facilities.

The island is served by a hybrid mini-grid (Fig. 6.3), incorporating both solar and wind energy systems, which supply the island with electricity. The installed capacity of the mini-grid is 15 KW (9 KW from solar and 6 KW from wind energy). The household interviews were conducted with both connected and unconnected households. Apart from households and businesses, the mini-grid also serves the only public primary school and health facility (Fig. 6.4) within the island.

Figure 6.3: Hybrid Mini -Grid at Ndeda Island



Photo credit: Abigael Okoko.

Figure 6.4: Institutions Served by the Mini-Grid: Left to Right; Health Facility and Public Primary School

A



B



Photo credit: Abigael Okoko.

6.4.3.2 County Energy Department of Siaya County

Siaya County has not installed any mini-grids. The mini-grids found within Siaya County are those developed by the private developers, e.g., at Ndeda Island, there is a solar and wind power mini-grid developed by Renewvia & Vesters, another one at Sika, Mageta Island, developed by Renewable world, and an ongoing project at Mageta Island estimated to have a capacity of 700 KW.

At the time of the visit to Siaya County, the energy department was not properly structured. It has one officer, and the department of energy was placed under the public works and roads/transport department, and, therefore, activities of the energy department were not prioritized over those of the other departments. The energy department was drafting a county energy policy, which was still at the draft stage. Training for the county energy planning was being conducted at the national level, after which all counties were expected to have their county energy plans (CEP).

In the draft Siaya County energy policy, there was a proposal for the development of an energy center in the county.

Regarding the mini-grids regulations and operations within Siaya County, the county played a very limited role. It was not involved in approval or regulation of mini-grids or tariff-setting. As such, there was a proposal that the county be involved in the process of setting tariffs. There had been complaints by the community served by the mini-grids that the cost of the electricity from the mini-grids were higher than that of Kenya Power. E.g., when Ndeda mini-grid was being set up, the tariff was set at 70 Ksh per unit, but after some negotiation and intervention, it was reduced to 65 Ksh per unit.

The Challenges Faced by County Government:

The Energy Petroleum & Regulatory Authority (EPRA) and the Ministry of Energy set the tariffs, and the county government is not involved in this process and is involved only as a stakeholder.

The Ministry of Energy at the national level does all the approvals. The county does not play any role. It is only involved in the change of user done by the ministry of lands at the county offices. However, change of user is a process done for any other project involving land, not only those unique to the development of mini-grids.

Kenya Power & Lighting Company (KPLC) works in isolation and, therefore, knowing where they are going to extend the grid is a challenge.

Funding is also a challenge, especially from the county government. Projects can run well if there is funding and, more so, external funding since the internal budgeting process is bureaucratic and takes long.

Challenges Faced by Stakeholders/Investors:

Houses are scattered and, therefore, heavy initial capital investment is required to put up the necessary infrastructure.

Impacts of the Mini-Grid

The mini-grids have contributed to the economic development and change of lifestyle of the residents; e.g., there are increased business opportunities, floodlights have been installed, facilitating more business hours and more security for the community in Ndeda Island.

6.4.4 Homa Bay County

Homa Bay County is located in the southern part of Nyanza, along the southern shores of Lake Victoria. Homa Bay County covers an area of 3,183.3 sq. km with a population of about 1.3 million people. It borders five other counties: Migori to the South, Kisii and Nyamira to the East, and Kericho and Kisumu to the Northeast. It is accessible by lake transport, road, and air. In Homa Bay County, we visited the Mfangano Island off-grid power system and the Ringiti Island mini-grid.

6.4.4.1 Mfangano Island

Located in Suba West constituency, Mfangano Island is served by a public off-grid system. The off-grid plant is operational and comprises diesel generators with an installed capacity of 520 kW and 10 Kilowatts solar PV cells, battery, and inverters.

The mini-grid was established in 2009 by Rural Electrification Authority (REA), currently known as REREC and was subsequently handed over to KPLC for transmission, operation, and maintenance. The off-grid was established on land acquired through the Government of Kenya tendering process. It serves 1,500 to 2,000 clients. However, at the time of the field visit, a current audit had not been done to establish the exact number of clients (households, institutions, businesses, etc.) that had been connected to the off-grid. The cost of power generation was cited to be too high. The running costs were high, making it hard to make profits but instead making huge losses. For instance, they require 0.34l liters of diesel to generate 1 kW of energy. At the time of the field visit, 1 liter of diesel was approximately 160 Kenya shillings, and thus the cost of generating 1 kW of energy was 0.34*160 = 54 shillings. This translates into a 200% loss since the tariff charged by KPLC is 22 Ksh per unit.

Previously, the Government of Kenya reimbursed the amount incurred on fuel consumption after receipt of the KPLC invoices. Nowadays, there is no reimbursement from the government since it is expected that KPLC off-grid should be self-sufficient/sustaining; hence, the reluctance in making reimbursements.

The project has had a massive impact on the community; hence, the efforts to make itself self-sustaining by ensuring its continuity in the future. In a bid to do so, the power plant acquired the 10 kW solar system to complement and act as a backup. This is still not sufficient given

the high population of the island. Plans were, however, underway to purchase and install a big solar plant and hydrogen fuel cells. According to the key informant, the hydrogen fuel plant is expensive to install; however, it would be cheaper to maintain since it only requires water, which is readily available from the nearby Lake Victoria. The hydrogen cell plant will require 200 liters of water a day, which is readily available from the lake. The future of the off-grid lies in moving from fossil fuel to renewable energy; hence the hydrogen cell and solar installation proposal.

Outcome from Focus Group Discussion at Mfangano Island

We conducted an FGD at Mgangano Island. One of the key points taken from this site was that the community had access to the station, and they had personal contact with the officials at the power plant. This made it easier for the community to voice their electricity-related problems compared to those served by the main grid or those living on the mainland in Mbita.

From the FGD, the impact that the off-grid system had had on the island was quite apparent. Impacts cited included:

The emergence of businesses such as welding, photocopying, printing services, barber shops, and salons therefore contributed to the economic development of the island

Electrification of institutions such as hospitals, which were thus able to perform their duties more efficiently. Health facilities could offer laboratory tests, perform nighttime deliveries, refrigerate vaccines, etc., which were a preserve of facilities in the mainland

Improved performance in the schools since students and pupils could study at night, serving as extra study time

Saved time and money traveling across the lake to do simple tasks such as printing and photocopying

Challenges in Mfangano Island:

Inconsistent tariffs

Frequent power outages

High connection cost, which varied from consumer to consumer depending on the distance from the nearby transformer.

6.4.4.2 Ringiti Island

Since we were already at Mfangano Island, we took a boat at Mulundu beach and rode pproximately 15 minutes to Ringiti Island. Renewvia owns the solar mini-grid at Ringiti Island (Figs. 6.5 and 6.6), which has an electricity generation capacity of 20.45 kW.

Figure 6.5: Mini-Grid at Ringiti Island



Photo credit: Rosebella Nyumba.

Figure 6.6: Shores of Lake Victoria at Ringiti Island



Photo credits: Abigael Okoko.

At the time of the field visit, the solar mini-grid was serving 290 clients, including households, a primary school, a health facility, and business/commercial establishments such as salons, barbershops, general shops, and a video hall. During the initial days, the electricity supply was not very reliable. There were frequent outages since the installed capacity was low. Later, the capacity was increased, and the outages reduced. However, toward the end of 2021, some batteries ran out, and the island therefore had electricity during the day only. To help solve the matter, some batteries were brought in from the other Renewvia sites, such as Ndeda Island, to support the mini-grid at Ringiti Island. In the meantime, batter-

ies meant for the Ringiti Island mini-grid were shipped into the country and they were replaced. The system was now operational, with outages experienced occasionally. Residents say that they sometimes experience outages due to bad weather like very cloudy weeks or rainy days. The electricity voltage was considered stable. Connected households and business establishments use electricity from the mini-grid for lighting. However, some connected households still use the home solar systems. They say they already had these systems before the arrival of the mini-grid. Unconnected households rely on alternative solar systems/home solar systems such as sunking and solar panda, which are the most common in the island.

6.4.5 Kisii County

Kisii County is located in the former Nyanza Province in southwestern Kenya. Its capital and largest town is Kisii. The county has a population of approximately 1.3 million people. It borders Nyamira County to the Northeast, Narok County to the South and Homabay and Migori Counties to the West. The county covers an area of approximately 1,317.5 sq. km and is inhabited mostly by the Gusii people.

We managed to visit Powerhive and had a chance to meet the Powerhive team at their office in Kisii. We also conduct interviews in two (2) of their mini-grids, that is, Powerhive 249 and Gienseri B, and conducted an FGD at Baranne. We also visited the Kisii County Energy Department.

6.4.5.1 Powerhive

We had the opportunity to meet and have a discussion with the Powerhive team at their office in Kisii. Powerhive has been in operation since 2012 and started with three (3) pilot mini-grids. They got a license to build 100 mini-grids in Kisii and Nyamira Counties in 2015. Many of the mini-grids in operation came alive in 2016. They had 21 mini-grids in operation, and five (5) had been decommissioned. At the time of the interview, Powerhive had connected 6,060 households to their grids. The mini-grids were constructed on land leased from the community members.

Connection fee for electricity started at 3,000 Ksh and was currently at 9,980 Ksh. Those who had paid 1,000 Ksh were eligible for connection. The rest of the amount was staggered, whereby 20% of the consumption fee paid

would go into paying the debt. The tariff charged was 70 Ksh per unit for residential supply, 43 Ksh per unit for businesses and 52 Ksh per unit for institutions. The villages also benefited from street lighting installed by Powerhive as part of their corporate social responsibility (CSR) program.

Business Models Adopted by Powerhive

Anchor projects:

Black Soldier Fly project: involved insect farming as animal feed (chicken and swine) using organic waste collected from the nearby municipal markets. This had incorporated the use of heavy electricity consumers, such as the grinder, mixer, and drier. They had collaborated with Insectivo on this project.

***Kuku Poa* project:** Powerhive had put up a chicken processing unit, which engaged in processing of birds for the market.

Appliance financing: These included financing of appliances such as electric pressure cookers, water-heating kettles, blenders, TV, and posho mills. to their clients.

Bundle model. Clients had an option to choose from the different consumption plans that Powerhive had developed. They could purchase daily, weekly, or monthly electricity bundles.

Venturing into e-mobility such as electric motorbikes and tuktuks. They already had electric motorbikes, which were being used by their staff.

Challenges faced by Powerhive include the following:

Power theft

Material theft, e.g., cables

Political interference in their sites, especially during the electioneering period

Grid intrusion by KPLC—the KPLC contractors sometimes intrude into the Powerhive grids without Powerhive's knowledge

Dependency syndrome—the community believes that they should be getting the electricity without paying for it.

Lack of ownership of the electricity projects by the community, which caused vandalism and eventual decommissioning of the sites

However, from their experience over the years, they had gained knowledge on community engagement and report that there had been enhanced

community unity; e.g., in the process of negotiating for wayleaves, there must be an agreement between neighbors as the poles are erected from one plot to another.

6.4.5.2 Powerhive 249

Powerhive 249 is a solar mini-grid that was developed by Powerhive. It had an electricity generation capacity of 60 kW. At the time of the visit, it was serving 169 clients, who included households and productive users. This mini-grid by Powerhive had adopted an anchor-client business model, rather than having the households as their primary clients. They adopted this model after the realization that the demand for electricity by the households was low and that building the demand for electricity was quite a slow process. As this could not sustain the mini-grids, the need developed for a paradigm shift in their operations. Among the anchor productive users was the Black Soldier Fly (BSF) production facility, which used municipal organic waste as the primary raw material. The process involved crushing the organic waste (Fig. 6.7) and then mixing it with blood sourced from the slaughterhouse. This mixture was then used as feed for the BSF larvae. The output from the facility was organic manure and the BSF (Fig. 6.8), which was used as animal feed, especially by chicken/poultry farmers and some pig/swine farmers.

Figure 6.7: Organic Solid Waste Collected from Kisii Municipal Market



Photo credit: Abigael Okoko.

Figure 6.8: BSF in the Drier



Photo Credit: Rosebella Nyumba.

The electricity from the mini-grid at the time of the field visit had not been connected to any of the public facilities within the area. There were electricity connections from the main grid within the area, most of which were alluded to be illegal connections.

6.4.5.3 Gionseri B

The Gionseri B mini-grid (Fig. 6.9) was established in 2019 with an installed electricity generation capacity of 60 kW and was serving 374 clients. The main clients were households, with some productive users such as posho mills and small shops as well as a hotel. At the time of the visit, this mini-grid had served no schools or institutions. Connected households used the electricity from the mini-grid to power the electric appliances, the common use being charging phones, watching TV, and listening to the radio. Unconnected households use the home solar systems for charging phones and listening to the radio. Some also take their phones to a neighbor's place or to the nearby shops for charging.

Figure 6.9: Solar Mini-Grid at Gionseri B, Kisii County



Photo credits: Rosebella Nyumba.

6.4.5.4 Baranne Mini-Grid

We conducted an FGD at Baranne Chief's camp. The Baranne mini-grid was commissioned in 2013. It operated for 5 years before its decommissioning. It had an installed capacity of 50 kW and was connected to 80 clients (households, businesses, and primary school) at the time of its decommissioning. Decommissioning was done because of a misunderstanding between the developer/operator and the community. A politician informed the community that there was a memorandum of understanding between Powerhive and the County government of Kisii that prevented extension or arrival of the main grid by KPLC in locations where Powerhive had put up a mini-grid. Therefore, the community, incited by the local politicians, began a mission to have the mini-grid removed so that KPLC could extend the electricity grid to Baranne. This led to vandalism of the electricity cables, poles, and other equipment installed by Powerhive.

Before the decommissioning, people often complained of power outages, occasioned by vandalism and theft, which happened mostly at night when it was raining. Powerhive had to keep doing repairs, replacing wires and poles, while the community kept experiencing outages. Due to the frequent outages, people with incubators made losses since eggs in the incubators were going bad and other businesses that relied on electricity would also be interrupted. No accidents were reported during the period the power plant existed.

Those involved in the theft were community members. Increased theft and vandalism necessitated discussions between Powerhive and the community on improving security to curb theft. Community members identified the culprits, but according to them, Powerhive did nothing regarding the theft. However, according to Powerhive, the community members were unwilling to become witnesses and it would therefore be a case in futility. Other complaints that arose were the prohibitive cost of electricity and the unspecified period one was required to pay for the staggered connection fee after paying 2,500 Ksh initially as connection fee.

After several negotiations between Powerhive, the community and the local leaders (chief, assistant chief), it was agreed that the mini-grid be decommissioned due to the losses incurred. The decommissioning took place in 2019. Residents complained that ever since the decommissioning of the mini-grid, they had suffered a great deal. The national grid had not arrived in this area, they could not charge their phone in their houses, and the number of lighting hours has reduced. The hatchery business initiated

by Powerhive closed down due to lack of electricity. The nearby primary school, which used electricity from Powerhive to facilitate learning activities, also remained without electricity.

The decommissioning of this site and other sites acted as a learning lesson for both the developer and the communities in the following ways:

Improved community engagement. Through constant engagement with the community, the community began to own and safeguard the projects in their sites. Communities with electricity witnessed the challenges that those in decommissioned sites were undergoing and therefore wanted to ensure their electricity remained stable. This has reduced cases of vandalism and theft.

Created a demand for electricity whereby disconnected clients wanted reconnection. Some other areas that did had no access to electricity also wanted to be connected to this electricity given its reliability.

6.4.5.5 County Energy Department of Kisii County

The energy mandate had not been fully devolved to the counties. The department of energy in Kisii County was at the inception stages. The county had not established any mini-grids, but those that were present within the county had been developed by private investors or partners such as Powerhive. Other mini-grids that were under development within the county included Nyakwama hydro mini-grid, on River Gucha ,financed by a Chinese group, and SUSEFA mini-grid, which was being developed with the assistance of the United Nations Development Programme (UNDP).

Stand-alone solar systems were also in use in the county. The county had adopted the integration solar and main grid electricity to create hybrid systems, which would act as backups during outages. These hybrid systems had been developed in hospitals such as Marani and at the level 5 hospital—Kisii Teaching and Referral hospital.

Kisii county government did not have an energy policy in place. However, the process of developing the CEP was underway. The CEP development was still in its rudimentary stages, and the county was conducting a stakeholder analysis to map out the potential stakeholders that would work with the county government on this. Mini-grids were to be included in the plan. The county was also preparing the CIDP, which was to inform

the CEP regarding energy planning for the county. The county was also developing an Energy Act and other affiliated regulations. The energy department was working in collaboration with other departments, such as the Legal department, to draft the Energy Act. There was also a plan to develop an energy center in the county.

Challenges

The Kisii County Energy department received minimal allocation, e.g., in 2022, it got 3 million Ksh, which went into buying transformers.

Energy issues in the county were not prioritized.

Technical challenges limited the uptake of renewable energy technologies such as solar and biogas.

6.4.6 Busia County

Busia is situated in the former Western Province of Kenya. It borders Kakamega County to the east; Bungoma County to the north; Lake Victoria and Siaya County to the south; and Busia District, Uganda, to the west. The county has about 893,000 people and spans about 1,700 sq. km, making it one of the smallest counties in Kenya. We had a meeting with the KUDURA Power East Africa Ltd team. We then visited Sidonge and Dirakho mini-grids. We also had an interview with the Busia County Energy officer.

6.4.6.1 KUDURA Power East Africa

We had a chance to visit KUDURA Power East Africa Ltd from March 16 to 17, 2022. The visit included a discussion with the KUDURA Power East Africa Ltd team. The discussions revolved around their operations in Busia County, their community engagement model, the regulations around mini-grids in the county, and the challenges they face in running mini-grids.

KUDURA Power East Africa targeted communities that did not have access to electricity, with the target being 100% connectivity in Busia County. Their entry points into the community included community-based organizations (CBOs) and community members who approached

KUDURA, stating the need for electricity. KUDURA then held consultative meetings with the community before the start of any project. Prior to the installation of electricity, the developer assessed the electricity needs of the households. A project management committee (PMC) would then be formed whose membership came from within the community. The PMC was composed of men, women, youths, the elderly, while observing the 30% gender rule as enshrined in the Kenyan Constitution. The total membership of the PMC should be an odd number. Issues deliberated during the consultative meetings included members' ability to pay and the tariff. (Although EPRA regulated the tariffs, the PMC were engaged at all stages of the mini-grids development, from inception to implementation.)

At the time of the field report, KUDURA had 11 operational/active mini-grids, with plans to establish 22 more. KUDURA had adopted a tier system of client connection, with the tiers ranging from 1 to 6, and the charges were as follows:

Tier 1–3,000 Ksh
Tier 2–4,500 Ksh
Tier 3–6,000 Ksh
Tier 4–7,500 Ksh
Tier 5–8,400 Ksh
Tier 6–10,500 Ksh

Therefore, if a client intended to increase their consumption beyond what their tier could support, they were required to apply for an upgrade, upon which they were charged a top-up connection fee to match the current tier they had applied for. The tariff charged was 73 Ksh for households and 68 Ksh for businesses and institutions. The lower tariff for business was intended to motivate electricity use for productive use.

The tariff-setting involved having negotiation meetings with the community and conducting a baseline survey to find out how much the community could pay for the electricity. The amount was then sent to EPRA, who would then come to the ground and discuss with the community before they determined and set the tariff.

Challenges:

Regulatory challenges had halted the establishment of the 22 planned mini-grids. The regulations require a 15-km radius between the grid and the mini-grid, which was not easy to achieve in a county like Busia due to its high population density.

Bureaucracies' in acquiring approvals. It took a long time for decisions to be made, and, therefore, many delays were experienced.

Strengths

KUDURA Power East Africa Ltd had a policy on densification of the grid, which ensured 100% connectivity to the electricity from an installed mini-grid in an area.

They have a strong community engagement arrangement, which allows community members to be aware of the products of KUDURA, e.g., the different tiers in place and their respective connection fees, what one needs to do in case they need a higher tier, and the tariffs they pay.

6.4.6.2 Sidonge Mini-Grid

Sidonge mini-grid was a pilot project of KUDURA Power East Africa Ltd, which started operations in November 2011. It had a capacity of 7.3 kW with 220 connections, which included households, five (5) business operations, two (2) churches, and a community library (Fig. 6.10).

Figure 6.10: Community Library Powered by Kudura Mini-Grid at Sidonge



The Sidonge mini-grid started with a flat rate payment system. The community members complained about this system since the consumption of electricity varied from one household to another. They said it was not fair for low electricity consumers to pay the same amount as heavy users. This led to the installation of prepaid meters, which allowed for payment for electricity consumed. The Kudura team cited this as a successful pilot project, which influenced the replication and upscaling of mini-grids to other sites.

6.4.6.3 Dirakho Mini-Grid

Located in Nambuku Lugala location, Samia Sub County, Funyula constituency, Busia County, Dirakho mini-grid began operations in 2019 with an installed capacity of 30 kW. The mini-grid has 524 connections, which served 8 churches, 1 institution (Dirakho Vocational Training Centre), 1 posho mill, and households within the community.

Dirakho CBO acted as the entry point for Kudura into the community. The CBO was already in existence and engaged in different programs involving agriculture and education. In a bid to promote education, the CBO members discovered that proper lighting was essential. With this in mind, the CBO approached Kudura and presented their need for lighting. After this initial engagement, follow-up consultative meetings were held, and later, installation of the mini-grid was done. During its installation, community members provided labor such as digging of holes, helping to carry and lay the electricity poles. The connection was done in tiers ranging from tiers 1 to 6, with the cost ranging between 3,000 Ksh for tier 1 and 8,000 Ksh for tier 6.

6.4.6.4 County Energy Department of Busia County

The County Energy Department of Busia implemented its duties in four main arteries:

Solar street lighting
Renewable energy initiatives (cooking and lighting)
Joint projects with REREC
Partnership with private investors, e.g., KUDURA Power East Africa

The Energy Act 2019 mandates the role of licensing mini-grids to EPRA. The County energy department collaborated with Kudura and helped them identify unserved areas, e.g., in the islands and the hills in Samia, where they would install mini-grids. The county also engaged in the public participation forums, which Kudura used to engage the community and create awareness. During these forums, community members were informed of the project intentions and their consent was sought. After the community had adopted the initiative, a memorandum of understanding (MOU) was drafted, indicating the roles of each party. The role of the

county was normally on land issues and assisting Kudura in identifying the ideal areas for mini-grid installation that REREC had not earmarked as areas where they would potentially construct the grid.

Busia county has a matching fund facility that financed energy projects. Through this fund, the county identified areas that needed electricity and would then supplement the budget by REREC for grid extension in Busia County. Through this fund, extension of the grid in the county was expected to go beyond that which had been budgeted for by REREC.

6.4.7 Turkana County

Turkana County is a county in the former Rift Valley Province of Kenya. It is Kenya's largest county by land area and is found in the northwestern most part of Kenya. It is bordered by Uganda to the west; South Sudan and Ethiopia, including the disputed Ilemi Triangle, to the north and northeast; and Lake Turkana to the east. The mini-grids visited in Turkana County included Longech, Lolupe, Nadwat, and Kalobeyei Integrated Settlement. Another visit was made at the county energy department, where an interview was conducted with officials in the department.

6.4.7.1 Longech Mini-Grid

The main economic activity in Longech is fishing in Lake Turkana. The fish are consumed locally but also dried and sold to external markets. Nal Offgrid developed the Longech mini-grid, which was a solar-powered system, in 2018 (Fig. 6.11).

For one to have been connected, one needed to pay 1,000 Ksh for registration and 11,000 Ksh for connection. Payment of the connection fee was staggered. To settle the debt, 183 Ksh was deducted from the customer's purchase of electricity every time they purchased electricity tokens.

At the time of the field visit, the electricity system was not operating optimally due to rundown of the batteries, causing a lot of dissatisfaction in the community.

Figure 6.11: Longech Mini-Grid, Turkana County



Photo credit: Abigael Okoko.

Challenges:

High tariffs. Households paid 65 Ks/unit, while businesses paid 53 Ksh/unit.
High connection costs that clients ended up paying for a prolonged period
Unclear repayment period of the staggered connection fee
Unclear tariffs for the community members
Increase in the water levels of Lake Turkana, which forced them to move away and start the reconnection process again
Power outages due to low storage capacity of the batteries
The area is very sandy, necessitating regular clearing since it builds up very fast and, if not cleared, would cover the mini-grid.

6.4.7.2 Lolupe Mini-Grid

We conducted an FGD in Lolupe, Turkana County. This mini-grid was developed by the Nal Offgrid in 2018 (Fig. 6.12). It took 3 years before it was operational. The mini-grid started by using a diesel generator, and later on, a solar system was installed. The mini-grid was currently operational and provided electricity for 24 hours.

Figure 6.12: Participants at a Focus Group Discussion in Lolupe, Turkana County



Photo credit: Rosebella Nyumb.

The mini-grid served 136 clients. It was set up on community land. The community had requested the developer to build two classrooms and sink a borehole as part of community social responsibility due to persistent water shortages. However, this had not been done.

Initially, when the mini-grid started operating, the meters that were installed indicated the number of electricity units purchased but were later changed to those that did not show the units. The participants preferred the initial meters to help them track their electricity consumption.

Challenges:

The community raised concerns over the tariffs charged, saying they were high. They had requested for a reduction of the tariff. The developer informed them that for this to happen, one had to prove continuous consumption of electricity for 8 hours.

The staggered payment system intended to cover the cost of connection was not clear to the clients, e.g., the repayment period

The community stated that there was a communication gap between them and the developer. Many issues, therefore, remained unresolved

The community had requested the developer to build two (2) classrooms and drill a borehole for them since the area experienced serious water shortages. The promises were not kept. The community had requested these infrastructural developments since they had offered community land for the establishment of the mini-grid, and it was to be a way of CSR by the developer. This failure by the developer and their lack of communication with the community resulted in a lot of resentment in the community. They felt it would be better to have the mini-grid removed and KPLC tasked to supply electricity to the area.

6.4.7.3 Nadwat

The mini-grid is located in the gold mining areas of Turkana North Sub County. It was developed by the Nal Offgrid to supply electricity to the residents of Nadwat. It started operations in 2018 and at the time of the field visit, it had 80 connections, including households, institutions such as a health facility, and businesses such as welding, mechanic shops, and gold crushers (Fig. 6.13).

Figure 6.13: Gold Processing Using Mini-Grid Electricity in Nadwat, Turkana County



Photo credit: Rosebella Nyumba.

The community gave the land for the mini-grid for free. During its conception, there was an agreement between the community and the developer that they would give the land free and that the developer would then build two (2) classrooms in the neighboring primary school as a way of giving back to the community. This had not been accomplished. In 2021, the mini-grid started to develop problems due to rundown batteries and, therefore, no storage of energy. The developer had not replaced the batteries despite the numerous complaints by the clients.

Challenges:

Technical challenges: the batteries could no longer store energy for use, especially when the sun began to set or on cloudy days. Residents had therefore resorted to alternative sources of energy such as the standalone home solar systems. Business owners lost business opportunities due to lack of electricity.

Classrooms that were to be built in the neighboring public primary school as requested by the community had not been constructed.

Lack of communication between the project developer and the community. Residents claimed the developer had never come back and that their complaints had been ignored.

6.4.8 Kalobeyei Settlement

The mini-grid is located within a refugee integrated settlement zone known as Kalobeyei integrated settlement, in Turkana County. The camp was established in 2016, and the mini-grid in 2019. It had an electricity generation capacity of 60 kW, designed to serve 250 connections. This

capacity was exceeded and at the time of the field visit, it was serving more than 500 clients. Due to this stretched capacity, the mini-grid was facing challenges in electricity supply. The batteries could not store power for use when the sun went down.

The developer had begun an expansion exercise for the mini-grid to 504 kW, and upon its completion, it was expected to accommodate more than 2,000 client connections, including households, institutions, and commercial users. Households paid a connection fee of 1,000 Ksh, while commercial users paid 2,000 Ksh to get connected. The households paid a tariff of 20 Ksh/unit, while commercial users paid 25 Ksh/unit, which, compared to other Renewvia sites, was minimal and comparable to that of KPLC. The developer subsidized the electricity tariff since it was a displaced settlement setting.

Challenges:

Technical challenges: Due to the overstretched capacity of the mini-grid, the batteries were unable to store electricity for use in the evening.

The developer had to disconnect some institutions that were connected to the mini-grid as part of managing the electricity supply system with the overstretched capacity.

Business establishments closed for the day as early as 4 p.m. due to electricity rationing.

6.4.9 County Energy Department of Turkana County

The energy department of Turkana County had the mandate of overseeing the electrification of institutions, lighting up health facilities, especially the vaccines sections, and doing street lighting in rural and urban centers.

In terms of mini-grids, the county department of energy facilitated documentation, facilitated the process of leasing land, although in most cases, the land was given for free. The county leadership, did not encourage selling of land and helped in the development of a memorandum of understanding between the different parties involved and acquisition of the no objection letters. The county was also involved in dispute management aimed at cushioning the developers while also taking care of the interests of the community.

The development of the Turkana County Energy Plan was at an advanced stage and was due for presentation at the County Assembly. Within the CEP, there was the provision for cushioning the community from the high electricity tariffs by introducing subsidies, which would be paid by the

county government to normalize the rate. There was an allocation of 10 Ksh to cushion the communities, i.e., the clients in Longech, Nadwat, and Lolupe in 2019/2020/2021. However, some laws tied the use of this fund since the mini-grids in these locations were of private developers. The political dynamics in fund allocation made it difficult to develop mini-grids in the county. The county was a beneficiary of the Kenya Off-grid Solar Access Project (KOSAP), and 23 mini-grids were set for construction in the county through this program. This program aimed at improving the electrification status in the county, which was estimated to be 30%.

6.4.10 Murang'a County

In Murang'a County, we visited Magiro Hydro mini-grid.

6.4.10.1 Magiro Hydro Mini-Grid

Magiro mini-grid (Fig. 6.14), located in Mathioya constituency, Murang'a County, is a hydro mini-grid located along river Gondu.

Figure 6.14: Magiro Hydro Mini-Grid, Murang'a County



Photo credit. Abigael Okoko.

It started as a local innovation using locally fabricated turbines. The innovation was then discovered by National Environment Trust Fund (NETFUND), which then helped create a link to investors such as Hydrobox, offered trainings and provided incubation of the innovation. Hydrobox has since become Magiro's partner with equal shareholding. For its expansion, Magiro power identified community electricity generation projects, which had collapsed. These community projects were mostly run by CBOs. They entered into an automatically renewable lease agreement of 25 to 30 years with the CBO. During this period, the community project relinquished all its operation rights to Magiro Hydro mini-grid. After reviving the project, the CBO members were connected to the electricity for free. Magiro power, as it was locally known, had developed a system of synchronizing electricity from its three mini-grids, namely, Kahinduini, Kituku, and Kiambogo grids, with a production capacity of 70 kW, 25 kW, and 20 kW, respectively. The mini-grids had connected 1,500 clients including households and business. At the time of the field visit, they were in talks with schools and hospitals around the catchment area to connect them with electricity. Interesting in this site was the fact that residents had the privilege of having connections from both KPLC and Magiro; a situation we had not experienced in any other site visited. The grid and the mini-grid co-existed, unlike the case with most of the other mini-grids. The residents only needed to install change-over switches and chose to use either of the two. They therefore had an alternative source of electricity if one provider experienced an outage.

The connection fee for households was 15,000 Ksh. Businesses paid 20,000 Ksh for a single-phase connection and 25,000 Ksh for a 3-phase connection. For institutions, a quotation had to be done to determine the electricity demand, which then informed the quotation.

Payment of the connection fee was done in phases. A 50% deposit was made, and the rest was paid in installments for a period of 6 months on a *lipa pole-pole* model. The tariff ranged between 15 and 25 Ksh per unit. Magiro hydropower encouraged use of electricity by reducing its costs based on increased consumption, which they monitored from their system. Payment of electricity was through a pay bill system or cash for those who were unable to use the cashless system.

Challenges:

The cost of installation was high for many people. However, the introduction of the lipa-pole-pole model enabled the residents to get connected.

Delays in getting approvals and the necessary licenses from the relevant authorities such as the Ministry of Energy, EPRA were common occurrences.

During drought, low levels of water in the river led to reduced production, necessitating rationing.

Difficult individuals in the community, e.g., those who refused to sign wayleaves, which led to redesigning and rerouting of the lines, therefore increased the cost of extending the Magiro grid line.

Illegal connections in the past before the installation of the smart meters, a situation that was managed by installation of the smart meters.

6.5 Crosscutting Findings

6.5.1 Governance

The energy department was not fully decentralized/devolved, and, therefore, counties seemed unclear about their roles in the energy docket. Some counties like Murang'a County did not have the energy department in place. Counties that had the department of energy in place were not involved in mini-grids regulation except for administrative tasks such as getting the no objection letters and obtaining clearance at the county land department for the developers. Mini-grid developers got all the necessary approvals from the Ministry of Energy, and EPRA, therefore, left out the counties. Budgetary constraints were common for all the counties visited, and this limited their planning and implementation of energy-related activities.

There was a lack of energy policies in the respective counties. However, progress was being made in some counties (Kajiado, Kisii, Siaya, Busia, Turkana) through the development of the CEP, which were still at very early stages of their development.

There were regulatory challenges or inconsistences observed. The current regulation requires a 15-km radius between the main grid transformer and a mini-grid. However, this posed a challenge to densely populated areas such as Kisii, Nyamira, and Busia Counties and had since curtailed the extension of mini-grid development in these densely populated counties. Noticeable were coexisting main grid lines with those of the mini-grid in Kisii, Nyamira, and Murang'a counties.

Even with the limited allocation on energy, some counties had initiatives in place for increased electrification in their counties. For instance, Busia County has a matching fund/facility that supplemented the electrification budget for Busia County by REREC. Turkana County was also in the process of subsidizing the cost of electricity for the residents. They

had planned to achieve this by passing a bill in the County Assembly that would allow for this expenditure. Once it was approved, they would subsidize the cost of the electricity by paying a percentage of the cost to the mini-grid developer/operator. This was a way of cushioning the vulnerable residents from the high cost of electricity yet ensuring that they had access to electricity. The county had also formed collaborations with development partners such as GIZ. The county was also a beneficiary of the government's KOSAP programs and had mini-grids that were set for establishment in the county.

6.5.1.1 Energy Use

The electricity from the mini-grids was for lighting and powering of electrical devices. Connected households and businesses could enjoy lighting in the evenings. Households cited being able to charge their mobile phones at the convenience of their homes, unlike earlier, when they would pay for the service or go for days without any means of communication.

Powering of devices for businesses has been a major boost. Salons, barbershops, general shops, welding, and carpentry could be done within the localities. Institutions could use printers and photocopiers and save on time and money spent to get the service outside the institutions. Health facilities can do simple procedures, laboratory tests, and vaccine storage and attend to nighttime emergencies such as deliveries due to the availability of electricity.

6.5.2 Cost of Connection and Use

The cost of connecting electricity to the households, institutions, and business establishments varied depending on the developer/operator/technology/use. Some developers such as Renewvia and Nal Offgrid applied a flat rate system, while others, such as Kudura, applied a tier system, with the lowest tier being the most basic connection of a switch and a single bulb. If a client felt the need to increase consumption, they were required to formally request an upgrade to the next tier and the payment for it also upgraded. The payment for these connections were done either as one-off payment or was staggered. Renewvia in most cases charged 1,000 Ksh for a household connection, and this payment was done as a one-off payment. Nal Offgrid, Kudura, Powehive, and Magiro, which had higher

rates of connection fees, staggered this amount. Different models were applied, such as a 50% deposit fee, with the rest being cleared in monthly installments, a deposit of 1,000 Ksh, and the rest being factored into the purchase of units etc.

The tariffs charged for electricity consumption were high compared to that of the main grid. Charges as high as 78 Ksh/unit were observed. However, cases of lower tariffs were witnessed, e.g., 15 to 25 Ksh/unit. A case of electricity subsidization was encountered in the Kalobeyei settlement camp as a way of social/economic protection of the already vulnerable group. Interestingly, Powerhive and Kudura had a higher tariff for the household consumers compared to business, unlike the rest, which had a higher tariff for the business/productive users. This was an incentive to encourage productive use of electricity.

Many of the mini-grids had adopted the metering system for electricity consumption. Some started with the flat rate system (e.g., Magiro and KUDURA Power East Africa), but because it became unsustainable for either the developer or the clients, they changed to the metered system. All mini-grids visited had a prepaid metering system, and mobile money was the predominant payment method. A few cases of cash payments were witnessed (Oloika, Magiro-by the old who could use the mobile money Apps). In Oloika, where cash was used, cases of mismanagement of funds were reported. The mini-grid had worn out batteries that had not been replaced.

6.5.3 Technical Sustainability

Across the different mini-grids, some technical challenges were witnessed. For instance, solar mini-grids needed replacement of the batteries. Some mini-grids, however, experienced delay in replacing the batteries, and, therefore, the electricity storage was not efficient. This led to blackouts and losses by businesses.

6.6 Lessons Learned & Limitations

6.6.1 Planning

Our fieldwork plan cut across various counties. The fieldwork was planned in a way that a single trip bundled up several sites, e.g., Busia/Turkana, Siaya/Homabay/Kisii. This was efficient but also presented a challenge in organizing for interviews with the operators and the

county energy representatives, bearing in mind different activities for the various counties.

Getting some of the contacts was an uphill task and led to delays in visiting a site, e.g., Central Kenya mini-grids proved to be the hardest to organize, yet they are the nearest from Nairobi.

Insecurity challenges in some parts of the country, especially Northern Kenya, forcing cancellation of the planned trip or exclusion of the region from the list of proposed sites.

6.6.2 Actual Fieldwork

Time/seasonal challenges: conducting an interview during the planting season (e.g., in Kisii) caused some delay.

In the islands, a respondent would accept an interview, but because the boat would be leaving in a few minutes, end up hurrying because the boats had a schedule.

Long travel hours due to the remoteness of most of the mini-grids was a challenge and caused fatigue.

Long waiting hours for interviews, especially at the county energy department.

Long distance between one interview site and the next (for instance between the mini-grid site and the county offices). This led to some inefficiencies since we all had to attend the same interview, especially those with the county energy department. However, this was also beneficial to the team since all had a feel of the happenings on the regulatory/policy scenario in the county on matters of energy and mini-grids.

Language barrier in some cases, although not predominant. This necessitated translation, although done at the local level.

Delays in getting an interview, especially with county officials.

Not getting the right person to interview due to nonestablishment of the energy department at the county government level.

Data acquisition challenges: getting data on the capital and operating costs of the mini-grids was not possible, and, therefore, filling in the DEA (Data Envelopment Analysis) form was a challenge.

Technological: data collection using tablets is limiting depending on how the coding of a question is done (one may want to take a point, but no provision exists for it).

6.7 Concluding remarks

This chapter provided a summary of the field work undertaken in Kenya. The original primary data collected through site visits and stakeholer interactions has been summarised here. The chapter has covered a wide range of situations existing in the mini-grid domain and has highlighted the transformative changes brought by mini-grid development in remote areas. It has also captured the challenges faced. This information formed the basis of subsequent analysis presented in the third part of the book.

CHAPTER 7

Nigeria Fieldwork Report

Unico Uduka, Temilade Sesan, Ewah Eleri and Okey Ugwu

International Center for Energy, Environment, and Development (ICEED), Abuja, Nigeria

Abstract

This chapter presents the details of the fieldwork undertaken in Nigeria as part of the SIGMA project. During our fieldwork, undertaken in 2022, a team of researchers purposively collected data from mini-grids across all six geopolitical zones in Nigeria. They visited 10 mini-grid communities, showcasing a range of three technologies. Additionally, they held key informant interviews with 15 stakeholders from government, industry, and development who are involved with mini-grid initiatives in Nigeria. For each site visited, a brief background of the mini-grid, its local impact, and the challenges are presented. The final section presents some reflections on the cross-cutting issues and lessons from the fieldwork.

Keywords: mini-grids, interviews, questionnaire, focus group discussions, impacts, challenges

Acronyms

DisCo	Distribution Company
ECN	Energy Commission of Nigeria
ECOWAS	Economic Community of West African States
ECREEE	ECOWAS Centre for Renewable Energy and Energy Efficiency
FGD	Focus Group Discussion
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
ICEED	International Center for Energy, Environment, and Development
KM	Kilometer
KVA	Kilo-volt-amperes
KW	Kilowatt
kWh	Kilowatt-hour

MW	Megawatt
NEPA	Nigeria Electricity Power Authority
NGN	Nigerian Naira
PV	Photovoltaic
REA	Rural Electrification Agency
REF	Rural Electrification Fund
SIGMA	Sustainability, Inclusiveness and Governance of Mini-grids in Africa

7.1 Introduction and Background

The International Center for Energy, Environment, and Development (ICEED) participated in the implementation of the 3-year research project titled "Sustainability, Inclusiveness, and Governance of Mini-grids in Africa (SIGMA)." The UK Research and Innovation—Global Challenges Research Fund funded this project. It involved collaboration with other researchers from the University of Surrey, the Open University, De Montfort University (DMU) and the University of Huddersfield in the United Kingdom, TaTEDO in Tanzania, the Center for Frugal Innovation in Kenya, and the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE) in Cape Verde.

The objectives of the project were to:

- Develop a comprehensive evidence base on the performance of mini-grids in sub-Saharan Africa.
- Establish an analytical framework for scrutinizing the political economy of energy access and a sustainability framework for mini-grids.
- Conduct in-depth case studies on the sustainability, inclusiveness, and governance of mini-grids in four sub-Saharan African countries, namely, Kenya, Nigeria, Senegal, and Tanzania.

Within the scope of this collaborative effort, ICEED was tasked with providing data specific to the Nigerian context. This contribution has ensured a nuanced and contextually relevant perspective within the broader SIGMA project.

7.2 Methodology

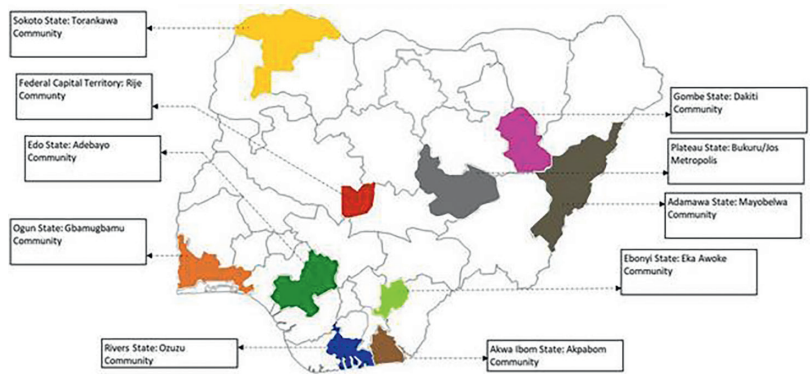
7.2.1 Research Design

To effectively address the foregoing research questions, the study adopted an embedded case study design (Yin, 2014). Nigeria was considered a case study, with a focus on multiple units of analysis. This design provided a nuanced and complex understanding of the case by comparing and contrasting the sub-units within it.

7.2.2 Research Area

The field visits encompassed mini-grid communities and sites distributed across all six geopolitical zones of Nigeria (see Fig. 7.1).[1] These visits were complemented by key informant interviews with relevant stakeholders from government, development agencies, and private sector actors within the Nigerian electricity supply industry.

Figure 7.1: Mini-Grid Sites Visited



7.2.3 Data Collection Plan

During our fieldwork, we purposively collected data from mini-grids across all six geopolitical zones in Nigeria. We ultimately visited ten mini-grid communities showcasing a range of three different technologies. Additionally, we held key informant interviews with 15 stakeholders from government, industry, and development who are involved with mini-grid initiatives in Nigeria. Table 7.1 provides a breakdown of the

[1] Nigeria is politically divided into six geopolitical zones, each comprising several states and reflecting the country's geographical characteristics. The geopolitical zones are Northwest, Northeast, North-Central, Southwest, Southeast, and South South.

Table 7.1: Mini-Grid Location and Composition

Mini-Grid Site/Community	*Technology*	*Geographical Zone*
Akpabom	Solar hybrid	South South
Adebayo community	Solar Hybrid	South South
Ozuzu	Solar Hybrid	South South
Eka Awoke	Solar hybrid	South East
Gbamugbamu	Solar Hybrid	South West
Rije Community	Biogas	North Central
Bukuru	Hydro	North Central
Torakanwa	Solar Hybrid	North West
Dakiti	Solar PV	North East
Mayo Belwa	Solar PV	North East

communities visited, detailing their respective technologies and locations. Table 7.2 delineates the stakeholders that participated in the key informant interviews.

The team conducted household and key informant interviews as well as focus group discussions (FGDs). The key informant interviews involved national government officials representing pivotal stakeholders in the electricity sector, including individuals from the Ministry of Power, the Nigerian Electricity Regulatory Commission, the Energy Commission of Nigeria (ECN), the Rural Electrification Agency (REA), mini-grid developers and operators, development organizations, and electricity distribution companies.

Mini-grid users, such as households and small enterprises, were interviewed at the community level using semi-structured questionnaires. In each community, the team interviewed 10 households that were connected to the mini-grid and 5 households that were not. Where available, we interviewed the owners of five small businesses per community, focusing on different types of business (e.g., general shops, barbershops, salons, betting shops, video halls, petrol stations, welding workshops, and pharmacies). Operators of community facilities such as schools and health centers were also interviewed where possible. To further enrich our understanding, FGDs were carried out with mini-grid users in each community, providing a platform for in-depth exploration of their perspectives and experiences.

Table 7.2: Key Informant Interviews

Institution	Position of Interviewee	Gender
Energy Commission of Nigeria	Managing Director	Male
Nigeria Electricity Regulatory Commission	Deputy General Manager, Research	Male
Ministry of Power	Chief Electrical Engineer, Chief Engineer (×2)	Male
Rubitec Solar Nigeria Limited	Operations Manager	Male
GVE Projects Nigeria Limited	Operations Officer	Male
Gen Sustainability Solutions	Managing Director	Male
Havenhill Synergy Limited	Managing Director	Male
Abuja Electricity Distribution Company	Head Regulatory Affairs	Female
Benin Electricity Distribution Company	Head Regulatory Affairs	Male
Ibadan Electricity Distribution Company	Head Regulatory Affairs	Male
Nayo Tropical Nigeria Limited	Managing Director	Male
Heinrich Boell Foundation	Program Manager	Male
Community Research and Development Centre	Executive Director	Male
Renewable Energy Association of Nigeria	President	Male
World Bank	Energy Specialist	Male

7.2.4 Questionnaire Development and Data Collection

Semi-structured questionnaires and interview guides were developed for the stakeholders interviewed, including government departments, owners/operators, organizations and productive users, private investors and financiers, project developers, regulators, utilities, and households. While there were general templates for each of the categories of questionnaires and interview guides from the broader SIGMA team, the Nigeria team adjusted the templates to fit the context and needs of

the stakeholders in Nigeria. This ensured the questions were relevant and tailored to gather the most helpful information from each group. For example, the household questionnaires collected views on energy use and expenditure, ease of payment, tariffs and affordability, community engagement, energy source and electric service quality, mini-grid impacts, etc.

The key informant interviews were conducted using Zoom and Microsoft Teams (depending on the interviewees' preferences). Using these virtual platforms for the key informant interviews provided a convenient and efficient way to gather information from participants, regardless of their location. It also allowed for easy recording and transcription of the interviews, ensuring accuracy in data collection. At the community level, data collection was done using a combination of audio recorders and note-taking. The recorders were responsible for documenting responses during face-to-face interviews, while note-taking was used to capture observations and additional information.

It is imperative to underscore that the data collection process adhered rigorously to ethical guidelines outlined by both DMU and the University of Surrey. These ethical approvals from both academic institutions were obtained, and the prescribed procedures followed throughout the entire data collection process.

7.2.5 Planning and Implementation of Key Informant Interviews

The SIGMA Nigeria team created a list of key contacts and shared this with the REA, with whom we had established an official partnership for our study. The REA then composed an introductory letter encouraging the identified stakeholders to participate in interviews with the SIGMA team. The letters were sent out, followed by phone calls to confirm availability. Respondents were free to suggest suitable times and dates, and the team arranged interviews accordingly (see Table 7.3). All interviews were conducted online, except for the one with the Ministry of Power, which utilized a hybrid format combining virtual and physical attendance. This approach was necessary due to the geographic distance between a SIGMA team member and the meeting location, which required virtual participation.

Table 7.3: Schedule of Mini-Grid Communities/Sites Visitation

Mini-Grid Location/Community	*Geographical Zone*	*Date(s) Visited*	*Mini-Grid Developer*
Adebayo	*South South*	*March 4 and 5, 2022*	*Fani Frank Global Resources Nigeria Limited*
Ozuzu	*South South*	*March 7 and 8, 2022*	*Darway Coast Nigeria Limited*
Akpabom	*South South*	*March 12 and 13, 2022*	*GVE Projects limited*
Eka Awoke	*South East*	*March 15 and 16, 2022*	*Cloud Energy Nigeria Limited*
Gbamu	*South West*	*March 23, 2022*	*Havenhill Synergy Limited*
Rije	*North Central*	*February 4 and 5, 2022*	*Ajima Farms*
Bukuru	*North Central*	*March 30 and April 2022*	*Nigeria Electricity Supply Company (NESCO)*
Torankawa	*North West*	*March 24 and 26, 2022*	*News Engineering Nigeria Limited*
Dakiti	*North East*	*March 6 and 7, 2022*	*Leading Diagonals Engineering Nigeria Limited*
Mayo Belwa	*North East*	*March 10 and 11*	*OG Fortune Limited*

7.2.6 Planning and Implementation of FGDs

The planning process for conducting FGDs involved developing questions that elicited diverse perspectives from mini-grid users. The FGDs covered the process of setting up the mini-grid, its impact on different segments of the population, views on mini-grid management, and overall satisfaction levels. FGDs were held in all the communities visited, and the participants were carefully selected to represent various community segments. Although the number of discussants ranged from 10 to 20, in some instances, more people showed up than expected. An example is the Rije community in Abuja, where the biogas mini-grid was not operational, and any meeting regarding the system attracted interest from the community members. The sessions included men, women, youth, community leaders, as well as individuals (both those connected and those not connected to the mini-grid). This latter group was included so the team could gain insight into why they were not connected to the mini-grids in their respective communities.

We spent 2 days in each mini-grid community, except for Gbamu Gbamu, where we had made prior arrangements before the trip, making sure to observe the appropriate community entry protocols on the first day. We informed the traditional rule makers and gatekeepers of our mission and sought their permission to conduct the assessment. Once approved, we conducted household interviews and notified the traditional rule maker(s) that we would return the next day for the FGD. We also requested the gatekeepers' assistance in mobilizing participants for the group discussion.

7.3 Observations and Findings

It is important to note that the information presented here provides a concise overview of our observations and findings and does not delve into the detailed outcomes of the fieldwork. A comprehensive analysis will involve transcribing each interview and coding the data in alignment with agreed themes for a thorough examination. The recorded community engagements will also undergo targeted analysis to extract specific insights.

7.3.1 Mini-Grid Site Visitation and Community Engagement

7.3.1.1 Rije Community Mini-Grid

This was the first mini-grid visited by the Nigeria research team on February 4 and 5, 2022. The Rije community is located in the outskirts of Abuja metropolis, about 67 km from the city center. The mini-grid was developed by Ajima Farms and General Enterprises Nigeria Limited with support from the United States African Development Foundation Off-Grid Energy Challenge in 2016. After development, it was handed over to the community for management.

Rije community, despite having existed for over 80 years and being located under high-tension wires, had never had any form of grid connection before the arrival of the mini-grid. The 20 kWp mini-grid is powered by two 100 kVA biogas generators and a 2-km distribution line. The power system, when it was functional, was originally connected to 66 households and served about 500 community members. New barbing salons sprang up in the community, as well as stores selling cold beverages and drinks. However, during our visit, the system was not operational due to lack of feedstock to fire up the installed generators. According to the interviewees, the last time the biogas plant distributed electricity was about a year prior to the date the SIGMA team visited, in 2022 (Fig. 7.2).

The mini-grid is situated on community land that was freely donated for the project. The land donation was part of the community's contribution to making sure that the project succeeded. In the build-up to the development of the mini-grid, the developer engaged with the community through the community leadership who were well-acquainted with the project. Respondents also said the community publicly deliberated over the project in a general assembly and agreed to its setup.

To keep the plant running, the developer initially installed subsidized prepaid meters. The meters, according to respondents, were not working properly, and users started paying a flat fee of N500[2] per month for each household accessing power from the plant. This arrangement was to be managed by a committee set up by the community.

[2] This is an equivalent of $0.92 at an exchange rate of 600 naira to I dollar.

Figure 7.2 (a and b): Rije Community Biogas Mini-Grid and Community

A



B



Challenges faced at the mini-grid:

Bypassing of installed meters by households. This mostly caused overloading, affecting power stability, as the system was always tripping once there were illegal connections.

Availability of feedstock to power the mini-grid. The mini-grid depended on feedstock from two medium-scale poultry farms operating in the community, including Ajima farms, which evacuated their poultry wastes to the plant. Due to logistics and an inability to continue with the farms, the poultry closed, and feedstock became a problem for the power station. Therefore, operators had to travel long distances to get feedstock and had to compete with other feedstock users. The cost of transportation also added to the overall running cost, and the mini-grid eventually stopped operations.

Users were reluctant to pay even the monthly flat rate because there were complaints that the number of hours they had light in a day (4 to 5 hours) was unsatisfactory to them. Some also complained that a flat rate was not a just tariff because households had different appliances at home.

There is a prevailing perception among users that the provision of electricity should transcend mere profit maximization and be viewed as a social responsibility of the government, rather than a purely business-oriented endeavor. This perception gains strength from the stark reality that within less than a kilometer from the community, a national grid is already connected to homes, and users in this location pay significantly lower electricity bills. There is therefore a reluctance to pay by the mini-grid users.

7.3.1.2 Adebayo Community Mini-Grid

Adebayo community is located more than 10 km off the Lagos–Benin expressway in Edo State, Nigeria. The community consists mainly of farmers, for whom farming is the primary source of income. Even those who engage in other businesses find time to farm. The community has existed for over 60 years, over which period it has never had any form of grid electricity except for those who could afford to buy generators. In 2020, Fanny Frank Global Resources Limited developed and commissioned a mini-grid (see Figs. 3 and 4). It has an installed power plant capacity of 100 kW, with 294 solar panels, 72 batteries, and a 27-km distribution cable. It also has a 100 kW generator. The system connects 320 homes and businesses.

Community engagement: According to the interviews, consultations were held with the local community leadership to initiate the process of mini-grid installation. Before the project development, community members were consulted and informed about the type of power system they would receive. They were also told that they would be paying a certain amount of tariff per kilowatt-hour. However, technical terms were not broken down for them to understand. For example, they were unfamiliar with jargon like "kilowatts," and they did not understand how the tariff came to be what they were paying. They were not adequately educated on the mini-grid system and how it differs from the national grid. However, they were engaged in all aspects of the project development, including participating in the non-technical aspects of mini-grid construction, including clearing the construction sites, fetching water for the construction of bat-

tery and inverter house. A village power committee (VPC) was formed as an institutional arrangement to interface between the developer and the community on all aspects of running the mini-grid.

Figure 7.3: Adebayo Community Mini-Grid

A 

B 

The community reported that the quality of electric service was excellent in the first year, with no complaints. However, that was no longer the case during the fieldwork, as community members complained that

the lights had started going off at 7 p.m. daily and did not return until the following day. Respondents stated that while the mini-grid was not perfect, it was still reliable compared to when the community was not electrified.

Figure 7.4: Focus Group Discussion with Community Members at Adebayo



Mini-grid impacts on the community:

Social impacts: Community members agreed that the mini-grid had improved their lives. For example, before the mini-grid was set up, only a few households and commercial businesses had power because they were the only ones who could run on a petrol generator. However, at the time of our fieldwork, the majority of houses were connected to the mini-grid. There were solar streetlights that illuminated the entire community. Also, the mini-grid was used to pump the communal bore-hole at no cost to anyone, so residents come to the public tap to fetch water free of charge. There was also a general viewing center in the community. While the center existed even before the arrival of the mini-grid, community youths were now able to extend their viewing time as the operator no longer needed to ration fuel to run the generator that previously powered the center.

Economic impacts: Some businesses in the community said they benefited from the mini-grid. Some benefited from business expansion due to the new availability of power. For example, a welder established a new business in the community after the mini-grid power arrived. A carpenter also reported that his works were now better appreciated by the community members, which translated into more commissions for him (Fig. 7.5). This was because the new mini-grid connection allowed him to showcase his skill using the electric saw, improving his work quality.

Challenges faced by the mini-grid:

Reduced quality of electricity supply: Community members reported that toward the end of 2021, they observed a decline in the mini-grid's performance, with the system tripping promptly at 7 p.m. daily, plunging the community into darkness. Community members involved in managing the system identified weak batteries incapable of delivering optimum capacity as the cause. They expressed concerns that the maximum power supply was effective only from morning until around 6 p.m. as many users switched off their connections while attending to farming activities and only reactivating them in the evening.

High tariff: Respondents complained that the tariff charged by operators was high. They paid NGN 208[3] per kWh, which they said was exorbitant for an agrarian community. Many users complained about having to spend NGN 3,000[4] every 2 to 3 days, and even as much as NGN30,000[5] monthly, especially for commercial users.

Unilateral decisions by the developer: Community members stated that in the agreement they saw, which they did not even have a copy of, it was noted that both parties (the developer and the community) should discuss any cost increments. However, community members reported that the developer had been making decisions unilaterally. According to them, the VPC was set up to interface between the developer and the community on any price increment. However, the VPC had been

[3] This is an equivalent of $0.35 at an exchange rate of 600 naira to I dollar.

[4] This is an equivalent of $5 at an exchange rate of 600 naira to I dollar.

[5] This is an equivalent of $50 at an exchange rate of 600 naira to I dollar.

rendered useless in that regard. For example, they said the developer never sought their consent when the connection fee was raised from NGN 5,000[6] initially to NGN 10,000.[7]

Meter unavailability: Community members also stated that prospective users could connect to the power only if they were able to latch on to neighbors with existing meters. They complained that they had asked the developer several times to install separate meters for new customers but that he had not obliged them (Fig. 7.6).

Figure 7.5: A Carpenter Who Uses Power from the Mini-Grid



[6] This is an equivalent of $8.33 at an exchange rate of 600 naira to 1 dollar.

[7] This is an equivalent of $16.67 at an exchange rate of 600 naira to 1 dollar.

Figure 7.6: Poles Waiting to be Energized



7.3.2 Ozuzu Community Mini-Grid

The Ozuzu community is situated in the Etche local government area of Rivers State, Nigeria, approximately 5 km from the central city of Port Harcourt. Recognized as the state's food basket, most of its residents are engaged in agriculture. Prior to the installation of the mini-grid, Ozuzu was never connected to the national grid and lacked public power supply. The community had previously experimented with a community power-generated unit using a diesel generator, but this proved unsustainable due to the high cost of diesel.

The Ozuzu mini-grid, established in 2020, is a 28 kWp hybrid system powered by 78 solar panels, 52.8-volt batteries, a 28 kVA inverter, and an 80 kVA generator (see Fig. 7.7). The mini-grid is located on private land leased out to the developer, and as part of the agreement, the landowner utilizes power free of charge. According to respondents, the mini-grid connects 142 households, businesses, and institutions, with 80 households receiving flat-rate unmetered connections. During the development phase, respondents highlighted a deep level of community engagement. Two developers, Darway Coast Nigeria Limited and Renewvia, visited the

community to discuss mini-grid construction. Both developers met with community leaders, and a formal presentation of their proposed projects was requested. One developer, Darwaycoast, attended the community meeting, while the other made excuses for not attending. Subsequently, another meeting was scheduled, and the developer who participated in the initial meeting attended, while the other declined. At this point, the community selected Darway Coast as their preferred developer due to the company's respectful approach.

Figure 7.7: Ozuzu Community Mini-Grid Plant



Ozuzu has a community development committee (CDC) chaired by a retired employee of Nigeria's public power company, Nigeria Electricity Power Authority (NEPA). Committee members were drawn from the six communities benefiting from the power system. This committee was the community's representative in the mini-grid development negotiations. Before signing any agreements with the developers, the CDC chairman (who retired from NEPA) insisted on a series of meetings and question-and-answer sessions. For instance, the developer had to demonstrate their ability to deliver power to the community by installing a few pieces of equipment and operating for 3 to 4 months before the community could sign their power purchase agreement (PPA). The equipment

brought to the construction site underwent testing and certification. Certification for meters and poles at the site was requested, and an impact assessment was conducted.

According to respondents, the tariff was discussed with the community before it was implemented. When the mini-grid became operational in 2020, the agreed tariff was NGN100[8] per kWh, but it has now been raised to NGN138.8[9] per kWh, which the community also said was discussed.

Mini-grid impacts on the community:

According to respondents, the mini-grid has had the following impacts:

Economic: The mini-grid has had a significant impact on businesses operating in the community. The manager of a petrol filling station in the community that uses power from the mini-grid reported substantial savings on diesel costs whenever the energy from the mini-grid is constant (Fig. 7.8). The community development chairman, who had to close his eatery and beer joint due to the COVID-19 effect, said that he was renovating his business premises as the mini-grid was now available and that he intended to include air conditioners.

Social: The streetlights that illuminate the major community roads provide more security to the community. Some respondents also said that the presence of the streetlights extended the community's nightlife.

Health: The presence of the mini-grid in the community has contributed to the location of a pharmacy in the area. The mini-grid will not only assist in preserving drugs and vaccines for use by members of the community but will also make available essential drugs to the community members.

Challenges:

System overload: At the time of the fieldwork, the mini-grid was facing an overload issue caused by an excessive number of connections, surpassing the capacity of the mini-grid. As a result, power rationing was being implemented during the day, affecting various households and businesses. Certain areas were experiencing power outages for as long as 4 to 8 hours on a daily basis.

Figure 7.9: Akpabom Commun

[8] This is an equivalent of $0.17 at an exchange rate of 600 naira to 1 dollar.

[9] This is an equivalent of $0.23 at an exchange rate of 600 naira to 1 dollar.

Figure 7.8: Filling Station Powered by Energy from the Mini-Grid in Ozuzu Community



Unfair billing system: In addition to the overload problem, there were complaints from users about flat-rate connections, which they felt were higher than the rate metered customers were paying.

7.3.3 Akpabom Community Mini-Grid

The Akpabom community is situated in Akwa Ibom State within the South South region of Nigeria and is primarily sustained by fishing and agriculture, with minimal petty trading activities. The community, comprising approximately 250 houses, endured more than 15 years without power after its connection to the national grid was severed due to damage to the power infrastructure caused during road construction.

In 2019, GVE Limited developed a 100 kWp solar PV mini-grid system powered by 270 solar panels, inverters, 36 batteries, and distributed to homes and businesses through a 5.5-km cable (Fig. 7.9). The mini-grid is located on community land donated free of charge.

According to respondents, when fully operational, the mini-grid offers users continuous 24-hour power supply, except for faults caused by thunder or trip-offs due to illegal connections (Fig. 7.10).

ity Mini-Grid

The mini-grid is connected to approximately 77 homes and businesses in the community, of which only 44 are energized. The remaining 33 homes only have their wires connected to the electric poles but have not been energized because they do not have meters.

Respondents said the mini-grid was facilitated by a political representative in the state legislature, whose constituency includes the Akpabom

Figure 7.9: Akpabom Community Mini-Grid



community. According to them, the representative initiated discussions with the developer, GVE Projects, inviting community participation. However, respondents highlighted that the engagement needed to be more comprehensive. For instance, although the developer verbally informed the community that the project would be operated by the company for 10 years before being handed over to the community, this agreement was not documented. The community claimed they had not seen any such document and emphasized the absence of postdevelopment engagement. According to the community, GVE Projects had not returned to the community for any discussions since the project's commissioning in 2019, despite complaints of faults lodged by the mini-grid users. Instead, proxies needing more technical knowledge about the power station handled communication with the community.

Mini-grid impacts on the community:

Economic: Regarding the economic impact of the mini-grid, it is worth noting that while its overall effect has been positive, the community's use of power for productive purposes and economic activities is still limited. Most power users are households, whose use of it covers only basic needs like lighting, television, and fans. Commercial users are few and far between, with only a handful of small shops utilizing the power to refrigerate beverages for sale. While this has resulted in a modest reduction in fuel costs for these businesses, there is one notable exception.

Figure 7.10: Akpabom Mini-Grid Battery Bank



One store, which previously did not have a deep freezer, was able to acquire one thanks to the development of the mini-grid. This expansion led to a significant increase in sales and income.

Social: Respondents said the mini-grid had contributed positively to societal bonding and bridging within the community. Providing a central location for people to gather, such as a cold-drink joint, fosters healthy relationships and bridges social gaps. Additionally, installing streetlights and security bulbs on houses had improved human security by illuminating the community.

Challenges:

Technical personnel were unavailable to promptly address system-related issues. Regrettably, the mini-grid lacked a resident technician to handle minor community and system complaints. Consequently, certain individuals had been waiting for over a year to be connected, despite having already paid for the service. Moreover, some individuals had faced challenges with their meters but lacked the necessary support to resolve these issues. This situation compelled some individuals with malfunctioning meters to illicitly connect their homes to their neighbors' electricity or use power without a meter.

A noticeable disconnect existed between the mini-grid developer and the community. Community members complained about the lack of formal communication channels for connecting with the developer. Consequently, users were left to address any technical difficulties related to utilizing the mini-grid independently of the developer. Regrettably, no one in the community was trained to resolve minor technical issues resulting from the mini-grid.

7.3.4 Eka Awoke Community Mini-Grid

The Eka Awoke community is located in Ebonyi State in the southeastern part of Nigeria. It has existed for over 100 years and has never been connected to any form of grid electricity. The mini-grid was developed and commissioned in 2020 by Cloud Energy Limited and connected to 75 households and commercial points (Fig. 7.11).

Figure 7.11: Eka Awoke Mini-Grid System



A



B

The mini-grid is located on land donated by the community to facilitate its development. The developer gave the community a monetary offering as a token of appreciation. The mini-grid is a 100 kWp solar hybrid system with batteries and a 100 kVA diesel generator, which was functional throughout the day all through the week—at the time of fieldwork.

However, according to the site operation assistant, the system operated at only 20% of its installed capacity, indicating it was being underutilized. As part of their business development model, the mini-grid developer had begun taking steps to increase demand by offering energy-efficient electrical appliances such as televisions, light bulbs, and refrigerators. The plan was for these appliances to be sold to users under mutually agreed terms to boost demand for the system.

Community members said they were engaged during the pre-development phase. According to them, the community chief briefed the community on the government's approval to install a solar mini-grid and that the developer was introduced. The developer consulted the community in different ways, including conducting feasibility studies to determine appliance usage and willingness to pay. The community members agreed that the developer consulted them at every phase of the development process.

Figure 7.12: Some Electrical Appliances Offered by the Mini-Grid Developer and Operator



A



B

Mini-grid impacts on the community:

Economic: The local market night hours had been extended to accommodate those returning late from their farms. The market was now open until late at night and was illuminated by floodlights powered by the mini-grid and

placed in strategic positions. This increased economic activity within the community as it attracted buyers and sellers from neighboring communities. The mini-grid also impacted individual businesses positively. For instance, a respondent who owned a mini cold room had seen increased customers and sales for frozen foods and cold drinks (Fig. 7.12). The store had become a popular destination for those looking to buy iced fish, which previously had to be purchased from traders in Abakaliki (an urban center more than 15 km away) due to the lack of power supply in the community. Other businesses that saw a boost in sales include those selling sachet drinking water, resulting in increased income. A few barbershops also opened in the community.

Social: According to the respondents, the streetlights served the dual purpose of illuminating the market and enhancing the surrounding environment. This, in turn, promoted security and fostered societal connections within the community, as individuals were afforded more opportunities to engage and discuss communal concerns.

Challenges:

Underutilization: The mini-grid is a 100 kWp power system with a 100 kVA diesel generator. The power was connected to only 75 households and businesses at the time of fieldwork. According to the site engineer, only about 20% of installed capacity was being utilized.

Developer's low capacity for expansion: The customer base of the mini-grid was insufficient to provide the necessary income for expanding operations. In one FGD, many people raised concerns that their areas were not receiving power. The community development chairman himself reported that his residence was still without power.

7.3.5 Torankawa Mini-Grid

Torankawa is an agrarian community situated in Yabo, a local government area of Sokoto State in the northwest region of Nigeria. The community comprises 350 households, with a population of approximately 1,750 people. Located about 10 km from the local government headquarters and 70 km from Sokoto, the state capital, Torankawa primarily engages in agricultural activities, producing food crops such as maize, millet, sorghum, beans, and vegetables.

The Torankawa interconnected solar hybrid mini-grid was inaugurated in 2019. Financed by the Green Bond, the Federal Ministry of Power executed the project through a contract awarded to News Engineering Nigeria Limited. Before the mini-grid was installed, the community received electricity from Kaduna DisCo. However, a lack of electricity plagued the community for about 5 years before 2019, which was attributed to the destruction of distribution lines by strong winds.

The solar installation in the community, housed in a generation/distribution station, consists of 200 units of 300W solar panels, 180 units of 2V 600A deep-cycle batteries, one unit of 120 kVA inverter, and one unit of 120 kVA backup diesel generator. The interconnectivity consists of an 11 kVA Kaduna DisCo distribution line, which is stepped down through a 300 KVA transformer to the generation/distribution station. A meter installed in the station records monthly supply from Kaduna DisCo, which is paid by the community through tariffs charged by the management of the installation. Changeover switches installed in the station switches supply from Kaduna DisCo to the solar and vice versa. Low-tension distribution lines with a cumulative length of about 2 km are installed along the roads in the community from where step-downs are made to households. Each house is supplied with a prepaid meter.

From the very beginning of the project, the community was consulted and actively involved. Community members provided both land and logistics support during the installation process. Furthermore, the contractor ensured that three individuals from the community were trained in essential maintenance and troubleshooting, ultimately becoming the skilled management personnel who took over when the contractor's involvement ended.

Mini-grid impacts on the community:

Economic: According to the respondents interviewed, the mini-grid had positively impacted the community's economy. Those previously using petrol generators and incurring high expenses had seen significant savings. This resulted in increased liquidity, allowing them to address other issues. A few new businesses had emerged, while existing ones had expanded to offer additional services such as cold drinks and film rental.

Social: The mini-grid electrified the mosques and public places within the community. Nighttime activities had been greatly enhanced, and the community no longer had to go to sleep at dusk. Means of worship had also been greatly improved, and the illuminated mosques and other public places had now become conducive to after-dark social gatherings.

Figure 7.13: Focus Group Discussion in Torankawa Community



Also, better human security was achieved by illuminating the community with streetlights and house security bulbs.

Challenges

The mini-grid was regarded as one of the most successful interconnected systems in Nigeria. However, during the field visit, it was observed that the interconnectivity was not functional as the Kaduna DisCo lines to the community had been destroyed again by strong winds. The community confirmed that the utility supply had not been available for over 2 years (Fig. 7.13).

The revenue profile of the mini-grid system is poor; it stands between NGN100,000[10] and NGN150,000[11] monthly. Once management personnel and other maintenance costs were settled, the net revenue dwindled to less than NGN50,000[12] monthly. The pressing concern revolves around financing the battery replacement, which costs as much as NGN10,000,000.[13] The Secretary of the Technical Committee emphasized the critical need for external support to address this challenge, as otherwise there's a looming possibility of abandoning the installation. The committee was optimistic about receiving additional support from the Federal Ministry of Power in the coming years.

[10] This is an equivalent of $166.67 at an exchange rate of 600 naira to I dollar.

[11] This is an equivalent of $250 at an exchange rate of 600 naira to I dollar.

[12] This is an equivalent of $83.33 at an exchange rate of 600 naira to I dollar.

[13] This is an equivalent of $16, 666.67 at an exchange rate of 600 naira to I dollar.

Unfortunately, the pool of productive users capable of bolstering the revenue remains limited.

The lack of adequate skilled personnel was also a significant problem. The mini-grid operators did not know how to test for dead batteries and isolate them. During fieldwork, the SIGMA team observed that the community was relying on the contractor, who had been providing pro-bono service since the installation's completion, to assist with battery testing. Moreover, the community was unsure how many batteries were affected and how to finance their replacement. Due to the drop in supply, the connection of additional customers beyond the initial 100 were put on hold until the battery issues could be resolved.

7.3.6 Dakiti Community Mini-Grid

Situated in the Akko Local Government Area of Gombe State, Dakiti is a predominantly agrarian community with a population of over 3,000 residents distributed across more than 500 households. The community is approximately 20 km from Gombe and 6 km from the nearest national electricity grid. Dakiti is renowned for cultivating diverse crops, including millet, sorghum, and soybeans, alongside animal husbandry.

The Dakiti mini-grid, a project developed by Leading Diagonals Engineering Nigeria Limited in collaboration with the Rural Electrification Fund (REF), was completed in March 2020 and commissioned in March 2021. The system comprises 282 solar panels, 74 batteries, and various other solar components, including approximately 6 km of distribution lines (Fig. 7.14). The power system had successfully energized 253 residences and businesses within the community at the time of the fieldwork. In addition to the solar components, a 60 kVA backup diesel generator is housed in the power station. This generator functions to recharge the battery bank in the rare event that its power level drops below 40%. Since its installation, the battery bank had consistently maintained a capacity above this threshold, rendering the generator unnecessary.

Community involvement played a pivotal role in the development process. According to respondents, the mini-grid project was initiated by an official from the Transmission Company of Nigeria (TCN), who owned farms near the community and had a positive rapport with the residents. When the REF call was announced, this official advocated for the com-

Figure 7.14: Dakiti Community Mini-Grid

A



B



munity's electrification, given its distance of approximately 6 km from the nearest electricity grid. Community members affirmed their willingness to accept the electricity and agreed to cover the associated costs during consultations, which were reported to have been attended to solely by men.

The land on which the village head generously donated the mini-grid stands at no cost to the developer. Local mini-grid management was entrusted to a technician trained by the operator in essential maintenance

and troubleshooting. Additionally, two local guards were employed to ensure security for the installation, receiving monthly compensation from the company. The local technician undertook routine maintenance tasks and called on the company to provide more complex maintenance services when necessary.

Mini-grid impacts on the community.

Economic: While the respondents agreed that the mini-grid had a positive overall impact, the community's use of power for economic activity and productive use was very low. The majority of electricity users were households (Fig. 7.15), only a few of which had used petrol generators prior to the installation of the mini-grid. Contrary to expectations, only a couple of businesses had been added since the mini-grid was installed. Nevertheless, the reduction in energy costs for those previously using petrol generators was quite significant, according to respondents.

Challenges:

During our fieldwork, there were no operational challenges with the mini-grid. This was corroborated by the respondents too. However, on closer analysis, a potential future challenge emerged concerning replacement of the battery bank. Insights from the local technician revealed that the average monthly revenue generated was approximately NGN100,000.[14] Projections indicated that the installation's anticipated battery lifespan was 6 years, with replacement costs exceeding NGN14,000,000.[15] Based on the current revenue stream, the gross revenue over the 6 years amounted to approximately NGN7,200,000.[16] Unfortunately, these financial calculations indicate that the mini-grid may not generate sufficient funds to cover the replacement of the battery bank in the future. This concern was raised with the local technician, who, regrettably, could not provide insights into the operator's strategy for financing the replacement when needed.

7.3.7 Mbela Lagaje Mini-Grid

[14] This is an equivalent of $166.67 at an exchange rate of 600 naira to 1 dollar.

[15] This is an equivalent of $ 8,420.53 at an exchange rate of 600 naira to 1 dollar.

[16] This is an equivalent of $ 4,332.22 at an exchange rate of 600 naira to 1 dollar.

Figure 7.15: Sample Electricity Meter at Dakiti Community



Mbela Lagaje is a rural community in the Mayo Belwa Local Government Area of Adamawa State. The community has an estimated population of 1,500 inhabitants and is situated about 15 km away from the local government headquarters. Mbela Lagaje is known for its agricultural activities, particularly the cultivation of sorghum and soybeans.

The Mbela Lagaje solar hybrid mini-grid was completed in December 2020. The installation has a 60 kVA diesel generator that is supposed to provide a backup electricity supply to the community (Fig. 7.16). Since it was installed until the SIGMA team visited, respondents said the generator had been used only once to power the community overnight. They said they could not continue using the generator due to the high cost of diesel. At the time of the visit, the mini-grid was not operational. However, of the 147 houses in the community, only 80 households were connected, only five of which had been connected by the contractor. The remaining 75 households had had to purchase their own poles and cables

for connection. Households unable to buy their own materials were left out of the connection.

The community said they had never been consulted during the process leading up to the installation of the mini-grid. They confirmed that a member of the House of Representatives facilitated the development of the mini-grid. Respondents said they were called for a briefing only when the developer mobilized to the site. According to the respondents, the developer and REA officials told them that the government had decided to provide them with electricity, which was why the developer was there. They were urged to keep the mini-grid secure after it was installed.

After the development of the mini-grid, the REA established the Rural Electricity Users Cooperative Society (REUCS) to be in charge of the mini-grid's operation, maintenance, and security.

Figure 7.16: Mbela Lagaje Mini-Grid Site



Mini-grid impacts on the community:

Economic: Respondents said when the mini-grid was working, it boosted economic activities in the community. Shops and barbing salons witnessed enhanced service delivery and cost savings. Only one respondent who operated a phone charging shop reported having negative growth in business when the mini-grid was working.

Social: When it was working optimally, the mini-grid improved social life in the community. The mosque and other public areas in the community were illuminated and enhanced during the night for the inhabitants. The mini-grid also improved relations with neighboring communities as they visited and enhanced friendships with the Mbela Lagaje inhabitants so they could charge their phones, torch lights and rechargeable radios.

Challenges:

When the SIGMA team visited the generating site and observed the distribution lines, the following technical deficiencies were noted:

The solar panels were a mixture of monocrystalline and polycrystalline, with more of the latter in the mix. It is very likely that the system was delivering lower-than-designed output.

All the labels in the solar panels had been removed so the power rating could not be determined without using a test meter.

The inverters were also being used as chargers instead of having separate charge controllers. This put a lot of pressure on the inverters.

The electric poles supplied were metal-based instead of concrete or wood. This is not good practice (Figs. 7.17 and 7.18).

Figure 7.17: Mbela Lagaje Mini-Grid Lines



Figure 7.18: Mbela Lagaje Mini-Grid Lines



A



B

7.3.8 Nigeria Electricity Supply Company, Jos

Plateau is the 12th-largest state in Nigeria. Located in the center of the country, it is geographically unique in Nigeria due to the boundaries of elevated hills surrounding the Jos Plateau, its capital, and the entire plateau itself. Plateau State is described as "The Home of Peace and Tourism." With natural formations of rocks, hills, and waterfalls, it derives its name from the Jos Plateau and has a population of around 3.5 million. The Jos-Bukuru Metropolis, which comprises much of Nigeria Electricity Supply Company's (NESCO) customer base, was previously considered two separate metropolises. Over time, however, the city of Jos has merged with the town of Bukuru to form the Jos-Bukuru Metropolis.

Jos Plateau has a rich, industrious heritage. The people are engaged in different economic activities, but their primary occupation is agriculture and trading; the people farm a lot of fruits and vegetables such as carrots, cucumbers, okra, tomatoes, potatoes, onions, rice, beans, groundnuts, maize, and watermelon. Besides agriculture, the metropolis has witnessed very rapid commercialization and industrialization. New markets, industries, and institutions are growing and expanding at almost every corner of Jos City, making Jos a metropolitan city. Some of these commercial and industrial centers include Jos primary market (Terminus), Bukuru market, Rukuba market, Faringada market, Coca Cola Bottling Company, NASCO Group, Naraguta Leather Works, Swan Bottle Water Industry, Jos University Teaching Hospital, aluminum roofing industries, and NTA(Nigerian Television Authority) Television College. Other important establishments in this city include the National Veterinary Research Institute, the National Institute of Policy and Strategic Studies (NIPSS), the Jos National Museum, the airport, the college of accountancy, the zoo, eateries, relaxation parks, and a host of other industries.

NESCO was originally a British company established in 1929 with the colonial administration's support. The first 4 MW hydropower plant was installed at Kurra Falls. The plant was upgraded to 8 MW: Jekko 1 and 2, each with a capacity of 4 MW, were installed in 1937 and 1954, respectively. Ankwil 1 was established in 1961 with a capacity of 1 MW, while Ankwil 2 was installed in 1963 with a capacity of 2 MW. The first hydropower station built by the tin miners in 1919, Kwall 1, with a capacity of 2 MW, was taken over by NESCO some years after it started operations. Kwall 2, with a capacity of 4 MW, was installed in 1968. These are small hydroelectric systems situated across different river networks.

The original operating license was for providing electricity for tin miners who operated in the area during the colonial era. Following the 1962 decline of the tin-mining industry and the subsequent loss of its key customers, NESCO shifted focus to the communities and towns surrounding the mines. The operating license was then expanded in later years to include selling electricity to the defunct ECN. Subsequent reviews included servicing customers whom the ECN could not reach then.

By 1970, NESCO had electrified 27 towns in the Benue-Plateau region and was the sole electricity supplier to Jos. When the defunct NEPA took over electricity supply in the city in 1978, the government permitted NESCO to operate independently of NEPA due to the former's reputation for reliability and superior service.

When it started operations, NESCO was financed by the colonial administration because of the latter's interest in tin mining. When Nigeria gained independence in 1960, financing by the colonial administration stopped. In 1975, when the Nigerian government was promoting the indigenization of foreign-owned companies, the then Benue/Plateau State (now Benue, Plateau, and Nasarawa States) first bought shares in the company. The Federal Government followed suit the following year. Its operations are now financed through revenue generated from the sale of electricity.

NESCO's main franchise area is the Plateau area. It supplies electricity to Jos Metropolis, Bukuru, and all the communities along the 107-km road from Jos to Kurra and beyond. Its customer base is 7,860, comprising domestic, commercial, industrial, and institutional users. NESCO has not conducted a recent enumeration to get the number of customers in each category, but the most extensive customer base is in the R2 band.[17]

All the respondents whom the SIGMA team asked about levels of community engagement said they were not part of the pre-power system development in the communities. There was no community engagement before its establishment, as the original focus was the tin mines. Surplus electricity was extended to communities surrounding the sites for a fee. From its inception to date, NESCO has been a commercial enterprise and solicits customers like any other electricity utility company. However, during its expansion phase, in addition to obtaining the necessary permits from the government, NESCO engaged with communities in its franchise area on the electricity supply, tariff, and benefits. Today, NESCO still engages with the communities it services on the safe use of electricity and cost recovery.

Mini-grid impacts on the community:

Economic: According to respondents who use NESCO's power, NESCO's electricity supply is much more stable than Jos DISCO's. This has led to very significant and sustained growth in economic activities. The few industries NESCO serves enjoy much lower production costs, according to the NESCO personnel interviewed.

Social: Because NESCO's supply is much more stable than that of Jos DisCo, the persons interviewed said they enjoyed a much more social life

[17] These are household customers with consumption above 50 kilowatt electricity.

than others in most parts of Nigeria. Nighttime recreational activities and gatherings were usually fun before insecurity became a problem in the region. Also, better human security has been achieved at the community level by installing streetlights and security bulbs on houses.

Environmental: NESCO's operations have not had any significant negative impact on the environment, according to the personnel interviewed. Even though a substantial area of land was set aside for the reservoir, not much agricultural land was condemned. Secondly, the dams were constructed in such a way as to avoid significant distortions to aquatic life. Water flow through the river is maintained at all times, albeit at different levels depending on the season. The personnel said this has boosted fishery and agriculture around the dam and downstream. Also, no case of flooding has occurred in the dams. Beyond the spillways, each dam has an underground tunnel that channels excess water downstream and helps maintain natural river flow.

Further, because the dams are earth dams, they have equipment that measures seepage. Where detected, any seepage is quickly plugged. Finally, the respondents said reduced dependence on petrol generators positively impacts their health and the environment.

Challenges:

Financing constraints: Currently, NESCO generates just enough money to finance its operations but not enough to finance its expansion plans. NESCO said it has tried to get a loan from the Bank of Industry (BoI) but that it was not successful due to the difficult terms proposed by the bank, including the provision that NESCO hand over the Certificates of Occupancy of its facilities as collateral to access a loan.

Low revenue generation—While the NESCO tariff is much lower than that of Jos DisCo, customers still complain that the amount is high. This has affected its revenue. According to NESCO, bill collection compliance, at the time of engagement, stood at about 70%.

Illegal connections are one of its biggest challenges. NESCO estimates its losses to be close to 50% of unlawful connections. Where detected, the offending customer is disconnected and must pay a penalty before reconnection. However, most offenders have found ways to continue illegal connections and do this mostly at night.

About 25% of NESCO's customers are in the rural areas. Recovery of bills in rural areas is quite tough given the challenging logistics involved in

getting to the rural communities. This is not helped because NESCO operates a postpaid metering system.

Since the last power plant was installed in 1968, NESCO has not expanded its generation capacity. Most of the turbines now operate at reduced efficiency. Lack of finance has hampered its plans to upgrade the aged turbines. This and the rising customer base have forced NESCO to adopt a load-shedding program. Currently, daily electricity supply varies depending on location and class of customer. In some areas, supply is limited to every other day, i.e., one day on and one day off. Some areas have only a few hours of disruption per day. High-value customers such as industrial users and public institutions enjoy 24-hour supply.

Changes in climatic conditions, which are increasingly becoming unpredictable, have also significantly impacted generating capacity. Water levels in their reservoirs are progressively dropping, according to NESCO personnel. The drop in water level is usually most felt during the dry season and has threatened NESCO's operations severely.

Insecurity has severely impacted NESCO's operations. The company has lost a couple of staff to attacks by insurgents operating in the region. Maintenance is greatly affected. The 33 KV lines from the power stations to the control stations pass through areas where insecurity is rife. Maintenance teams now go with military escort. This has affected the schedule of their maintenance. Also, all their power stations now have military personnel guarding them. These have substantial financial implications.

7.3.9 Gbamu Gbamu Mini-Grid

Gbamu Gbamu, settled by farmers from Owu-Ijebu (Ijebu East L.G.A.) of Ogun State, was established over two decades ago. The settlers were drawn to the area's fertile land, peaceful surroundings, and trade opportunities offered by the renowned Gbamu Gbamu market. Over the years, the community has attracted people from different parts of Nigeria, including Cross River, Osun, Sokoto, and Lagos States. The Ogun state government initially designated the land as a forest reserve, where nature was preserved by allowing crops like Gmelina, trees, and animals like elephants to thrive.

Before the introduction of the solar hybrid project, a significant development had already occurred in Gbamu Gbamu. Nigeria's most extensive network service provider, M.T.N., had installed a telecommunications mast 7 to 8 years earlier in the area. This development was instrumental in selecting Gbamu Gbamu as a potential site for a solar mini-grid, as it allowed for real-time communication necessary for the plant's effective daily operations. Additionally, the community's distance from the national grid was crucial. The absence of electric poles miles before the community meant that the national grid would not have been accessible anytime soon.

The Gbamu Gbamu 85 kWp Solar Hybrid Mini-Grid Project, initiated in 2018, was still functioning at the time of fieldwork in 2022, albeit at reduced capacity (Figs. 7.19 and 7.20). The mini-grid operator, Rubitec Utilities, views the project as its most significant undertaking, and GIZ provided the funding. Before the establishment of the mini-grid, the approximately 500 households and businesses in the community had no electricity, and only a few of them could afford to run petrol or diesel generators sets to meet some of their energy requirements.

Figure 7.19: Gbamu Gbamu Mini-Grid Site



At its inception, GIZ tasked Rubitec with the role of seeking potential sites that were suited for mini-grid solutions, and this effectively led to the final selection of Gbamu Gbamu amid five other communities identified by the operator. The operator, knowing the importance of government

inclusion, encouraged GIZ to interface with the Ogun state government before further engagements were made with the community through the traditional ruler and his governing council.

However, due to various unrealized schemes and projects proposed by external bodies to the community in the past, the villagers and their leaders initially considered the mini-grid project another hoax. This did not deter the operator from carrying out feasibility studies and energy needs assessment of households and businesses about 5 years before the project commenced in 2017. This included proper sensitization of the community to how stable electricity can induce socio-economic growth and development. Nonetheless, a number of interviewees admitted that they did not fully believe the developer's promises until the first set of electric poles and connecting cables were installed.

With a proper understanding of the benefits, the community stood to gain from the project much later; the traditional ruler and his governing council of 14 members (comprising a secretary, a treasurer, a public relations officer, two women, and eight other male members) selected a suitable location for the mini-grid installation beside the telecommunication mast. The land in question was formerly used by a member of the community for cocoa farming, and he was duly compensated for it by the mini-grid operator. Proper documentation (in the form of an Memorandum of Understanding) was also put in place and signed by the representatives of the community and the mini-grid operator. The MoU primarily outlined the roles of the community and the mini-grid operator and the initial tariff structure, as pre-determined by the mini-grid operator and regulated by the REA.

Mini-grid impacts on the community:

The villagers acknowledged that the mini-grid had directly impacted the community's socio-economic life in the following areas:

- Improved productivity levels, especially by businesses that were reliant on constant power supply such as barbing, tailoring, vulcanizing, and hotel/motel businesses.
- Migration of people from neighboring villages or communities to Gbamu Gbamu to carry out productive activities, relax, and sometimes settle with their households. This led to an increase in housing units from an estimated 500 houses to over 1,500 houses within 4 years of commissioning the mini-grid.

Improved academic performance by students in the early days of the mini-grid's operation. However, it was gathered from the village school head teacher that constant electricity had not necessarily led to improved performance of students in the long term, as some were distracted by excessive consumption of TV shows and videos. An exception would be the introduction of information technology instruction (done with one laptop on Fridays) by the school as a result of improved electricity access.

With regard to health care workers, since the storage's efficiency declined, they have had to rely on rechargeable lamps and lights from their mobile phones for delivery of pregnant women at night. They have also resorted to storing their vaccines with cold-drink retailers in the local market. This indicates that for social users such as schools and health centers, electricity access has not been much of a game changer.

Challenges:

The challenges faced by the mini-grid operator were mostly financial and operational. This specifically has to do with managing the backup solutions deployed to help keep power supply going round the clock. Since solar is an intermittent energy source solely dependent on the sun's availability, the mini- grid has a battery storage backup (96 batteries) and an 80 kVA diesel generator that has to be constantly maintained and serviced. The high cost of diesel and the reduced efficiency of the batteries after 4 years of operation had reduced power supply for the community from 24 hours daily to around 18 hours daily.

Out of more than 600 houses currently connected to the grid, over 400 are believed to be household users. This category of users are primarily nighttime users who rely on power for lighting and entertainment, consuming around NGN200[18] worth of electricity daily. Therefore, their complaints revolve around recent outages and reduction in the number of daily hours of power supply—especially in the evenings when batteries have been drained and the diesel generator is rested. This, coupled with the perceived poor communication from the operator to notify them ahead of power outages and status of their tariff (resulting in sudden power cuts even when there is electric supply)

[18] Equivalent of $0.33 with the exchange rate of N600 to a dollar.

affects their ability to secure their homes and surroundings at night and is seen by them as the opposite of what they had been promised at the beginning—24/7 power supply.

Another major challenge pointed out by household owners is that of the social conflicts that are generated in situations where a meter is shared by two or more households. While the operator has assured zero energy theft since every household is metered and only one electrician is authorized to attend to electrical faults, customers are sometimes left unhappy because others are free-riding on the power they purchase. The monopoly enjoyed by the electrician and the power vendor also raised doubts among some users (including productive and commercial users) regarding the efficiency and transparency of the complaints resolution system.

7.4 Key Informant Interviews

7.4.1 The Energy Commission of Nigeria

Our interview was with a member of the top management team of the ECN, which was established in 1979 and started operations 10 years later, in 1989. This was after Economic Community of West African States (ECOWAS) heads of state decided in Cotonou, in 1985, that each member state should establish a government agency to serve as its energy commission. The respective commissions were expected to be in charge of the surveillance, development, monitoring, and coordination of energy in each state. The ECN's key functions involve collecting data, producing periodic master plans, and coordinating national energy policies.

According to the respondent, the ECN has participated as a critical stakeholder within the mini-grid sector. For example, during the development of the 2016 Mini-grid Regulation driven by Nigeria Electricity Regulatory Commission (NERC), the ECN was part of the energy stakeholders in Nigeria that participated in the process. According to him, preceding the regulatory framework, the ECN actively engaged in pilot mini-grid projects, exemplifying diverse technologies aimed at enhancing energy access for rural communities. Those initiatives included the installation of 5 kWp and 10 kWp capacity mini-grids. To date, the ECN still implements mini-grid projects budgeted for by the National Assembly under the banner of so-called constituency projects.

The respondent underscored a substantial impediment to the sustainability of mini-grids in Nigeria, specifically, their placement within com-

munities where users do not remit payments, with politicians mainly utilizing constituency projects to garner popular support.

7.4.2 Renewable and Rural Policies Department (Ministry of Power)

Our respondents were three senior officers of the Ministry of Power. The ministry is responsible for overseeing power sector policies, program formulation, and intervention development as needed. The ministry has a specific department, the Renewable and Rural Power Sector Department, dedicated to renewable energy. This department manages the formulation and implementation of renewable energy policies, including the renewable energy policy, energy efficiency policy, national renewable energy action plans, sustainable energy action agenda, and other related policies. Overall, the ministry is actively involved in shaping and executing initiatives to advance the power sector, particularly in the realm of renewable energy.

The respondents pointed out that the Ministry of Power plays a pivotal role in coordinating the electricity sector as a whole, including the development and regulation of mini-grids. This strategic involvement ensures that the expansion and management of mini-grid systems align with national policies and standards.

The respondents identified two major challenges to the development of the mini-grid sector in Nigeria. First, impatient investors pose a significant hurdle, with some individuals seeking quick returns within unrealistically short time frames. Second, the issue of double-digit interest rates in the country adds to the financial pressure on developers. Beyond these challenges, the respondent highlighted the need to address changes in lifestyle among electricity consumers, particularly those encountering electricity for the first time. The shift in daily routines and the lack of awareness about electrical gadgets affect the consumption patterns and financial viability of mini-grid projects. They also emphasized the importance of incorporating productive use strategies to stimulate energy consumption and ensure the success of mini-grid projects in the unique context of Nigeria.

7.4.3 Heinrich Böll Stiftung (HBS)

The team interviewed a senior member of HBS staff. HBS is an international development organization and has been in Nigeria since 1999. According to the respondent, HBS works on increasing energy access

and started its work on mini-grids by mapping the solar energy sector in Nigeria, where a lot of solar players were identified and grouped into what roles they played in the solar sector. HBS's strength in advocacy has resulted in collaboration with other energy sector stakeholders, including the Nigeria Economic Summit Group (NESG) and Rocky Mountain Institute. Utilizing its strength, the HBS looked into reforming renewable energy by organizing a roundtable discussion with many government officials. They discussed import duties, harmonized systems (HS) codes throughout the value chain, and how to interact with Nigerian customs, all with the goal of lowering the costs of renewable energy, mini-grid, and solar home solutions.

As an organization that has conducted much advocacy and research on energy access in Nigeria, HBS sees the following as barriers to mini-grid growth and success in Nigeria.

Under-sizing issues arise during project deployment, where initial plans for delivering a certain capacity of, say, 50 MW may fall short upon assessment, often due to technical malfunctions or performance degradation. Inefficiencies in load carriage capacity have been observed, leading to disconnections and a reliance on backup generators. Sustainability is a broader concern, particularly in government-led projects, where value for money and long-term viability are questioned.

The lack of formalization and training in the industry has hindered the growth of the formal sector, despite widespread informal adoption of solar solutions. The industry's relative infancy, less than 5 to 6 years old, has resulted in a learning curve for institutions, banks, and experts.

The absence of suitable incentives, coupled with the government's focus on revenue generation, further challenges the establishment of a robust sustainability framework.

7.4.4 The World Bank

The team spoke with an energy specialist at the World Bank. The respondent asserted that the Bank actively engages in transformative initiatives, participating in market reforms, regulatory enhancements, and the development of sustainable systems in countries like Nigeria that face energy deficits. Despite the considerable challenges posed by energy deficits, the

Bank is committed to designing and implementing effective programs that effectively address and bridge these gaps in energy supply.

The respondent emphasized that the Bank's dedication lies in meticulously assessing ongoing initiatives, scrutinizing existing policies and regulations to identify potential gaps, and integrating global expertise to enhance efficiency in implementation. A notable instance of this commitment occurred in 2016, when the Bank played a pivotal role in supporting Nigeria's development of the mini-grid regulation. This initiative not only proved successful in Nigeria but also served as a benchmark for numerous African countries, receiving positive acclaim for its effectiveness.

Following a comprehensive evaluation of the Bank's support, the respondent highlighted a critical concern regarding size in the current regulatory framework. Specifically, the regulation restricts mini-grid capacities to 1 MW, hindering developers with ambitions beyond this limit. In response, the Bank is actively pursuing the revision of the existing regulation, advocating for an increase to 5 MW. Additionally, there is a concerted effort to provide heightened support, both in terms of funding and regulatory facilitation, for interconnected mini-grids to further catalyze their development.

7.4.5 Renewable Energy Association of Nigeria (REAN)

The team engaged with a top official of REAN to gain insights into the association's perspective on Nigeria's burgeoning wave of mini-grid development. REAN, an industry association comprising renewable energy professionals, project developers, and practitioners, is dedicated to advancing the interests of the private sector in Nigeria's renewable energy domain. As a private sector–led association, REAN prioritizes considerations of the economics of scale and commercial viability in selecting technology for developing mini-grids. According to the president, developers within the association invest in technologies that offer swift deployment and rapid scalability. Hence, solar power is prevalent in the mini-grid landscape in Nigeria. The emphasis is on choosing technologies that enable efficient and quick rollout, aligning with the economic considerations within the sector.

Addressing challenges in the sector, the president underscored a noteworthy observation. Many of the developed mini-grids have benefited from some concessional funding, whether through grants or subsidies.

There is a legitimate concern about the commercial viability of these mini-grids in the absence of such concessional funds, so this highlights the delicate balance between sustainability and financial feasibility.

The president identified security as another prominent challenge. Most mini-grid communities are rural, necessitating deep penetration into off-grid communities. Security concerns become particularly pronounced in these remote areas, posing additional complexities for the development and maintenance of mini-grids. He also mentioned that customs duty is a big issue for players in the sector and that it creates a situation where end users will have to pay a higher tariff. He urged for an enhanced enabling environment and called for both development and commercial finance to be injected into this market.

7.4.6 Havenhill Synergy Limited

The team spoke with one member of the top management team of Havenhill Synergy Limited, who shared insights into the company's operations. According to him, Havenhill is positioned as a clean technology micro-utility company specializing in harnessing solar energy to generate clean, safe, cost-effective, and sustainable electricity in rural and urban Nigeria.

The company predominantly employs solar technology in rural areas to energize commercially viable off-grid rural communities. This includes serving a diverse range of customers, encompassing residential, commercial, and productive segments. At the time of the fieldwork, the company had four mini-grids in operation and was planning to commission 26 more, bringing their total to an impressive 30. This expansion is poised to provide electricity to approximately 200,000 people across these 30 communities. The commitment to sustainable energy solutions and community impact is evident in Havenhill's strategic and operational endeavors. On the question of how the company has sustained revenue from some low income customers, the respondent said they used a social enterprise model that helped farmers to increase their productivity.

The company has implemented an innovative initiative in its demand stimulation strategy. In 2017, when it constructed its first grant-funded mini-grid, the company went beyond energy provision: they established a barbing salon for a barber, created a viewing center for another individual, and opened a provisions store for yet another person. The provisions store, equipped with a refrigerator, allowed the owner, a woman, to sell

cold beverages. The respondent also spoke of a demand creation model in which the company formed groups of five farmers, each cultivating 3 to 5 hectares during a farming season. These farmers were provided with improved seedlings, tractors, and access to capital. Surprisingly, with this support, the farmers significantly expanded their cultivation to 13 hectares, a notable increase from the 3 hectares they would have managed without assistance. During the harvest, Havenhill purchased the yield from these farmers, providing a market for their products and enabling them to generate income to cover their energy usage expenses. These community-driven endeavors not only showcased Havenhill's commitment to holistic development but also significantly contributed to an increase in energy consumption within the community.

7.4.7 Community Research and Development Center (CREDC)

The team spoke with one member of the top management team of the CREDC. According to the respondent, CREDC is a sustainable development organization that has been actively involved in renewable energy and energy efficiency since 2006. He explained that the organization's journey commenced with advocacy and evolved to implementing small stand-alone solar home systems (SHS) projects in various communities. Over time, CREDC transitioned to microgrids and subsequently to mini-grids. Notably, the organization has successfully developed three mini-grids, with the first one initiated in 2013—all embracing a social enterprise model.

The respondent emphasized the relevance of the social enterprise model, stating that it aligns with the current needs of many communities in Nigeria. Going fully commercial might not be viable, and the respondent highlighted the fact that commercial electricity is subsidized in Nigeria. In his view, the government should also subsidize mini-grids, emphasizing that this approach is crucial for sustaining numerous communities. He argued that adopting a purely business-oriented model could jeopardize the survival of many rural mini-grids and developers because the business activities in those communities cannot sustain them. Therefore, with necessary subsidies, the social enterprise model is the key to ensuring the long-term success and sustainability of mini-grids in Nigeria.

The respondent highlighted the paradox of promoting commercial mini-grids in local communities. He questioned the logic behind charging

residents in wealthy cities, where many people are above the poverty line, N50[19] per kilowatt-hour, while those in local communities, often living below the poverty line, are charged N100[20] per kilowatt-hour. In his view, it defies logic that the government subsidizes electricity for those in the city and does not extend similar support to those who need it the most.

7.4.8 Rubitec Nigeria Limited

At Rubitec Nigeria, the team spoke with a staff of the company's project team. According to the respondent, Rubitec is a renewable energy company specializing in solar, small hydro, and biomass energy systems. The company has been actively involved in developing mini-grids. One of the company's projects, an 85 kWp installation at Gbamugbamu, had been operational since February 2018. Additionally, at the time of the fieldwork, the company was participating in an interconnected mini-grid initiative funded by grants from the European Union and the German government, implemented by GIZ, and supported by the REA. The interconnected mini-grid project, in collaboration with the Ibadan Distribution Company (DisCo), aimed to provide electricity to three communities simultaneously. The system was designed to generate 447 kW at peak capacity, facilitating over 3,100 connections. However, when discussing the challenges of mini-grid expansion, the respondent highlighted a significant hurdle: the regulatory restriction limiting mini-grid size to 1 MW.

According to the respondent, this limitation discouraged potential investors interested in larger systems. He expressed the view that Nigeria has surpassed the stage of building 50 kWp and 30 kWp mini-grids, deeming them sustainable only for small communities with minimal power consumption needs. He emphasized the necessity of accommodating large-scale renewable energy integration to foster industrial growth. Furthermore, he identified Nigeria's foreign-exchange volatility and high inflation rates as additional drawbacks to mini-grid development. These economic factors contribute to the complexities and uncertainties faced by companies involved in renewable energy initiatives.

[19] Equivalent of $0.8 with the exchange rate of N600 to a dollar.

[20] Equivalent of $0.17 with the exchange rate of N600 to a dollar.

7.4.9 GVE Projects

The team spoke with one of the field staff of the GVE Projects Limited. GVE is a leading renewable energy solution provider in Nigeria and has a presence in four of Nigeria's six geopolitical zones. At the time of the fieldwork, the company had 14 functional mini-grid sites, and another 50 were in the works, either at the construction or at the pre-construction stage. Further, the company was in the process of developing an interconnected mini-grid at Wuse Market in Abuja, in collaboration with the Abuja Electricity Distribution Company. On the question of what the developer did to keep tariffs relatively low and still maximize profits, the respondent stated that the company encourages productive uses of electricity, leverages equity and grants, and minimizes operational and maintenance costs. However, he also pointed out that tariffs depended on the funding dynamic of particular mini-grids. Grant-funded mini-grids reduce the project's payback period and, most significantly, reduce the tariffs to end users.

On the challenges of navigating the complex landscape of mini-grid development, the respondent identified the imposition of value-added tax on photovoltaics and storage equipment as a significant impediment. Another challenge he identified had to do with the potential ramifications for existing mini-grids when the primary grid expands into a community, with foreign investors expressing apprehensions about perceived ambiguities in that aspect of regulatory provision. Beyond fiscal challenges, the respondent highlighted logistical problems where security operatives on the road hampered the seamless movement of mini-grid equipment from one location to another. The respondent further underscored challenges relating to the disruption of entrenched norms within specific communities by the introduction of mini-grids. In one instance, for example, a particular community declined to have a mini-grid installed by the company on the ground that their ancestors would not want them to have electricity.

7.4.10 Nayo Tropical Technologies Limited

The team spoke with a lead executive officer of Nayo Tropical Technologies Limited. The respondent described the organization as a vertically integrated renewable energy company, offering a comprehensive spectrum of services ranging from product development to system design and prod-

uct design to equipment procurement, construction, utility establishment, and the operation of micro utilities. At the time of the fieldwork, the company had been in the space for over 23 years. The company pioneered the first metered mini-grids in 2010 in Onitsha, Anambra State, with support from the United Nations Development Programme (UNDP). In discussing the mini-grid landscape in Nigeria, the respondent pointed out three major development programs: The Mini-Grid Acceleration Scheme (MAS) and the Interconnected Mini-Grid Acceleration Scheme (IMAS) supported by the Nigeria Energy Support Programme (NESP) of the GIZ; the Nigerian Electrification Project (NEP) supported by the World Bank; and the REF.

On raising finance, the respondent noted the unfavorable macroeconomic conditions in Nigeria, which deter foreign direct investment and lead to a reluctance among local banks to invest in mini-grids. This, the respondent emphasized, remains a significant obstacle across various mini-grid projects in the country. Despite these challenges, the respondent acknowledged that when considering capital expenditure and incentives as key indices, the incentives offered by the NEP outweighed those of MAS and REF. He underscored the necessity for mini-grids to secure a unique form of capital characterized by low interest rates. Drawing a parallel with infrastructure development, the respondent lamented the unavailability of longer-tenure, single-digit funding from Nigerian banks for such ventures.

7.4.11 Gen Sustainability Solutions Limited

The team spoke with one of the lead directors of the organization. Gen Sustainability Solutions supports stakeholders (private and public) in the mini-grid sector in training, research, and market expansion. The organization was part of the team that developed Nigeria's mini-grid site selection criteria and provided training to REA directors in that capacity. Reflecting on the challenges faced by pioneer developers of mini-grids in Nigeria, the respondent emphasized the historical issue of site selection. According to him, in the early years of mini-grid implementation, poor site selection contributed significantly to project failures, accounting for 80% of the setbacks. The introduction of site selection criteria proved instrumental in alleviating this challenge, streamlining the process, and enhancing project viability.

The respondent underscored a contemporary challenge in the Nigerian mini-grid landscape, that of the disproportionate emphasis on solar PV technology. While acknowledging the importance of solar energy, the respondent highlighted the need for a more balanced approach, expressing concern over the neglect of alternative technologies such as bio-ethanol and hydro. He stressed the importance of diversifying the focus within the mini-grid development sphere to ensure a more inclusive and sustainable energy landscape.

7.4.12 Rural Electrification Fund

The team spoke with one of the lead directors of the REF. According to the respondent, the REA is committed to supporting underserved areas and those without access to electricity. As a crucial outcome of privatization reforms, the REA was established with a mandate to enhance access for citizens not connected to the grid and those who are underserved. This involved infusing private sector finance and capacity and introducing various technologies to enable swift deployment to villages far from the grid. While mini-grids have currently taken precedence, the REA is continuing its grid extension initiatives, transformers, and related projects, driven partly by political pressures and influence. The REF operates within the REA as a distinct department. The respondent highlighted that the REF explores innovative approaches to reach isolated areas, going beyond solar to embrace emerging technologies. Additionally, the REF encourages contributions from academic and research actors.

On the subject of political influence, the respondent acknowledged the substantial impact of the legislature on the REA's activities, particularly in non-donor-funded projects. While the National Assembly maintains reporting and oversight obligations over the REA, its influence on donor-funded projects like the World Bank's Nigeria Electrification Project is somewhat limited. However, a dedicated committee within the National Assembly oversees domestic and foreign loans, ensuring funds are utilized as intended. The respondent highlighted a central bank–managed government loan facility worth about N140 billion[21] to support local content and drive sector expansion. This facility is strategically designed to

[21] Equivalent of $233,333,333.33 with the exchange rate of N600 to a dollar.

encourage local companies to invest in renewable energy technologies by establishing local assembly plants.

7.4.13 Nigeria Electricity Regulatory Commission

The team spoke with one of the top officers at the research department of the NERC. According to the respondent, as the regulatory body in the power sector, NERC works toward ensuring that Nigeria's electricity sector reform succeeds by enabling a level playing field for all market participants through regulation. NERC's mandate is to set the rules and guidelines and ensure that all stakeholders play according to those rules. NERC provides entry and exit permissions through licensing and other regulations and determines what conduct is permissible within the market, including tariff determination to ensure the market is sustainable. NERC also creates standards that actors must abide by to ensure that consumers get value for thei money in terms of access to electricity, the quality of power, and the safety of installations and humans.

The respondent revealed that the development of the 2016 Mini-grid Regulation did not initially have the blessing of the distribution companies, who thought that their respective franchise areas would be balkanized and shared with smaller entities. However, the proviso in the regulation that a mini-grid cannot be situated in any community that is within the 5-year expansion plan of a distribution company eased the tension.

7.4.14 Abuja Electricity Distribution Company (AEDC)

The team spoke with a leading member of the regulatory team at the AEDC. The utility is one of the 11 electricity distribution companies that emerged after the privatization of the power sector in Nigeria in the 2000s. AEDC holds the franchise for the distribution and sale of electricity in the Federal Capital Territory, Niger, Kogi, and Nassarawa States. According to the respondent, AEDC recognizes the value that mini-grids bring to the mix in terms of helping to achieve the business objective of delivering electricity to customers. Accordingly, at the time of the fieldwork, the company was working with two mini-grid developers toward the establishment of interconnected mini-grids.

The respondent acknowledged that a proactive approach was essential to maximize the advantages that organizations such as AEDC can gain from mini-grid development. The respondent underscored the importance of providing incentives to catalyze the expansion of mini-grid projects. She specifically advocated a review of the 1 MW capacity limit that NERC set for licensing and suggested increasing the limit to support further growth. Additionally, the respondent advocated for fostering collaborations in executing mini-grid contracts, emphasizing that such cooperative endeavors would play a pivotal role in propelling the nation toward meeting its energy access targets.

7.4.15 Benin Electricity Distribution Company (BEDC)

The team spoke with a leading member of the regulatory team. Similarly to AEDC, BEDC is one of the 11 power distribution companies that emerged after the privatization of the power sector in Nigeria. BEDC is responsible for the retail distribution of electricity in Delta, Edo, Ekiti, and Ondo states. At the time of the interview, BEDC did not have any existing collaborations with mini-grid developers in its franchise zone; however, serious plans for one were underway with the utility because it was already in advanced talks with mini-grid developers.

When asked about the factors that could pique the interest of distribution companies in mini-grid development, the respondent highlighted the significance of transaction size. He noted that certain mini-grid transactions might not be lucrative enough to entice DisCos to participate actively. According to him, DisCos were primarily focusing on mitigating losses within their existing networks and might hesitate to invest in creating isolated islands that would require additional oversight.

7.4.16 Ibadan Electricity Distribution Company (IBEDC)

The team spoke with a leading member of the regulatory team. Like AEDC and BEDC, the distribution company is 1 of 11 that emerged after the privatization of the power sector in Nigeria. The respondent stated that IBEDC was aware of the mini-grid wave, especially the REA's efforts to promote interconnected mini-grids. At the time of the fieldwork, IBEDC had received requests from contractors under the REA's IMAS initiative,

and it had a couple of projects to showcase its readiness in the mini-grid sector.

The respondent mentioned infrastructural and liquidity challenges as issues that have constrained IBEDC and influenced its reaction to mini-grid development within its franchise. According to the respondent, this is the case because ability to pay is a major consideration for IBEDC's involvement in the electricity sector. This means that a DisCo will strongly consider its ability to recover expenditure in any area of energy investment because there is a stipulated amount that it is required to remit to NERC monthly. The upshot of this, according to the respondent, is that local communities with low productivity levels are not good areas for DisCos to invest in.

7.5 Cross-Cutting Findings

7.5.1 Energy Access and Use

In all the communities we visited, before the advent of the mini-grid, households' major energy uses were for lighting, mobile phone charging, radio, television, and cooking. Lighting technologies included rechargeable battery torches and gasoline generators, while cooking was predominantly done using firewood and charcoal stoves. While household energy needs remained more or less constant, a significant technological shift occurred following the introduction of mini-grids to those communities. All connected households had transitioned to using mini-grid electricity for lighting, phone charging, television, fans, and radio. However, in certain areas like Ozuzu community in Rivers State, some households still relied on petrol generators and rechargeable lanterns. Interestingly, cooking energy patterns and technologies remained consistent. The introduction of the mini-grid did not influence cooking preferences, as households expressed concern about the cost of purchasing energy units for cooking.

However, in Dakiti community, Gombe State, there was a remarkable surge in energy usage, with most households expanding their loads. A local technician confirmed that at least 10 consumers had purchased televisions since the arrival of the mini-grid. Furthermore, four households had acquired fridges, while at least five households owned electric irons. Notably, one consumer acquired an electric stove. Commercial users in the area, specifically five shops, had also invested in fridges since the introduction of the mini-grid. This indicates a positive trend in increased energy consumption and improved access, particularly in the Dakiti community.

7.5.2 Tariffs and Affordability

The 2016 Mini-grid Regulation stipulates a negotiated tariff agreement between developers and communities. While this was effectively executed in numerous communities, including Eka Awoke, Ozuzu, Akpabom, and Torankawa, some communities found it difficult to understand this process. In Adebayo community in Edo State, for instance, members acknowledged the inclusion of a tariff in the initial agreement with the mini-grid developer. However, they lacked understanding, having never experienced power supply before. Consequently, they accepted the tariff provision without complete comprehension.

In the actual implementation, developers set varied tariffs. In Adebayo community, the tariff for private households commenced at NGN140[22] per kWh, while commercial entities paid NGN160[23] per kWh. After 3 months, the tariff was surreptitiously increased to NGN172.40[24] per kWh for commercial entities and NGN208.[25] per kWh for private households. The community also reported an initial fixed connection cost of NGN5000,[26] which was later raised to NGN10000.[27] Despite these increases, users, especially those transitioning from petrol generators, found the costs affordable.

In Ozuzu community, users initially paid NGN100[28] per kWh, which was later increased to NGN138.8[29] per kWh after community discussions. Notably, there was no customer segmentation in this community, as all customers paid the same tariff per kilowatt-hour, with household and commercial customers paying N3,000 and N5,000 connection fees during connection, respectively. Regarding affordability, the initial subscription was as low as NGN50[30] per kWh, but it had now been raised to NGN100, the minimum amount of power a user could purchase. Users

22 Equivalent of $0.23 with the exchange rate of N600 to a dollar.

23 Equivalent of $0.96 with the exchange rate of N600 to a dollar.

24 Equivalent of $0.29 with the exchange rate of N600 to a dollar.

25 Equivalent of $0.35 with the exchange rate of N600 to a dollar.

26 Equivalent of $8.3 with the exchange rate of N600 to a dollar.

27 Equivalent of $16.67 with the exchange rate of N600 to a dollar.

28 Equivalent of $0.17 with the exchange rate of N600 to a dollar.

29 Equivalent of $0.23 with the exchange rate of N600 to a dollar.

30 Equivalent of $0.08 with the exchange rate of N600 to a dollar.

expressed satisfaction, affirming they did not face difficulties paying this amount.

In Gbamu Gbamu community, the tariff structure was grouped into residential, commercial, productive, and social. While the initial average tariff was around NGN160/kWh, the average tariff across these user categories at the time of the fieldwork stood at around NGN190/kWh, after consulting with the regulators. Tariff reviews at Gbamu Gbamu did not seem to be frequent, as the tariff had been reviewed upward only once as of the time of our visit. Also, the tariff was set to encourage more daytime usage by ensuring that daytime users got charged lower compared to nighttime users.

Akpabom community's tariff structure included fixed and variable components. Users paid a connection fee of NGN7,500, covering the meter and cables from the pole to the house. However, an unstructured tariff design existed: early connectors paid NGN270 per kWh, while later users reported receiving 4.3 kWh for an NGN1,000 credit unit. This discrepancy led to a shop owner leaving the community, citing excessive energy costs as being detrimental to her business profitability.

In Eka Awoke community, NGN2,500 was the lowest tariff for users to purchase 20 kWh of electricity. Users complained that this was usually insufficient unless used solely for lighting and phone charging and could not last more than 4 weeks. Additionally, there was a one-time connection fee of NGN10,000, excluding the cost of wires. Those costs posed challenges in a community where subsistence farming is the predominant productive engagement, affecting households and effective users. A welder in the community even voluntarily disconnected from the mini-grid, stating that spending over NGN20,000 monthly on power units did not contribute to his business profitability. Although some users acknowledged that the electricity from the mini-grid was cheaper for them than that from generators, overall affordability remains a significant concern.

7.5.3 User Perception of Mini-Grids

In nearly all the communities we visited, the respondents expressed overall satisfaction with the mini-grid's performance, particularly when the systems were functioning optimally to meet their energy needs. Some users also considered the tariff they were paying to be reasonable. However, these positive sentiments are rooted in the fact that several of those communities had gone

years without electricity, making the current situation an improvement on their previous conditions. This context may explain why, despite their contentment, all the communities visited advocated for a reduction in the tariff.

Amid this widespread approval, there were users who remained unconvinced of the significance of the mini-grid. For instance, many users in Torankawa exhibited indifference toward the mini-grid. From their perspective, there was minimal distinction between the period when they had power supply from the main grid and the period since the mini-grid became functional. The only noticeable difference for these users was the improved street illumination at night.

7.6 Lessons Learned and Limitations

Collaborating with the REA on the SIGMA project proved to be beneficial. The agency assisted with drafting introductory letters, which we subsequently sent out to prospective key informant interviewees in government and the private sector. This approach yielded positive results for our key informant interviews, as we successfully engaged with all the individuals we intended to speak to. However, the effectiveness of this strategy was limited in opening doors to engage with mini-grid developers. The challenges arose because it proved difficult to obtain access to respective mini-grid installations. Most developers are not physically present at their facilities in the communities, instead delegating responsibilities to operators or facility caretakers. Unfortunately, those individuals were often instructed not to grant interviews or permit the taking of pictures of the installations. Compounding this issue, only a few operators were willing to allow their technicians to provide information on the technical makeup of the mini-grids. Most developers found it very difficult to disclose information about their mini-grid systems. Consequently, the gathering of detailed information, especially regarding the technical aspects of many mini-grids (mostly for the data envelopment analysis undertaken by the team), was hindered.

Most of the mini-grids we visited are situated in remote villages several kilometers from the main roads. For example, it takes approximately 30 minutes to travel from the nearest highway to Adebayo community by motorbike, which is the fastest option. Traveling by car would entail waiting patiently at the motor park for about an hour, given the paucity of inbound traffic to the community. This is also the case for

Eka Awoke in Ebonyi State. Our trips to those communities proved physically demanding, especially as we had to make multiple trips to each community to ensure we could engage with all the relevant stakeholders.

Security emerged as a significant concern, particularly in the northern part of the country, where insurgency is prevalent. The mini-grids in Dakiti, Torankawa, and Mbela Lagaje are situated in regions marked by insurgency and banditry. Although we successfully conducted interviews in these areas, the engagements were characterized by a heightened awareness of risk. Our interactions in those communities were not as relaxed as they might have been in more peaceful environments.

Language posed a significant barrier in some communities, particularly during FGDs and household interviews. The majority of the villagers did not speak or understand English, which was the working language of the SIGMA team. To surmount this challenge, we adopted the strategy in each community of recruiting a local villager as an interpreter. This individual facilitated communication by conveying our questions to the villagers and, in turn, articulating their responses. Although this approach proved effective for data collection, it extended our engagement time in the communities beyond the initially budgeted field duration. Further, the approach increased the possibility of some details of the exchanges in those communities being lost in translation.

7.7 Concluding remarks

This chapter has provided the information related to primary data collection in Nigeria. The project team visited mini-grid sites, interacted with stakeholders and conducted key-informant interviews. The chapter has summarised the evidence collected, which is used in the subsequent analysis.

Reference

Yin, R. K. (2014). *Case study research design and methods* (5th ed.). Sage.

CHAPTER 8

Tanzania Fieldwork Report

Shukuru Meena,[1†] Maneno Katyega,[1] Mtendo Butije[1] and Estomih Sawe[1]

[1]TaTEDo—SESO, Dar es Salaam, Tanzania
†Corresponding author e-mail: shukurumeena@gmail.com

Abstract

As a project partner, the Tanzanian team undertook an extensive fieldwork and visited mini-grid sites in different parts of the country. During these visits, the team interacted with developers/promoters of the mini-grid and their users to gather relevant information about the projects. This chapter presents the background of each mini-grid visited by the team and offers a brief evaluation using the three dimensions considered in the project, namely governance, sustainability, and inclusivity.
Keywords: field visit, mini-grids, challenges, lessons

Acronyms

Ah	*Ampere hours*
CHP	*Combined Heat and Power*
COD	*Commission Operation Day*
CT	*Current Transformer*
DARESCO	*Dar es Salaam and District Electric Supply Company*
EASTRIP	*East African Skills Transformation Regional Integration Project*
ECOWAS	*Economic Commission of West Africa*
ECREE	*ECOWAS Center for Renewable Energy and Energy Efficiency*
EEP	*Energy and Environment Partnership (Finland)*
EPC	*Engineering Procurement Construction*

EU	*European Union*
EWURA	*Energy and Water Utilities Regulatory Authority*
FBO	*Faith-Based Organization*
Hh	*household*
Hrs	*Hours*
IPP	*Independent Power Producer*
Km	*Kilometer*
KPGC	*Kikuletwa Public Power Generation Company*
KPLC	*Kenya Power Lighting Company*
kV	*Kilovolt*
kVA	*Kilovolt Ampere*
Kw	*Kilowatt*
KWh	*Kilowatt hour*
MFP-SVO	*Multifunctional Platform—Straight Vegetable Oil*
MoE	*Ministry of Energy*
MW	*Mega Watts*
O&M	*Operation and Maintenance*
PPA	*Power Purchase Agreement*
PPP	*Public-Private Partnership*
PV	*Photovoltaic*
REA	*Rural Energy Agency (of Tanzania)*
REF	*Rural Energy Fund*
RC	*Roman Catholic*
SIGMA	*Sustainability, Inclusiveness, Governance of Mini-grids in Africa*
SMEs	*Small and Micro Enterprises*
SPP	*Small Power Producer*
SPPA	*Standardized Power Purchase Agreement*
SPPT	*Standardized Small Power Projects Tariff*
TANESCO	*Tanzania Electric Supply Company Limited*
TANWAT	*Tanganyika Wattle Company*
TaTEDO-SESO	*TaTEDO-Sustainable Energy Services Organization*
TPC	*Tanganyika Planting Company*
TPDC	*Tanzania Petroleum Development Company*
TSh	*Tanzania Shilling*

UNCDF	*United Nations Capital Development Fund*
USADF	*United States African Development Foundation*
US$	*United States Dollar*
VSPP	*Very Small Power Producer*
W	*Watt*
Wh	*Watt-hour*
w.e.f.	*with effect from*

1 USD = 2,700 Tshs (May 2025)

8.1 Introduction

TaTEDO-SESO of Dar es Salaam, Tanzania, a collaborating organization in the SIGMA project, was responsible for providing data specific to the Tanzanian context. The team, led by Engineer Sawe, has carried out fieldwork to collect information about mini-grids in Tanzania and analyzed the data and disseminated the findings through local events. This chapter presents the details of mini-grids visited by the team and a synthesized case study of each project in a standardized format.

Tanzania has set a target of 100% electrification access target by 2030. In 2023, the population was 61.5 million with 35% being urban and 65% rural. Electricity connectivity remained low, particularly in rural areas. In 2022, there were 176 mini-grids and embedded systems in 21 regions with a total installed capacity of 160.7 MW connecting 279,723 customers. Current challenges to mini-grid development in Tanzania include: limited data availability, lengthy and cumbersome planning and licensing processes, low level of coordination among the stakeholders, inadequate local capacity to develop mini-grids, and low affordability.

As part of the project activities, the team visited 18 mini-grids in 9 regions, 13 of which were operating and 5 were nonoperating, 4 were grid connected and 14 were decentralized, 4 coexisted with the national grid, 13 were private, 2 public, 1 public-private partnership, 1 faith-based organization (FBO), and 1 community owned (see Table 8.1). Visited mini-grids are powered by the following energy sources/technologies: 4 hydro, 1 wind, 2 biomass combined heat and power, 1 diesel, 1 straight vegetable oil/diesel, 4 solar PV, 1 solar PV + biomass gasification hybrid system, and 3 solar PV + diesel hybrid systems (see Table 8.2). The mini-grids are in 9 out of 26 regions, 12 supply isolated mini-grids while 6 supply

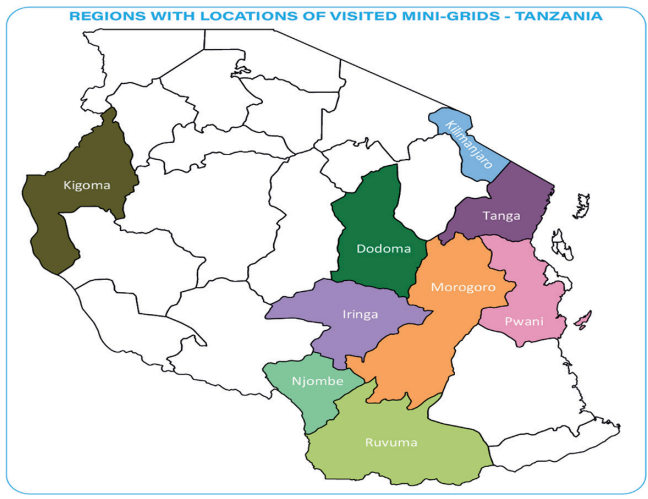
Table 8.1: Selected Mini-Grids by Technology and Ownership Model

Technology/ Energy Source	*Total Number*	*Ownership/Business Model*				
		Public	*Private*	*PPP*	*FBO*	*Community*
Mini-hydro	*4*	*1*	*2*		*1*	
Wind	*1*		*1*			
Biomass	*4*		*2*	*1*		*1*
Solar	*4*		*4*			
Hybrid systems	*4*		*4*			
Diesel and natural gas	*1*	*1*				
Total	18	2	13	1	1	1

the national grid, 2 are powered by 2 different energy sources/plants (see Fig. 8.1) but operate as integrated energy mini-grid systems one of which supplies a decentralized mini-grid and the other one supplies the integrated mini-grid as well as the national grid with excess power.

The organization of the chapter is as follows: After this introduction, the approach used in the fieldwork is briefly presented in Section 8.2 and the details of the cases visited are then captured in Section 8.3. Some concluding remarks are presented at the end of the chapter.

Figure 8.1: Visited Site Regions



Source: Authors compilation.

Table 8.2: Mini-Grid Location, Technology, Energy Source, Capacity, Operating Status, and Type of Operating Network

S/No	*Mini-Grid Name/Village*	*Energy Source/Technology*	*Region*	*Capacity kW*	*Operating Status*	*Connection*
1	*Tulila*	*Hydro*	*Ruvuma*	*5,000*	*Operating*	*Grid*
2	*Chipole*	*Hydro*	*Ruvuma*	*400*	*Nonoperating*	*Grid encroached*
3	*TANWAT*	*Biomass CHP*	*Njombe*	*1,500*	*Operating*	*Grid*
4	*Mwenga*	*Hydro*	*Iringa*	*4,000*	*Operating*	*Integrated mini-grid and grid*
	Mwenga	*Wind Power*	*Iringa*	*2,400*	*Operating*	
5	*Leganga*	*Solar PV*	*Dodoma*	*15*	*Operating*	*Coexists with grid*
6	*Ngutoto*	*Solar PV*	*Dodoma*	*15*	*Operating*	*Coexists with grid*
7	*Songambele/ Kitaita*	*Solar PV + diesel*	*Morogoro*	*6 + 8*	*Operating*	*Coexists with grid*
8	*Leshata*	*Solar PV + diesel*	*Morogoro*	*6 + 8*	*Operating*	*Coexists with grid*
9	*Mvuha*	*Solar PV*	*Morogoro*	*20*	*Nonoperating*	*Grid encroached*
10	*Biro*	*Biomass gasifier*	*Morogoro*	*50*	*Nonoperating*	*Grid encroached*
11	*Kibindu*	*Biomass gasifier + solar PV*	*Pwani*	*30 + 20*	*Operating*	*Coexists with grid*
12	*TPC*	*Biomass CHP*	*Kilimanjaro*	*17,500*	*Operating*	*Grid*
13	*Mji Mwema MFP*	*MFP Vegetable oil/diesel*	*Kilimanjaro*	*8.8*	*Nonoperating*	*Grid encroached*
14	*Kikuletwa*	*Hydro*	*Kilimanjaro*	*1,650*	*Nonoperating*	*Grid encroached*
15	*Kigoma TANESCO*	*Diesel*	*Kigoma*	*6,250*	*Operating*	*Integrated mini-grid*
16	*Kigoma NextGen*	*Solar PV*	*Kigoma*	*5,000*	*Operating*	
17	*Mpale*	*Solar PV + diesel*	*Tanga*	*8.8*	*Operating*	*Grid encroached*

NB: Mini-grid 4 comprises two renewable mini-grids located 55 km apart operating as an integrated system; in total, there are 18 mini-grids visited.

Source: Authors compilation.

8.2 Approach Followed for the Fieldwork

Immediately after the launch of the project, the COVID pandemic started, which required a significant adjustment to the planning and delivery of the project activities. There was also a budgetary adjustment due to a cut in the project budget subsequent to the reduction in international development budget by the UK government. The fieldwork was undertaken under these circumstances.

The fieldwork plan considered the budgetary and resource constraints, travel and logistical needs, health and safety issues, and approval and access issues, among others. A pragmatic approach was taken to cover different areas of the country and visit both operating and nonoperating mini-grids of different types of technologies, modes of operation, and ownership styles. The team initially established contacts with the operators and agreed on a visit schedule. The team also planned for interactions with users of the mini-grid at the site and developed a guiding template for semi-structured interviews with the participants. Interactions with households, small and medium enterprises connected to the mini-grids, and public institutions were planned. A purposive sampling technique was used, and references from participants through a snowballing technique were used to recruit additional participants. The sample size varied for each location due to availability of willing participants at the time of visit. However, the team has managed to collect relevant information to develop a nuanced understanding of the mini-grids visited.

The data collection process has adhered strictly to ethical guidelines, as outlined by both De Montfort University (DMU) and the University of Surrey. These ethical approvals from DMU and Surrey were taken, and the procedures outlined there were followed. Informed consent was taken from the participants, and the team explained the purpose of the interaction. The information presented in the chapter maintains anonymity of the participants, and no personally identifiable details are provided.

8.3 Mini-Grid Case Studies from Tanzania

This section presents a synthesized report of mini-grids visited by the team. A case study approach has been adopted, and all cases are reported using a common template. The synthesis relied on the team's observation on the site, views expressed by the participants, and any secondary information gathered at the time of the visit.

RUVUMA REGION

8.3.1 Tulila Mini-Hydro-Based Mini-Grid

8.3.1.1 Plant Development

Tulila is a 5 MW (2 × 2.5 MW) mini-hydro-based plant that supply a small mini-grid at 0.4 kV for own use at Mpepai village and is connected to Mbinga District, Ruvuma Region, and Tanzania national grid at 33 kV about 55 km away[1]. The plant has a rated head of 21.7 m and a rated discharge 13.3 m^2/s. Plant construction began in 2014. It was commissioned on September 15, 2015. Albert Korch from Switzerland owns 80% shares, and 20% is owned by Benedictine Sisters of St. Agness Chipole Tanzania.

Power plant financing came from Swiss bank credit US$18.5 million at 5% interest for 13 years, Albert Foundation US$0.75 million, Benedictine Sisters US$1,000, and labor contribution worth US$2 million (Bank guarantee). The land consisting of 500 acres each was purchased by Benedictine Sisters from Mpepai and Mipeta villages. The 33 kV line to Songea was funded by Rural Energy Fund and was erected by TANESCO. Planning, design, and construction were done by foreign experts assisted by local experts.

8.3.1.2 Governance

Tulila mini-grid is owned by the Tulila Hydro Electric Company Ltd which has an SPPA with TANESCO, an anchor customer, with most of its power sold to previously decentralized Songea–Mbinga–Namtumbo mini-grid network and currently the national grid via a standardized feed-in tariff provided by the regulator. The feed-in tariff is computed based on avoided costs of the off-taker. During 2015 to 2018, the tariff was TSh 480/kWh sold to the Songea–Mbinga–Namtumbo mini-grid. The tariff changed to TSh 180/kWh in 2018 following Ruvuma Region being connected to the national grid via a 220 kV line. Currently, the tariff is denominated in US dollars. The prevailing tariff is not cost-reflective. However, since plant's commission, the plant owners and operators have never defaulted on Swiss bank loan payments. Previous good

year's revenue accumulated is being used to offset current reduced revenue collections.

It should be noted that the plant does not directly supply any village. All nearby villages are TANESCO customers who are powered by Tulila mini-grid.

8.3.1.3 Sustainability

Financial Sustainability

Long-term financial sustainability of the mini-grid exists since it sells via power purchase tariff (PPT) its power to an anchor customer (TANESCO). However, the prevailing tariff needs to be revised regularly to be cost-reflective. Optimal revenue collection sometimes in the past was not reached due to anchor customers' insolvent situation—a situation that does not currently exhibit.

Technical Sustainability

O&M is undertaken by local experts—seven Benedictine Sisters assisted by two male employees. The plant is web-connected and monitored by Swiss experts. Minor maintenance is undertaken by local technicians consisting of one sister and two men, whereas major maintenance is done by foreign technicians.

Spare parts availability is a challenge as it has to be imported from overseas. They had experienced a breakdown of the circuit breaker in April 2021, which they had to order from outside the country; so, they had to stop the operation. In the meantime, in June 2021, the sisters were helped by ABB (the suppliers) of the particular spares to bypass the system and continue to produce while waiting for the required spare part. It was also informed in a month's time the card also blew, which had to be ordered from Switzerland.

Onsite training of plant operators was undertaken by two TANESCO experts from Kihansi and Kidatu Dams for 1 year. During that time, TANESCO experts were positioned at the plant to run the facility along with Benedictine Sisters. TANESCO experts left the plant when they were sure the plant owners had developed the capability to operate it.

Environmental sustainability requires the communities surrounding the project to disassociate or do not involve in deforestation activities, avoid agricultural practices that contribute to soil erosion and

siltation of the plant's reservoir, and collectively uproot bad weeds whenever they surface in the project catchment area. As part of the mini-grid social responsibility, the mini-grid has built four classes and one church.

The main challenge is water flow in the river substantially diminishes during August to November months affecting power production. Also, there is a coffee farm developed upstream—the plant has diminished water flow for mini-grid power generation.

Affordability

The current pan-territorial retail electricity tariff paid by end-user customers appears affordable.

Business Model

The prevailing business model whereby most of the electricity produced by the mini-grid is sold to the national grid based on the computed feed-in tariff made available by the regulator is financially sustainable as long as the prevailing feed-in tariff is regularly revised so that it is cost-reflective. There is a challenge of the mini-grid inability to produce at full capacity (only 3 MW) due to the reason that TANESCO has reduced the quantity of electricity bought from the mini-grid after the arrival of the national grid in the Region.

8.3.1.4 Inclusivity

During project development from site selection, plant construction, and O&M, the communities surrounding the project area have been closely engaged with the project. Compensation was paid in acquiring the project site. Gender balance was exercised during project development and during O&M whereby seven out of nine plant operators are women (Benedict sisters). Local content in the project was observed whereby Benedictine Sisters have 20% ownership of the plant.

The existence of the mini-grid in the area has had positive contributions, including employment creation for the village youths during the construction period as well as during clearance for the line way leave; electrifica-

tion has made village life more comfortable, improved services like health and education facilities, and has curbed rural-to-urban youth migration. Indeed, electrification has enforced social justice in the project community.

8.3.1.5 Challenges and Lesson Learned

Despite having the SPPA with TANESCO, the 11 Benedict Sisters living in 3 main houses do access electricity directly from the mini-grid at a different arrangement.

Tulila Dam head is 747.55 m and quality of electricity produced is 3 MW during a day from 8 a.m. to 10 p.m., and only one turbine remains on during the night to produce 2 MW.

The power plant has an option of adding another turbine of 2.5 MW.

It is a routine that every November in a year the penstocks and the trash racks are cleaned ready for the heavy rains, the effects of the water hyacinth are also controlled by cleaning 2 to 3 times during rain seasons.

Despite the awareness campaigns/education to the surrounding communities, there are water conflicts upstream with coffee plantations that lead to low water flows downstream, especially in the months of July to October each year.

There are times they face challenges with their computers and internet connectivity, so they are forced to do operations manually.

During the repair of the machines, the oil extracted is given for free to local technicians and villagers for other uses.

8.3.2 Chipole Mini-Hydro-Based Mini-Grid[1]

8.3.2.1 Plant Development

Chipole is a 415 kW (1 × 415 kW) mini-hydro-based plant that is connected to 11 km of 11 kV network at Magagura village in Songea District, Ruvuma Region, consisting of a Roman Catholic Church and mission, grain mill, edible oil press mill, a boarding secondary school, a day primary school, a vocational training school, and residential buildings for

[1] The plant was visited on September 14, 2021.

the various staff. Student enrollment: secondary school 400, primary school 400, trade school 10, and orphanage center 60.

During the period 1999 to 2000, feasibility studies were undertaken by local Tanzanian experts. Financing in a form of aid grant to Benedictine Sisters of St. Agness Chipole was secured during the 1990s from Robert Fuchs of Switzerland who had a passion for extending electrification access to rural areas. Plant construction began in 2000 and was commissioned in 2005. Plant equipment and construction cost was in the tune of US$200,000. The mini-grid is wholly owned by Benedictine Sisters of St. Agness Chipole.

Since March 9, 2021, to date, the plant has not been producing power following heavy floods that washed away part of the earth dam, and the machine hall was flooded.

8.3.2.2 Governance

The plant was developed as a faith-based (charity) business model. Chipole mini-grid owned and run by the Benedictine Sisters of St. Agness of Chipole was part of the Magagula Roman Catholic Mission. The plant had a committee responsible for O&M. Power was supplied free of charge to the Roman Catholic Community including a church, offices, schools, residences, and milling plants. There was no tariff set for end-users.

8.3.2.3 Sustainability

Financial Sustainability

Long-term financial sustainability of the mini-grid does not exist since the mini-grid does not receive any revenue; therefore, there exist difficulties in meeting operating and maintenance costs. At the time of field visit, financing for the repair of the plant had not been secured. Owing to the expected huge costs involved in the repair of the dam and power house, financing of the repair shall have to be accompanied by adoption of a sustainable and resilient business model to propel the hydro-based mini-grid.

Technical Sustainability

O&M was undertaken by local experts—Benedictine Sisters who were trained in Switzerland and are assisted by male employees. Minor maintenance was undertaken by local technicians. Major maintenance was done by foreign technicians. Spare parts availability was a challenge, as there were no proper funds available for such activities, and parts were imported from overseas. They often depended on the donor Mr. Robert Fuchs. In year 2006, the donor Mr. Robert Fuchs died and was succeeded by his daughter who continued to provide assistance. In such donor-dependent arrangement, technical sustainability of the mini-grid could not be guaranteed.

Training of the plant operators was undertaken in Tanzania by foreign experts who installed the plant. Also, whenever they ran into problems, they sought assistance from other experts in Benedictine Sisters–owned mini-grids, for example, Imiliwaha of Njombe.

Environmental sustainability of the mini-grid was questionable since communities surrounding the project are involved in deforestation activities, and agricultural practices along the river banks (water rights conflicts) contribute to soil erosion and siltation of the plant's pondage. The mini-grid had no social responsibility to the surrounding communities.

The main challenge experienced was intense floods that occurred in 2007 resulting in the plant machine hall being flooded for 3 months, and power generation was stopped as a result. Since then there was constant machine failures due to lack of spare parts and proper maintenance. On March 9, 2021, there occurred another intense flood that washed away part of the earth dam connected to the spillway (See Fig. 8.2). The concrete spillway remained with sustained cracks. Power generation was stopped.

Affordability

Electricity was provided free of charge for all those connected.

Business Model

This is a self-generation and donor support model, which is common among faith-based organizations in the country.

Figure 8.2: The Chipole Hydro Power Dam After It Was Washed by Floods



8.3.2.4 Inclusivity

During project development and implementation phase—from site selection, plant construction, and O&M—the communities surrounding the project area have been closely engaged with the project. Compensation was paid in acquiring the project site. Water right and environmental clearance to go ahead with the project was obtained. Gender balance was exercised during project development and during O&M whereby some of the plant operators are Benedictine Sisters. Local content in the project was observed whereby Benedictine Sisters have 100% ownership of the plant.

Existence of the mini-grid in the area has had positive contributions, including employment creation to the village youth during construction period as well as during clearance for the line way leave; electrification has made village life more comfortable, improved services like health and education facilities, and has curbed rural-to-urban youth migration. Fishing was being practiced in the pondage. Indeed, electrification has enforced social justice in the project community.

Lessons learned include the following:

The dam was not built to optimal design due to financing shortages.
Construction period was 5 years due to funding difficulties.
The dam was built by a Chinese contractor based in Tanzania.
The dam failure is so huge that its repair may require it to completely be built afresh.
Financing solicitation for the dam repair is ongoing without much hopes.
Since March 2021, Chipole Network has been importing power from TANESCO whose monthly bill is about TSh 1.5 million.

NJOMBE REGION

8.3.3 TANWAT Biomass-Fired Mini-Grid[2]

8.3.3.1 Plant Development

TANWAT biomass-based (combined heat and power) mini-grid has existed since colonial times. During 1950s to 1995, it was based on a wood-fired steam engine technology that provided about 540 kW. In 1995, it was replaced with a 2.5 MW steam turbine technology employing the same amount of feed stocks. In both cases, the plants were developed to provide power to the mill for extraction and processing of tannin from the wattle tree backs, the saw mill, pole treatment plant, plywood factory, and a carpentry workshop. The plant also provides power to the offices, housing estate, and a hospital.

In about 1996, the mini-grid started selling excess power to TANESCO Njombe–Makambako–Uwemba decentralized diesel and mini-hydro-integrated mini-grid via a negotiated PPA. The negotiated tariff was slightly cheaper than TANESCO's own diesel-generated power. TANESCO grid was extended to the Njombe–Makambako–Uwemba mini-grid in 1998 following erection of a 220/132/33 kV substation at Makambako. As such, TANESCO stopped importing TANWAT power as its own grid power was much cheaper than TANWAT imports.

The World Bank, via TEDAP project, developed a standardized small power producer's regulatory framework that was nonnegotiable and would facilitate renewable mini-grids to sell power to TANESCO distribution networks via standardized feed-in tariffs to be set by the regulatory authority. As such on September 17, 2009, TANWAT was the first mini-grid to sign a SPPA with TANESCO, and power supply to TANESCO national grid started on June 15, 2010.

In November 2019, the turbine ruptured into pieces and generation stopped. The turbine failed due to reverse power that occurred and also the equipment had lasted its lifetime. Since then TANWAT has been importing power from TANESCO at an average bill of TSh 75 million per month.

During our visit on September 15, 2021, we observed a new 2 MW turbine and alternator system was being erected by local engineers and

[2] The plant was visited on September 15, 2021.

technicians. The old boiler would continue to be used. Development cost was TSh 4 billion. The plant was expected to be commissioned within 2 months. And would resume selling excess power of about 1.2 MW (864,000 kWh/month) to TANESCO and 0.8 MW (576,000 kWh/month) for own consumption. The SPPT during the dry season is TSh 243.73/kWh and during the wet season it is TSh 182.80/kWh. The plant is wholly owned by Mr. Ray from Kenya.

8.3.3.2 Governance

Tanganyika Wattle Company (TANWAT) is a private company that owns a large wattle tree plantation, a tea estate, a biomass-based mini-grid, a wattle processing factory, saw mill, pole treatment plant, plywood factory and carpentry workshop, offices, housing estate, and a hospital. The company is run by management under guidance of a board of directors.

Governance is via standardized small power producers' regulatory framework, standardized power purchase agreement, and associated standardized feed-in tariff set by the regulator.

8.3.3.3 Sustainability

Financial Sustainability

Potential for long-term financial sustainability of the mini-grid exists by selling power to an anchor customer via standardized feed-in tariff if it can be regularly revised by the regulator so that it is cost-reflective, and TANWAT mini-grid strives to minimize its operational costs.

Technical Sustainability

Mini-grid O&M was undertaken by local engineers and technicians. Spare parts availability was a challenge as they were to be imported from overseas. The staff are well trained and have long experience in running the mini-grid. Whenever they ran into major problems, they sought assistance from equipment manufacturers. Funds for O&M were allocated. With

the new turbine in place, operators will also be trained on how to run it for sustainable service provisions.

When the grid goes out, the plant has to synchronize with the grid and has to import power from the grid, which tends to be expensive if the grid goes out frequently and for long durations.

Environmental sustainability of the mini-grid could be maintained by implementing environmental safeguard standards being regularly given by the environmental regulator via regular environmental audits of the mini-grid. Also, the mini-grid is expected to maintain its social responsibility to the surrounding communities.

Affordability

Electricity produced is sold to TANESCO, and the customers pay based on uniform pan-territorial tariffs charged by TANESCO. TANWAT staff who stay in the company housing estate do not pay for electricity.

Business Model

TANWAT mini-grid operates on a private business model.

8.3.3.4 Inclusivity

The mini-grid has not allowed local content in ownership of the mini-grid. During project refurbishment with a new turbine and alternator system, the communities surrounding the project area have been engaged in one way or another for denied services and goods from the various factories that have stopped production. The surrounding communities are involved in wattle harvesting, and there is an out-growers' arrangement with the company. Gender balance has not been exercised during project development and during O&M.

From colonial times in the 1950s to date, existence of the mini-grid in the area has contributed to employment creation for youth in the surrounding village; electrification has made village life more comfortable, improved services like health and education facilities, and has contributed to reduced rural-to-urban youth migration.

Lessons learned include the following:

The TANWAT mini-grid PPA was suspended upon extension of national grid to the interconnected Njombe–Makambako–Uwemba mini-grid due to difficulties faced in renegotiating a tariff.

Standardizing SPPA and SPPT is key to the financial performance of the mini-grid.

When the grid goes out, the plant has to synchronize with the grid and has to import power from the grid, which tends to be expensive if the grid goes out frequently and for long durations.

IRINGA REGION

8.3.4 A Case Study on Mwenga Hydro- and Wind-Integrated Mini-Grid in Tanzania[3]

8.3.4.1 Background

This case study is a brief account of an integrated mini-grid system consisting of two different renewable mini-grid sources supplying power to both its own local mini-grid systems and the national grid. The focus is on the lessons learned on the integrated system's sustainability, inclusiveness to the society during its development and O&M processes, and how energy governance aspects are addressed.

8.3.4.2 Plants Development

Feasibility study, business plan, and construction of the project were undertaken by foreign companies. Project financing came from REF, EU, DFID, and World Bank. Project development was undertaken by Rift Valley Energy Company.

The 4 MW Mwenga hydro-based mini-grid at Itipi village in Mufindi District was commissioned in October 2012. It was integrated with the 2.4 MW Mwenga wind-based mini-grid located at Usokami village 55 km away commissioned in June 2020 (Fig. 8.3). The integrated mini-grid

[3] The hydro plant–based mini-gridS at Ifupila and Ludilo villages were visited on February 2, 2016 and April 5, 2025, respectively, and the wind-based mini-grid at Usokami was visited on September 16, 2021.

comprises 430 km MV and LV distribution network and 70 transformer stations. As of February 2022, the integrated mini-grid provided power to the Rift Valley Energy offices, housing estate, hospital, and to more than 5,000 customers in 32 villages in Mufindi District. Moreover, it supplied power to Luponde Tea estate and factory, whenever there was a power supply failure of the national grid.

The 4 MW Mwenga hydro-based mini-grid signed an SPPA with TANESCO on January 19, 2010 and started selling excess power to the national grid on October 21, 2012, employing standardized feed-in tariff issued by the regulator. During the dry season, the river flow is so low that Mwenga hydro plant cannot provide the national grid the contracted 4 MW power. Since June 2020, the 2.4 MW Mwenga wind plant supplements the hydro plant so as to meet the contracted capacity. Mwenga wind plant does not

Figure 8.3: Mwenga Mini-Grid Wind Turbines with Transmission Lines



have a signed SPPA with TANESCO. As such, the integrated mini-grid cannot sell more than the contracted 4 MW to the national grid.

Mwenga hydro- and wind-integrated mini-grid is wholly owned by Rift Valley Energy Company, which is registered in Mauritius and has activities in Mauritius, Zimbabwe, and Tanzania.

8.3.4.3 Governance

Mwenga hydro plants and wind plants are owned and operated by Rift Valley Energy Company. Others are Luponde Hydro and Suma Hydro plants, which are not integrated with the Mwenga Hydro- and Wind-Integrated Mini-Grid. The company is run by management under guidance of a board of directors.

Governance is via standardized small power producers' regulatory framework, standardized power purchase agreement, and associated standardized feed-in tariff set by the regulator as well as the national grid code.

Other governance aspects include environmental management in O&M aspects of the plants and power networks and health and safety.

8.3.4.4 Sustainability

Financial Sustainability

About 95% of electricity generated is sold to an anchor customer TANESCO via the feed-in tariff. As much 5% of the power is sold to customers located in the 32 villages via integrated mini-grid based on the regulated year 2022 tariff of TSh 100/kWh, which is the same as that of TANESCO for lifeline tariff (single phase D1) category consuming less than 50 units against 100 units for TANESCO customers. D1 consumers who consecutively exceed 50 units per month in less than 3 months pay a higher tariff of TSh 273/kWh. After 3 months they are automatically transferred to T1 single phase category. The tariff for large customers like domestic customers, factories, and grain mills in the 32 villages (single phase and three phase T1) is TSh 292/kWh (see Table 8.3).

It is to be noted that 5% of the energy distributed in its integrated mini-grid is largely used for lighting the households, as most of the consumers are on D1 lifeline category that is cross-subsidized by T1 category. Owing

Table 8.3: Energy Charge Tariff 2012 to February 2022 for Mwenga and TANESCO

Mwenga Integrated Mini-Grid			*TANESCO*		
Tariff Category	**2012–January 2022**	**February 2022**	**Tariff Category**	**April 1, 2016**	**February 2022**
	TSh/kWh	**TSh/kWh**		**TSh/kWh**	**TSh/kWh**
D1 < 50 kWh	*60.00*	*100.00*	*D1 < 75 kWh*	*100*	*100*
D1 > 51 kWh	*273.00*	*273.000*	*D1 > 75 kWh*	*350*	*350*
T1-1 phase	*234.00*	*292.00*	*T1-1 phase*	*292*	*292*
T1-3 phase	*234.00*	*292.00*	*T1-3 phase*	*292*	*292*

NB: The tariff is exclusive of VAT 18%, REA 3%, and EWURA 1%.

Source: EWURA, Rift Valley Energy.

to the low tariff paid by the customers, Rift Valley Energy often conducts energy efficiency awareness campaigns to its customers so as to minimize such consumption. It also provides incentives for productive energy consumption; for example, T1 customers' connection fees are lower than D1 customers (see Table 8.2) if their energy tariff is cost-reflective.

Connection fee is TSh 27,000, 25,000, and 150,000 for D1 single phase, T1 single phase, and T1 three phase connection, respectively (see Table 8.4). Upon receiving connection with a meter, each customer is provided with initial 50 energy units. In February 2022, there were more than 5,000 customers in the 32 villages.

Furthermore, existing customers can obtain loans to purchase efficient productive-use equipment supplied by the Rift Valley Energy Company, such as fridges, grain mills, oil presses, welding sets, hair saloon gadgets, and woodworking and carpentry gadgets. Reimbursement is done in monthly installments whereby during energy purchases a customer pays for energy as well as for loaned productive-use gadgets.

Potential for long-term financial sustainability of the integrated mini-grid exists by selling most of the power generated to TANESCO, an anchor customer via standardized feed-in tariff if it can regularly be revised by the regulator so that it is cost-reflective; furthermore, Mwenga hydro- and wind-integrated mini-grid strives to minimize its operational costs. The potential also exists to sell excess power from the 6.4 MW integrated system above the contracted 4 MW SPPA as well as expand the wind plant by additional 2 units of 0.8 MW each if the signed SPPA with Mwenga hydro can be renegotiated with the regulators' consent.

Technical Sustainability

Hydropower technology is robust, reliable, and durable. Wind technology is currently commercialized in many parts of the world. If both plants are optimally designed to resources availability, regular scheduled maintenance is undertaken, and optimally operated, the plants can last 20 to 30 years.

The integrated mini-grid O&M is undertaken by local engineers and technicians trained locally and abroad. Spare parts availability is not a challenge as adequate budget is allocated for importation from overseas. The staff are well experienced in running the integrated mini-grid. They are assisted by foreign experts who regularly visit the power-generating

Table 8.4: Connection Charges for Mwenga Customers

Tariff Category	October 2012–November 2018		December 2018–January 2022		February 2022	
	Application Fee TSh	Connection Fee TSh	Application Fee TSh	Connection Fee TSh	Application Fee TSh	Connection Fee TSh
D1	*5,000*	*150,000*	*5,000*	*150,000*	*0*	*27,000*
T1-1phase	*5,000*	*150,000*	*5,000*	*25,000*	*5,000*	*25,000*
T1-3phase	*5,000*	*380,000*	*5,000*	*380,000*	*5,000*	*150,000*

NB: The tariff is exclusive of VAT 18%; upon receiving connection, each customer is provided with 50 kWh.

Source: Rift Valley Energy.

plants. Whenever they run into major operational or maintenance problems, they seek assistance from equipment manufacturers.

Environmental sustainability of the mini-grid could be maintained by implementing environmental safeguard standards being regularly given by the environmental regulator via regular environmental audits of the integrated mini-grid. Also, the integrated mini-grid is expected to maintain its social responsibility to the surrounding communities.

Lessons learned include the following:

The Mwenga 4 MW hydro plant cannot supply the contracted power due to low river flows during the dry season.

Mwenga 2.4 MW wind plant supplements the hydro plant with part of its plant capacity being idle for a fair portion of the year with fair wind resources availability due to existing SPPA contract limitations.

The wind resources at Usokami has a potential for expansion with additional 2 × 0.8 MW wind units if the Mwenga Hydro SPPA can be renegotiated.

Standardized SPPA and SPPT are key to the financial performance of the integrated mini-grid.

Affordability

About 95% of electricity generated is sold to TANESCO and 5% is sold to customers who pay the same pan-territorial TANESCO tariffs including affordable lifeline tariff for monthly consumption of less than 50 kWh per month.

Business Model

A private business model is employed, with smart prepayment energy metering, and payment for energy services is made via cellphones. As regards single phase consumers of categories D1 and T1, they purchase electricity via pay-as-you-go web-based system. The same system is used for disconnecting the consumers when purchased energy is exhausted.

8.3.4.5 Inclusivity

The integrated mini-grid has not allowed local content in ownership of the mini-grid. During project development, the communities surrounding the projects were engaged in the project. Compensation was paid to project-affected people who gave their land to the project. Gender balance efforts have been exercised during project development and during O&M. There are four female technicians involved in the operation and maintenance of the MV and LV network. One female technician is involved in operation of the wind plant. There is no female technician involved in the operation of the hydro plant.

8.3.4.6 Customer Aspects

Households

Five households (hh) were interviewed in Mwenga Hydro premises and six households in Mwenga Wind premises. Average age of interviewees was 40 to 45 years. All households use firewood and charcoal for cooking with none on e-cooking. On average, each household has five to six bulbs, one radio, one phone charger. As much 40% to 50% of households have TVs and fridges.

Productive Uses

Five SMEs were interviewed in Mwenga hydro premises and six SMEs in Mwenga wind premises. Average age of interviewees was 30 to 40 years. Productive usage involves grain milling, bakery, bars, shops, stationery, saloon, and welding workshops.

Common electrification challenges experienced by customers:

Power supply reliability is poor with several power cuts in a day especially during the wet season.
Frequency and voltage drops especially on Saturdays and Mondays.
Tariff increase in 2022.
Energy meter shortage.
Wooden poles shortage.

Sometimes, purchased energy units do not get coded in the meter and therefore it is lost.
Customers complain that they are never informed of power cuts even during planned O&M of the plant or network.
The plant operators inform the customers of planned outages by WhatsApp messages to customers with smartphones.

Electrification contribution to the rural communities:

Existence of the mini-grid in the area has contributed to employment creation for youth living in the surrounding village.
Electrification has made village life more comfortable.
There is improved services like health and education facilities.
Electrification has reduced rural-to-urban youth migration.
Businesses and productive energy consumers' hours of service provision increased, income increased, customers pay lowered fee for services rendered, and customer relations have significantly improved.
Productive energy users have access to loans from the owners of the mini-grid.
The mini-grid provides better services than the national grid.

DODOMA REGION

8.3.5 Leganga Solar Mini-Grid[4]

8.3.5.1 Plant Development

Leganga 15 kW solar PV mini-grid was established in 2015 with Swiss government's financial support. In the said year, the mini-grid was supplying power to 60 customers. In August 2018, the plant failed to operate due to charge control unit malfunctioning, and power supply services came to a stop. The plant could not be repaired since there were not enough funds to finance its repair.

During the period December 26, 2021 to January 2022, the plant was repaired by ELICO Foundation from United States that privatized the mini-grid with consent of the Ministry of Energy on the obligations to

[4] The plant was visited on February 3, 2022.

rehabilitate the solar mini-grid and operate it on financial sustainability aspect. The repair consisted of replacement with new 23 solar panels[5] each of 270 W, 1 charge control unit, replacement of 11 electric poles, and replacement of 24 batteries each of 1,000 Ah. In February 2022, there were 64 connected customers receiving reliable power supply from a plant that was still on trial operation. Customers consisted of 4 small SMEs, 2 large SMEs, 3 public institutions, 52 households, and 3 churches.

In October 2021, national grid was extended to the village. Large productive users have been connected. Power supply reliability of the grid network is rather not satisfactory during the wet season.

8.3.5.2 Governance

The plant is registered by the regulator but is not regulated. During the period between 2015 and January 2022, the village community committee was responsible for management and revenue collection, leaving O&M to a contractor. Tariffs were agreed upon during the annual meetings. Revenue collection was poor since some of the customers did not pay for rendered services.

Since February 2022 tariffs are set by the power supplier, a private contractor and customers have shown commitment to pay for services rendered. The payments process was monitored online with support from locally based software development firm.

8.3.5.3 Sustainability

Financial Sustainability

Potential for long-term financial sustainability is there since revenue being collected can meet O&M costs. With more customer connections and use of smart metering and pay-as-you-go business model, there is limited potential for financial sustainability of the power services due to lack of productive users and/or anchor customer. The plans are from June 2022, to introduce other productive uses such as compressor, popcorn machine,

[5] Solar PV panels were broken by children hunting birds with their catapults.

milk chillers, so as to improve sustainable financial cash flow of the business. See Fig. 8.4 for a view of the site.

Figure 8.4: Containerized Leganga Solar PV Mini-Grid



Technical Sustainability

The solar mini-grid O&M is being undertaken by a village local technician. Spare parts availability is no longer a challenge as there are adequate spare parts available within the country. The staff are well trained and have long experience in running the solar PV plants.

Environmental sustainability of the mini-grid could be maintained by implementing environmental safeguard standards being regularly given by the environmental regulator via regular environmental audits of the mini-grid.

Affordability

During the period 2015 to 2018, electricity produced was expensive and not affordable to some of the households in the village; it is one reason why some of them remained unconnected. However, grid power is affordable via pan-territorial lifeline tariff.

Business Model

The mini-grid employs a private business model, with smart prepayment metering and pay-as-you-go billing and revenue collection system.

8.3.5.4 Inclusivity

Initially, the solar mini-grid was community owned, whereby participation of the community in the O&M process as well as tariff-setting and approval process was very inclusive. Following the community failure to repair the mini-grid due to lack of financial resources, the mini-grid was privatized. The privatization process did not consider land and other contributions made by the village community. Gender balance is not exercised, as there is a single male operator.

Lessons learned include the following:

The community-owned business model practiced during 2015 to 2018 lacked leadership and management capabilities, and as such revenue collection was poor, and, when the plant failed, they could not repair it due to lack of funds.

Flat-rate metering proved ineffective, since it did not encourage consumers to be energy-efficient in their electricity consumption.

The current private business model employing pay-as you-go billing and revenue collection system has opened up hopes for improved financial performance of the mini-grid.

The village is currently also supplied by national grid whereby five customers are connected to both the solar mini-grid and national grid.

Large productive uses cannot be supplied by the solar mini-grid due to capacity limitations of the solar plant.

Solar power sometimes exhibits weak illumination, flickering, and rarely is completely out during the day times.

Coexistence of the solar mini-grid and national grid requires the regulator to revisit existing regulations and rules. Alternatively, to enforce existing rules and regulations for entry and exit conditions of the mini-grids when the national grid encroaches their premises.

Financial sustainability of the plant though limited, improved revenue collection has also been contributed by water services and charges from the village water pump which is connected to the mini-grid. Customers

are charged TSh 100/ bucket of water and more than 4,000 animals at the village are charged TSh 50/animal when watered from village pump.

8.3.6 Ngutoto Solar Mini-Grid[6]

8.3.6.1 Plant Development

Ngutoto 15 kW solar PV mini-grid was established in 2015 with Swiss government financial support. In the said year, the mini-grid was supplying power to 60 customers. During 2018 to 2022 the plant remained operational though often stopped needing restart.

During December 26, 2021 to January 2022 the plant was repaired by ELICO Foundation from USA that privatized the mini-grid with consent of the Ministry of Energy on the obligations to rehabilitate the solar mini-grid and operate it on financial sustainability aspect. The repair consisted of replacement with new 12 solar panels[7] each of 270 W, and 24 batteries each of 1,000 Ah. In February 2022 there were 53 connected customers receiving reliable power supply from the solar mini-grid.

In April 2021, national grid was extended to the village. Large productive users have been connected. Power supply reliability of the grid network is rather not satisfactory, especially during the wet season. Following repair, the solar mini-grid has become quite reliable except for failure to generate sufficient power due to insolation levels falling from clouds overcast.

8.3.6.2 Governance

The plant is registered by the regulator but is not regulated. During the period 2015 to January 2022, the village community committee was responsible for management and revenue collection leaving O&M to a contractor. Tariffs were agreed upon during the annual meetings. Revenue collection was poor since some of the customers did not pay for rendered services.

[6] The plant was visited on February 3, 2022.

[7] Solar PV panels were broken by children hunting birds with their catapults.

Since February 2022, tariffs are being set by the power supplier, and customers have shown commitment to pay for services rendered.

8.3.6.3 Sustainability

Financial Sustainability

Potential for long-term financial sustainability is questionable since revenue being collected cannot meet long-term O&M costs. With more customer connections—especially productive end-uses and use of smart metering and pay-as-you-go business model—there is potential for improved financial performance, and long-term financial sustainability remains questionable due to size of plant and plant not being able to provide service for much more productive uses of the power.

Technical Sustainability

The solar mini-grid O&M is being undertaken by a local technician from the village. Spare parts availability is no longer a challenge as there are adequate spare parts available within the country. The staff are well trained and have long experience in running the solar PV plants.

Environmental sustainability of the mini-grid could be maintained by implementing environmental safeguard standards being regularly given by the environmental regulator via regular environmental audits of the mini-grid.

Affordability

During the period 2015 to 2021, electricity produced was expensive and not affordable to some of the households in the village, and that is the reason why some of them did not connect. However, grid power is affordable via pan-territorial lifeline tariff.

Business Model

The mini-grid employs a private business model, with smart prepayment metering and pay-as-you-go billing and revenue collection system.

8.3.6.4 Inclusivity

Initially, the solar mini-grid was community owned whereby participation of the community in the O&M as well as tariff-setting and approval process was very inclusive. Following the community failure to repair the mini-grid due to lack of financial resources, the mini-grid was privatized. The privatization process did not consider land and other contributions made by the village community. Gender balance is not exercised, as there is a single male operator.

Lessons learned include the following:

The community-owned business model practiced during 2015 to April 2021 lacked leadership and management capability; as such, revenue collection was poor. The flat-rate metering that was being used was ineffective since it did not encourage consumers to be energy-efficient in their electricity consumption.

The current private business model employing pay-as-you-go billing and revenue collection system has opened up hopes for improved revenue collection; however, the financial sustainability of the mini-grid remains questionable due to the small size of the plant as it cannot service many of the productive uses.

The village is currently also supplied by national grid whereby seven customers are connected by both the solar mini-grid and national grid.

Coexistence of the solar mini-grid and national grid requires the regulator to regularly revisit and/or revise existing regulations and rules. One alternative in this case is to enforce existing entry and exit rules and regulations for mini-grids when their service area is encroached by the national grid.

MOROGORO REGION

8.3.7 Songambele/Kitaita Solar–Diesel Hybrid Mini-Grid[8]

8.3.7.1 Plant Development

Songambele/Kitaita 6 kW solar PV and 10 kVA diesel hybrid mini-grid was established in 2016 by PowerGen Company. In 2016, the mini-grid was supplying power to 103 solar customers. In May 2020, the national grid was extended to the village. Since then large productive users have

[8] The plant was visited on February 7, 2022.

been connected. In 2022, the number of customers connected to national grid was 103. There were 15 customers who received both solar and grid supplies. Power supply reliability of the grid network is rather not good.

8.3.7.2 Governance

The plant is registered by the regulator, but it is not regulated. Since power supply establishment in the village as of 2020, tariffs are set by the power supplier, and customers do pay for services rendered. Those who fail to pay for services are denied services.

8.3.7.3 Sustainability

Financial Sustainability

As the grid power supply offers a competitive and affordable tariff, the long-term financial viability of the plant becomes doubtful. The reliability of grid supply would play an important role here.

Technical Sustainability

The solar and diesel mini-grid O&M is being undertaken by a locally based technician from the village. Spare parts are available within the country. The staff have experience in running the solar–diesel hybrid power plants.

Environmental sustainability of the mini-grid could be maintained by implementing environmental safeguard standards being regularly given by the environmental regulator via regular environmental audits of the mini-grid.

Affordability

During connectivity, customers had to pay TSh 40,000, which included wiring of 1 bulb, and the electricity produced was expensive and not affordable to some of the households in the village; this is why some of

the households did not connect. The tariffs charged were TSh 1,000 per day, and after payment sometimes it may not activate to connect the customer. However, grid power available in the village is affordable via pan-territorial lifeline tariff. As such, customers have a choice of who to supply them.

Business Model

The mini-grid employs a private business model, smart prepayment metering, and pay-as-you-go billing and revenue collection system.

8.3.7.4 Inclusivity

The solar–diesel hybrid mini-grid is privately owned. Gender balance is not exercised, as there is a single male operator.

Lessons learned include the following:

- Mini-grid power services are not reliable with frequent outages, poor customer care, expensive tariff, and power supply is not available for 24 hours; when you purchase electricity, it takes at least 20 minutes to be connected. In case it is not connected, there is no means of re-activating the electricity token.
- When grid power is out, and there are only a few (less than 18) mini-grid customers who have paid for services the diesel genset cannot be switched on to provide power supply.
- Grid power supply is available for 3 to 4 days a week. As such, large productive users have installed own backup diesel gensets to address the problem. For households' level, others have turned to use of kerosene and batteries for lighting.
- The solar–diesel hybrid mini-grid coexists with national grid in the village so as to guarantee security of supply for customers especially SMEs connected to both systems.
- Coexistence of the solar mini-grid and national grid requires the regulator to revisit existing regulations and rules. One alternative is to enforce existing rules and regulations for establishment and operation of the mini-grids and the national grid.

The private business model employing pay-as-you-go billing and revenue collection system is a good business model for revenue collection.

Coexistence of the grid offering affordable tariff with the solar PV and diesel hybrid mini-grid offering expensive tariff cannot guarantee long-term financial sustainability of the mini-grid whenever grid power supply reliability is guaranteed.

Some customers use electricity for cooking via efficient electric pressure cookers (EPCs). This has proved the potential of mini-grids in addressing challenges of accessing clean cooking solutions in the rural.

8.3.8 Leshata Solar–Diesel Hybrid Mini-Grid[9]

8.3.8.1 Plant Development

Leshata 6 kW solar PV and 10 kVA diesel hybrid mini-grid was established in 2017 by Power Gen Company. In 2022, the mini-grid was supplying power to 155 customers consisting of 4 public institutions, 5 religious institutions, 21 SMEs, and 125 households. In August 2021, the national grid was extended to the village. Since then large productive users have been connected. In February 2022, grid-supplied customers numbered more than 200. Power supply reliability of the grid network was rather not good.

8.3.8.2 Governance

The plant is registered by the regulator, but in reality it is not regulated. Since power supply establishment in the village from 2017, tariffs are set by the power supplier, and customers do pay for services rendered. Those who fail to pay for services are denied services.

8.3.8.3 Sustainability

Financial Sustainability

[9] The plant was visited on February 7, 2022.

Potential for long-term financial sustainability is questionable, as the coexistence with the grid power supply that offers competitive and affordable tariff if grid power supply reliability is maintained.

Technical Sustainability

The solar and diesel mini-grid O&M is being undertaken by a local technician from the village who appears to be quite competent and experienced in running the solar PV and diesel hybrid plants. For reliability of power supply, the genset is serviced twice a year. Spare parts are available within the country.

Environmental sustainability of the mini-grid could be maintained by implementing environmental safeguard standards being regularly given by the environmental regulator via regular environmental audits of the mini-grid.

Affordability

Electricity produced was expensive and not affordable to some of the households in the village; hence, some of the households did not get connections. The operation costs are very high: a genset uses 5 litres of diesel per hour, which costs TSh 12,500. The consumers were charged TSh100/day for unlimited supply for all appliances in 1 hour, which costs TSh 12,500. The packages charged were expensive whereby a TSh 1,000/day was unlimited for all appliances. Due to customers' low ability to pay, a review was carried out, and, currently, three packages are offered with costs ranging from TSh 500 to 2,000/day. The difference is only in terms of numbers and types of appliances used by the customers. However, grid power available in the village is affordable via pan-territorial lifeline tariff. As such, customers have a choice as to who can supply to them.

Business Model

The mini-grid employs a private business model, with smart prepayment metering and pay-as-you-go billing and revenue collection system.

8.3.8.4 Inclusivity

The solar–diesel hybrid mini-grid is privately owned. Gender balance is not exercised, as there is a single male operator.

Lessons learned include the following:

Mini-grid power service is not reliable with frequent outages, expensive tariff, and sometimes power supply is not available for as long as 24 hours, and when you purchase electricity it takes at least 20 minutes to be connected.

When grid power is out and there are only a few mini-grid customers who have paid for services, the diesel genset cannot be switched on to provide power supply.

Grid power supply is available for 3 to 4 days a week. As such, large productive users have installed own backup diesel gensets to address the problem.

The solar–diesel hybrid mini-grid coexists with national grid in the village so as to guarantee security of supply for customers connected to both systems.

Coexistence of the solar mini-grid and national grid requires the regulator to revisit existing regulations and rules. Alternatively, existing rules and regulations can be maintained for establishment and operation of the mini-grids and the national grid.

The private business model employing pay-as-you-go billing and revenue collection system is good for revenue collection.

Coexistence of the grid offering affordable tariff with the solar–diesel hybrid mini-grid offering expensive tariff cannot guarantee long-term financial sustainability of the mini-grid, particularly whenever grid power supply reliability is guaranteed.

8.3.9 Mvuha Solar PV–Diesel Hybrid Mini-Grid[10]

8.3.9.1 Plant Development

Beginning in 2015, a solar PV mini-grid plant of 20 kW with 5.6 km distribution network was developed by Husk Power System company (HPS)

[10] The site was visited on September 22, 2022

Limited and was installed at Mvuha Village. It was commissioned in 2016. The number of customers initially provided with connections was 20, and the number increased up to 72, which included 60 households and 12 SMEs. The SMES (Small and Medium Enterprises) were stationeries, tailors, retailers, barbershops, and beauty salons. Village government office and other social centers were connected to the mini-grid.

In June 2020, the national grid was extended to the ward/village, which led most of the customers to abandon the mini-grid and got connected to the national grid network. This was due to both low connection costs and subsidized tariff charges. The energy system faced management and technical challenges that led to its shutdown in 2021. The owner sold it to another buyer, who disassembled it and shifted all the major components to other places. When the team visited the village in September 2022, only a few poles of the distribution network existed. This information was provided by the local operator who was working with the power plant.

8.3.9.2 Governance

The solar PV plant was neither registered nor regulated, particularly because its establishment, management, and setting of tariffs were done by the operator/ owner who presented tariffs and schemes at meetings with customers. The tariffs were categorized for households and businesses and were also based on the number and type of appliances and equipment used by a particular category of customer.

8.3.9.3 Sustainability

Financial Sustainability

Based on the challenges that emerged in the management of the solar PV power plant, the potential for long-term financial sustainability was lacking. The higher operational costs surpassed the revenues, which led to the retrenchment of some of the staff working with the system. Furthermore, the arrival of the national grid, which was offering an affordable tariff, encouraged the customers to abandon the mini-grid; hence, there was no revenue to sustain the operations.

Technical Sustainability

The **O&M** of the solar PV was undertaken by local technicians who were trained and had gained experience in system management aspects. There were no major technical issues experienced during the operations of the plant, and no challenges were faced in the availability of spare parts of the system, as spare parts were readily available in the market.

Affordability

Customers were connected to the mini-grid at a fee of TSh 55,000, which included house wiring with 2 bulbs, a socket, and a bracket. The customers were charged TSh 700 to TSh 1,000 per day based on the tariff category. This was expensive to some households and businesses; hence, some did not get connected. The arrival of the national grid with connectivity charges being TSh 27,000 and affordable lifeline tariffs to the majority led to a shifting wave from the mini-grid services.

Business Model

The mini-grid employed a private business model, with smart prepayment metering and revenue collection system.

8.3.9.4 Inclusivity

The solar PV system was privately owned, but the community was engaged from the beginning. Essentially, they were involved in the community mobilization meetings and site identification and selection processes to install the power plant. During system operations, gender balance was not observed as the operations were solely carried out by male staff.

Customer Aspects

Customers in the village were served by the national grid with affordable subsidized connection fees and lifeline energy charges. As such, productive

energy usage by SMEs mushroomed along with improved public institutions' services in health, education, and religious activities.

Lessons learned included the following:

The arrival of the national grid in the village, which is highly subsidized, led to a total shifting of the customers from mini-grid due to affordability issues, and this led to the beginning of the downfall of mini-grid business.

As the PV mini-grid components have been sold out, customers still face challenges of unreliable power supply; hence, some have gone back to using generators and other alternatives to access electricity.

Despite the reliability challenges of the grid electricity, the mini-grid developer could not see this as an opportunity to coexist with the grid to provide services when grid electricity is not available.

Despite being connected to the national grid since 2020, firewood and charcoal are the main sources of energy used for cooking in all families in this village. More awareness of the benefits related to e-Cooking is required.

8.3.10 Biro Gasifier Mini-Grid

8.3.10.1 Plant Development

The Biro Gasifier Minigrid Power system with 32 kW installed capacity was designed, developed, and constructed in year 2015 and then commissioned in 2016 at Biro village, Malinyi District, Morogoro Region. This was done in partnership with three organizations, which are Husk Power Systems, TaTEDO, and Spanish NGO-ONGAWA Engineering. This project was financed by the Energy and Environment Partnership (EEP S&EA) under the Finish government. The project cost was €263,950.

The 5.3 km distribution network was developed, and about 70 customers were connected. This included SMEs, households, primary school teachers' quarters, and the Catholic Mission dispensary and nurses' quarters. The project was also designed to have a section of production and commercialization of the briquettes using by-products from the gasification processes. The unit including the house to install the briquette machine was established, the briquette machine was installed and operated for sometime, but there were challenges in operations, such as lack

of feedstock availability unreliable power supply, and insufficient yield of biochar.

In year 2020, the national grid was extended to the village, and this led to a number of mini-grid customers opting out and connecting to the national grid whose tariff was low and affordable. The mini-grid stopped operations as a result.

8.3.10.2 Governance

The plant was developed under a build–own–operate arrangement between ONGAWA Engineering, Husk Power, and TaTEDO. The power plant was operated in partnership with Husk Power Systems, ONGAWA Engineering, TaTEDO, and Biro village government, under a rather loose form of PPP arrangement without proper documentation. The formulation of the Special Purpose Vehicle (SPV) was initiated, and the registration process with BRELA started but could not be formally registered due to numerous operational and management challenges that emerged in the process.

8.3.10.3 Sustainability

Financial Sustainability

Financial sustainability of the power plant was not possible because the number of connections to the mini-grid was not significant enough to generate revenues that could support operations. The mechanisms to collect tariff were implemented by the electricity committee that comprised representatives of village leadership and consumers of electricity. Revenue collection was challenging, as some customers did not pay on time; this posed challenges to the entire operations. If the briquettes business would have been operational successfully as expected, that could have assured stable financial flow and, hence, sustainability.

Technical Sustainability

The power plant was designed to use rice husks, and various tests were done to determine the calorific value of the husks produced within and

around the village. The operations of the gasifier required up to 16 bags of the husks to run the plant for 6 hours in a span of 16 hours to 22 hours. Enough feedstock availability was also a challenge, as there were times the feedstock had to be procured from outside the village for TSh 1,000/ bag. In plant operation, they also used petrol fuel for ignition start when batteries were at low voltage.

Another technical challenge experienced involved availability of spare parts; only some of them were available in the local market while others had to be ordered from India, which took a lot of time for some services to resume. Regular maintenance, approximately after every 2 weeks, was required, but this was challenging for operator to maintain. This was because there was not enough revenue collected to cover costs for replacement of some key items like oil, gas filters, and worn-out pipes of the gasifier.

Affordability

Service affordability was an issue for customers, as only 70 customers managed to connect even though the project had identified a potential to connect to more than 150 customers. The connection charges were TSh 20,000 per households. Payment of TSh 10,000 per month as the agreed tariff was also not affordable to some households as they defaulted several times. The connection charges were also perceived as high to some of the unconnected households but were affordable to SMEs and institutions. The connection charges covered for one ready board, two bulbs, one socket, and one earth rod. It was mandatory for the customers wiring to be done by the developer to assure quality and safety.

Business Model

Biro power plant was operated in the public-private partnership business model that involved the ONGAWA Engineering, TaTEDO, HPS, and Biro village government. In this model, the SPV was conceived and set for its registration to oversee the operations. This started by establishing the village electricity committee, which operated the system in transition to SPV whose registration did not mature.

8.3.10.4 Inclusivity

The project partners followed procedures by first involving the district authorities on the plans and identification of the village and later the villagers. The site identification, land allocation, involvement of the community on the project activities, and the formulation and registration of the SPVs and their operations were well stipulated and agreed with villagers.

The local artisans were involved in construction of the power house, the storage of the rice husks, and even the distribution network. Two of the village youth were employed as security guard and the operator, respectively. On the management of the operations, 40% of the electricity committee members comprise women.

Lessons learned include the following:

The project partners wanted to be sure on the energy generation from the feedstock; hence, several tests on the calorific values of the rice husks from the village and nearby areas were done. The tests were expensive, but there were no results availed to the community.

During the phase of power plant design, availability of sufficient feedstock from the village was not appraised; thus, the plant started to experience feedstock shortages after 9 months of operations. They had to buy rice husks from nearby villages, and transporting them proved to be expensive.

The gasifier operator was technically competent in electrical technology; thus, even after the mini-grid stopped its operations, he was subcontracted by the power utility to support on the immediate technical challenges, as TANESCO offices were far from the village.

It was learned that during site identification, a certain family at the village donated land with a verbal agreement that when the grid arrives the project will uproot the equipment and would hand over the powerhouse building to the land donor. This agreement was not honored when the national grid arrived; the gasifier was not working, the equipment was not uprooted, and that powerhouse building was not handed over to that family. If there was a written agreement, things could have been different.

PWANI REGION

8.3.11 Kibindu Gasifier–Solar Hybrid Mini-Grid[11]

8.3.11.1 Plant Development

The Kibindu Minigrid Power System was developed in 2015 by Sustainable Energy Services Company (SESCOM) Limited, which installed a 20 kW gasifier system under the support of the USADF Power Africa Grant. Initial number of connections was 21 customers, and the reliability of the power supply was low due to various reasons, including seasonal availability of the feedstocks. To increase the reliability of the electricity supply services, SESCOM and Husk Power hybridized the mini-grid in 2017 by adding another 20 kW of solar PV. After the hybridization of the power plant, the reliability of the power supply improved and enhanced the connectivity, which in turn led to an increase in the number of customers to 104. In the year 2020, the national grid was extended to the village, whereby some customers, in particular the SMEs, chose to have dual connections with both the mini-grid and the national grid.

8.3.11.2 Governance

The mini-grid was developed on a build–own–operate model. The system is registered by the regulator but is not regulated. The customer's tariff was based on the possession, type, and usage of appliances. The packages were billed on a weekly and monthly basis and were not affordable to the majority of customers.

8.3.11.3 Sustainability

Financial Sustainability

The arrival of the national grid in the village has provided customers with alternative electricity sources that assure productivity and financial

[11] The plant was visited on January 21, 2022.

sustainability. The mini-grid tariffs are higher, but the national grid tariffs are affordable. In view of the above, if the national grid power supply continues to remain reliable, the long-term financial sustainability of the Kibindu mini-grid is highly questionable.

Technical Sustainability

The gasifier plant was designed to use different types of biomass wastes, including maize cobs and rice husks. It used 6 to 7 bags of rice husks each weighing 30 kg to run the engine for about 4 to 5 hours. There were times when the feedstock was not enough to sustain the operations.

Some spares for the gasifier systems were available in the market while others had to be ordered from India, as the technology is still not common in the country.

The by-products from gasification and biochar were useful products for the briquette production; the developer had previously thought of introducing briquette machines as a mechanism for ensuring environmental sustainability. Prevailing various other national environmental safeguard guidelines and standards were being regularly followed by the operator.

This hybrid system was operated and maintained by a trained local technician who is based at the village. The schedule for the gasifier is maintained and adhered to according to the manufacturer's O&M manuals. The Venturi was maintained weekly, oil was changed every 2 months, and engine overhauling, including changing of pistons and valves, was done every 4 months based on the operating hours. As for solar components, there were regular checks on the batteries, inverters, and panels that were washed once a month, but dust was cleaned weekly.

During operation, there were challenges when the synchronization was taking place, shifting from solar PV to the gasifier caused power blackouts for some minutes before it stabilized.

Affordability

The rate of customer connectivity was very low in the first 6 months after the plant was installed; this was due to high connectivity charges and energy tariff. The customers paid TSh 50,000/per connection, including

house wiring. The package included one bulb holder, one switch, one bulb, one switch socket, one main switch, 5 m earth wire, one conduit pipe, earth rod, and 5 m of 1.5 mm^2 cable. Some villagers were not able to connect due to the high costs of electrical accessories. The developer had to explore other mechanisms that could help customers to easily connect. They installed a ready body in houses, which allowed connectivity, and customers could extend wiring in their houses at their own convenient time. Since there was the national grid and the tariff was affordable, some customers opted for both sources.

Business Model

The Kibindu mini-grid operated as a joint private business by SESCOM and Husk Power Systems. The connected customers were installed with the smart meters, and they purchased electricity using their mobile phones. The payment system was a computerized pay-as-you-go model; customers could see their balance of the paid charges at the powerhouse control room.

8.3.11.4 Inclusivity

During the setup of the mini-grid power system, villagers were involved in different steps, including participation in the meetings to decide on project site identification, distribution networks, and powerhouse/feedstock storage construction. Both the operator and the power plant guard originated from Kibindu. The plant was also operated by a female operator, which indicates how valuable gender balance and equality and inclusivity were for the developers.

Lessons learned include the following:

Since its installation and operation between 2015 and 2017, the power plant, especially the solar part, has been operated with minor technical challenges, and whenever such challenges arose, they were immediately solved. For the biomass gasifier, there have been some technical challenges that have led to the use of the solar part of the plant most of the time. The use of solar has been possible because of the small load to the mini-grid as there is not much productive use.

When there were low agricultural harvests, there were challenges in getting sufficient biomass feedstocks, which posed operational risks, especially on the gasifier power systems.

The gasifier–solar hybrid mini-grid coexisting with the national grid in the village guaranteed the security of supply for customers, especially SMEs connected to both systems. Despite the stimulated demand for other productive uses such as milling, carpentry, brick making, welding, and e-Cooking services in the village, the mini-grid system's capacity was small and, hence, it could not power all the machines.

The villagers appreciated the presence of the developers (both HPS and SESCOM), as their technicians provided immediate technical responses whenever there was a challenge even to the grid-connected houses, as TANESCO offices were more than 100 km away from the village.

There were issues such as low frequency and voltage with the gasifier power system, but the supply provided with the use of solar power plant system was much more stable.

KILIMANJARO REGION

8.3.12 TPC Biomass-Fired Mini-Grid[12]

8.3.12.1 Plant Development

Tanganyika Planting Company (TPC) biomass-based (combined heat and power) mini-grid has existed since 1930s colonial times. During the period between 1931 and 2010, it was based on a bagasse-fired steam engine technology. In 2010, it was replaced with a 17.5 MW steam turbine technology utilizing the same amount of feedstocks. In both cases, the plants were developed to process sugar from sugar canes, in order to provide power to the offices, workshops, irrigation pumps, hospital, primary school, secondary school, three mosques, six churches, a kindergarten, and housing estate. Owing to the boiler limitations, the plant could generate power only up to 14 MW. Also, there exist standby diesel generators of 2 MW and 4 MW.

[12] The plant was visited on April 22, 2022.

On October 6, 2009, TPC signed an SPPA with TANESCO, and the 9 MW contracted excess power supply to TANESCO national grid was commissioned on September 13, 2010.

Development cost for the plant could not be availed. Amount of excess power contracted is 9 MW. The SPPT during the dry season is TSh 243.73/kWh, and TSh 182.80/kWh during the wet season. As much as 75% shares of the plant are owned by Alteo Company of Mauritius, and 25% of the shares are owned by the government of Tanzania Mainland.

8.3.12.2 Governance

The company is run by management under the guidance of a board of directors. Governance is via standardized small power producers' regulatory framework, standardized power purchase agreement, and associated standardized feed-in tariff set by the regulator.

8.3.12.3 Sustainability

Financial Sustainability

Potential for long-term financial sustainability of the mini-grid exists by selling power to an anchor customer via standardized feed-in tariff if it can be regularly revised by the regulator so that it is cost-reflective as well as TPC mini-grid strives to minimize its operational costs. Revenue from electricity sales is of the order of 2 to 3 billion TSh per annum. Sugar production is about 100 tons per annum, which is sold at 2.8 million TSh per ton.

Technical Sustainability

Mini-grid O&M was undertaken by local engineers and technicians. Spare parts availability was a challenge as they were imported from overseas. The staff are well trained and have long experience in running the mini-grid. Most of the spare parts for the plant are manufactured at the company's factory. Others are imported from India. Whenever they ran into major problems, they sought assistance from equipment manufacturers. Funds for O&M are allocated.

Environmental sustainability of the mini-grid could be maintained by implementing environmental safeguard standards being regularly given by the environmental regulator via regular environmental audits of the mini-grid. For instance, the liquid waste from sugar production is processed at the open bio digester to lower the pH before it is drained to sugar cane estate as fertilizer. Also, the mini-grid is expected to maintain its social responsibility to the surrounding communities.

Affordability

Electricity produced is sold to TANESCO and the customers pay based on uniform pan-territorial tariffs charged by TANESCO. TPC staff who stay in the company housing estate and the connected institutions, that is, dispensary, do not pay for electricity. However, junior staff are allowed to use 100 kWh per month while senior staffs' consumption is not limited.

Business Model

TPC mini-grid operates under a private business model.

8.3.12.4 Inclusivity

The mini-grid has allowed local content in ownership of the mini-grid. During project refurbishment with a new turbine and alternator system, the communities surrounding the project area have been engaged in the project. Gender balance has not been exercised among the power plant staff recruitment, but it has been exercised in the network O&M whereby female staff are employed.

Lessons learned include the following:

- The TPC generating plant produces only 14 MW due to boiler capacity limitations.
- The generating plant is shut down during off-season, that is, April to May, so as to carry hindrance-free maintenance of the plant. If the plant had a redundant boiler, plant shut down could be avoided.

Standardized SPPA and SPPT are key to the financial performance of the mini-grid.

TPC bagasse-based mini-grid has contributed in employment creation for the youth in the surrounding villages; electrification has made peri-urban life more comfortable, improved services like health and education facilities, and contributed to reduced rural-to-urban youth migration.

8.3.13 Mjimwema Multifunctional Platform Straight Vegetable Oil/Diesel Mini-Grid[13]

8.3.13.1 Plant Development

Mjimwema Rosilini 8.8 kW Multifunctional Platform (MFP) straight vegetable oil- or diesel-powered mini-grid was established in 2012 with EU, HIVOS financial support and implemented by TaTEDO. The plant was installed and operated by the community group well known as Bank Imani Upendo. The plant was a representation of the early initiatives of promoting the productive uses of energy in off-grid areas using biofuel-powered solutions. The sets consisted of a 20 HP Lovson diesel engine and used for productive uses with machines used for milling, dehusking, oil press, and battery charging.

The 8.8 kW generator was supplying power to 25 to 38 customers in years 2012 and 2013, respectively. Straight vegetable oil from jatropha was the desired fuel for the genset. However, due to land and other farming issues, very few jatropha trees were planted in the village. As such, straight vegetable oil for the plant was not available. The plant had to run on expensive imported diesel fuel.

The plant was not registered by the regulator. Development cost for the plant and associated accessories was estimated to be US$50,500.

Daily fuel cost for power generation was in the range of TSh 525,000 to 703,000 per month. The operational costs included salaries for a plant guard, at TSh 100,000 per month; for plant operator, TSh 50,000 per month; and for repayment charges, TSh 200,000 every 3 months. Daily revenue collections were much less than operational costs. Customers complained that power supply services lasting between 6 p.m. and 10 p.m.

[13] The plant was visited on April 22, 2022.

was inadequate and the bills were very high. As such, seven customers left the MFP mini-grid and joined the scheme introduced by Mobisol Company to acquire solar PV systems of different capacities with flexible repayment terms in the village. Hence, the MFP mini-grid was running at a loss. Power supply services stopped on September 14, 2013.

High operational costs and stiff competition from solar schemes were the main contributing factors. A solar Mobisol connection cost was 250,000 TSh for 200 W metered power services, which was recovered as a loan in 36 months at TSh 71,000 per month. Though the solar option tariff proved cheaper than the MFP tariff, the solar service also wound up upon national grid extension to the Matadi and Mjimwema Rosilini area undertaken by REA.

However, grain milling continued until February 28, 2016, when it was stopped. High fuel costs and nonavailability of spare parts were the main contributing factors. By then monthly financial loss was in the tune of TSh 72,000 per month. In view of the circumstances, the village community entered into an agreement with an individual private person who repaired the MFP and was able to continue with grain milling services. Ultimately, the village community sold the MFP to the individual at TSh 7 million.

8.3.13.2 Governance

The village community group, popularly known as Bank Imani Upendo Group, owned and operated the facility and had a committee that was responsible for supervising the operator, revenue collection, and overall management of the MFP facility. Tariff was set during meetings with their customers. The tariffs agreed upon were not regulated by the regulator. The MFP facility was not registered by the regulator either.

8.3.13.3 Sustainability

Financial Sustainability

Potential for long-term financial sustainability was lacking due to higher operational costs that exceeded revenues and other problems such as difficulty in securing fuel and spare parts from distant major towns.

Technical Sustainability

MFP mini-grid O&M was undertaken by village local technicians. There were regular breakdowns of the engine, and spare parts availability was a challenge as they were to be purchased and transported from major towns in the country. The staff were well trained and had long experience in running the diesel plants.

Environmental sustainability of the mini-grid could be maintained by implementing environmental safeguard standards being regularly given by the environmental regulator via regular environmental audits of the mini-grid.

Affordability

Electricity produced was expensive and not affordable to majority in the village; this is a reason why about seven customers dropped out from the services. The MFP mini-grid was outshined by the solar PV systems introduced in the village by Mobisol, as they had flexible terms in repayments.

Business Model

MFP mini-grid operated under a community business model.

8.3.13.4 Inclusivity

The MFP mini-grid, being community owned, had 100% local content in ownership. During project development, the village community was closely engaged. Gender balance was exercised with female members in the organizing committee.

Lessons learned include the following:

MFP straight vegetable oil–fueled mini-grid failed due to nonavailability of jatropha plants that were supposed to provide the raw material for oil.

MFP-based mini-grid is fueled by expensive imported diesel and spare parts, and spare parts availability was a problem in rural areas, which rendered MFP mini-grids technically and financially unsustainable.

MFP diesel-based mini-grids cannot compete with solar-based mini-grids and systems in the same village.

MFP mini-grids and solar mini-grids cannot compete with subsidized REA power services connected to the national grid.

It turns out that Lovson engine that was installed was not very popular in Tanzania and a major reason for the failure is getting the required spare parts.

Lack of a clear biofuel policy by the time of the project implementation by then led to contradictions in information regarding benefits of Jatropha and its use potential in the operation of mini-grids and power systems.

8.3.14 Kikuletwa Mini-Hydro-Based Mini-Grid[14]

8.3.14.1 Plant Development

Kikuletwa is a 1.65 MW mini-hydro-based plant that is connected to the national grid at Kikuletwa hamlet, Chemka village, Hai District, Kilimanjaro Region. The plant was built and commissioned during colonial time of Tanganyika, a mandated territory to Great Britain, by a private individual who supplied power at Moshi in 1937 under an agreement with Dar es Salaam and District Electric Supply Company Limited (DARESCO). The said undertaking was purchased by DARESCO in 1950. DARESCO was owned by Tanganyika Electric Supply Company Limited (TANESCO) with majority shares of Kenya Power and Lighting Company Limited (KPLC) and minority shares of Tanganyika (currently Tanzania Mainland Government). In 1964, the government of Tanzania reached an agreement with KPLC to purchase all the shares it owned. Hence, the two power companies were merged to form a single company with a changed name of Tanzania Electric Supply Company Limited (TANESCO). Tanzania Mainland Government slowly purchased TANESCO shares and, by 1975, all the shares were public.

In 1989, the plant ceased to operate due spare parts nonavailability, as spare parts could no longer be purchased anywhere in the world. The original plant manufacturers no longer existed by then.

[14] The plant was visited on April 23, 2022.

Feasibility studies and construction and operation of the plant and network were undertaken by foreign experts. Nearby villagers were engaged as unskilled laborers during construction and operation. Later on, local staff were trained to operate and undertake minor maintenance leaving major maintenance to foreign experts. Financing for the plant development came from Europe the cost of which could not be retrieved easily.

In 2003, Arusha Technical College was given permission by the government to own the plant, refurbish it, and make it a renewable energy training center for Tanzania.[15] Arusha Technical College is receiving World Bank assistance via East African Skills Transformation Regional Integration Project (EASTRIP) benefiting Tanzania, Kenya, and Ethiopia. In Tanzania, recipient colleges and areas of excellence are Arusha Technical College, renewable energy; Dare es Salaam Institute of Technology (Dar es Salaam Campus), ICT; Dar es Salaam Institute of Technology (Mwanza Campus), tanneries technology; and National Institute of Technology (Dar es Salaam), aviation. EASTRIP aims at advancing accessibility of vocational training and improvement of infrastructure in the project areas.

EASTRIP has set up at Kikuletwa new project offices, classrooms, and hostels and provided various services like water supply and sanitation and electrification of the vocational college. Currently, a number of vocational students are benefiting from various courses being provided at Kikuletwa Renewable Center of Excellence.

Recently, a new company, Kikuletwa Public Power Generation Company, (KPGC) has been formed, water rights been renewed, and Environmental Impact Assessment (EIA) and Environmental Impact Management Plan (EIMP) have been conducted. A consultant was hired to redesign the plant layout and documentation work, and a contractor was engaged to construct a 1.65 MW plant as an SPP to supply power to an anchor customer TANESCO; the service was ongoing at the time of our study.

8.3.14.2 Governance

Kikuletwa mini-grid is to be redeveloped as an SPP by KPGC as a public project or by PPP arrangement depending on financing arrangements to be

[15] Considerations to include a solar PV plant, wind power plant and biogas plant as backup facilities at the center were indicated.

secured. As such, the existing SPPA, SPPT, national grid code, and associated rules and regulations for SPPs are to be followed. If PPP arrangement is secured, then KPGC will operate as a private company with private and public shares.

8.3.14.3 Sustainability

Financial Sustainability

Long-term financial sustainability of the mini-grid exists if development will culminate into an SPPA signed with TANESCO and SPPT arrangements that guarantee adequate revenue to the mini-grid.

Also, potential exists for the intact old plant to be made a tourist attraction so as to improve the financial sustainability of the plant.

Technical Sustainability

The old-generation plant is technically unsustainable due to nonavailability of spare parts. A refurbished plant with up-to-date and optimal inlet gates, water conveyance structures, turbine, generator, and control and switching equipment need to be relocated and installed. Training of the plant operators need to be undertaken, and adequate running spare parts need to be made available.

To maintain sustainable flow into the powerhouse during low-flow season, the mini-hydro is fed by two tributaries of Mbuguni and Kware rivers both of which originate at Mount Meru in Arusha. The two rivers join at the plant to form Kikuletwa River that ultimately drain into Nyumba ya Mungu Reservoir located downstream.

Various project stakeholders have been closely engaged by the project, and awareness campaigns are being conducted so as to ensure environmental sustainability of the planned mini-grid project. Communities surrounding the project are involved in activities to curb deforestation activities and avoid agricultural practices along the river banks that could contribute to soil erosion and siltation of the plant's pondage. Also the mini-grid will protect tourist attractions in the area, for example, the waterfall, Chemka hot spring, and the surrounding natural forest.

Affordability

Electricity to be sold via SPPT arrangements to TANESCO and end-use customers will benefit from TANESCO tariffs including affordable lifeline tariff.

Business Model

A public commercial business model is to be employed if KPGC is funded purely as a public utility. Alternatively, a private model will be employed if the project will be developed via PPP arrangements.

8.3.14.4 Inclusivity

The project development process—from EIA, EIMP, and feasibility studies to design and construction—is inclusive of various stakeholders—international, national, and regional to ensure surrounding villagers' interests are accommodated. Water rights have been renewed, gender aspects are observed in the EASTRIP projects, and, via KPGC, local content in the project will be observed.

Lessons learned include the following:

- Mini-hydro-based mini-grids are robust and have low O&M costs and long lives as demonstrated by Kikuletwa that operated from 1937 to 1989, roughly 52 years.
- To maintain sustainable flows into the powerhouse, two intakes from two tributaries of Mbuguni and Kware rivers are used and the two join at the powerhouse to form Kikuletwa River that drain into downstream Nyumba ya Mungu Reservoir.
- Out dated mini-hydro plants built many years ago are technically unsustainable due to unavailability of spare parts for O&M.[16]
- The Kikuletwa Renewable Center created employment for the population of the surrounding villages during its construction.

[16] Other mini-hydro plants built during the colonial times and are currently nonoperational include 1,220 kW Tosamagamga in Iringa Region, which was commissioned in 1951, and the 336 kW Mbalizi plant in Mbeya region, which was commissioned in 1958.

Gender aspects have been observed in the center's staff recruitment process, and students are being trained.

The Kiluletwa Renewable Center of Excellence is already providing much-needed vocational training to the youth in the district, and surrounding villagers sell some of the food and basic center's requirement thereby contributing positively to the community's economic development.

Potential exists to make the mini-hydro plant a tourist attraction for those interested in viewing outdated and obsolete plants.

KIGOMA REGION

8.3.15 Kigoma Diesel-Based Mini-Grid[17]

8.3.15.1 Plant Development

TANESCO, a public utility, owns and operates a 6.25 MW diesel plant that is located at Kigoma. Prior to 5 MW solar plant commission in March 2021, it was the sole source supplying the decentralized Kigoma–Ujiji–Uvinza mini-grid. Upon commission, the 5 MW solar plant was integrated with the 6.25 MW diesel plant via a dedicated 11.4 km 33 kV line. In 2021, the maximum demand in Kigoma was 8 MW.

In turn, the 5 MW solar PV plant is wholly owned by NextGen Solawazi Company registered in Tanzania.

The Ministry of Energy via REF allocated TSh 1.4 billion for erection of 11.4 km dedicated 33 kV line from the solar plant to TANESCO substation. The substation was also upgraded.

8.3.15.2 Governance

The plant was developed as a public property to be run commercially. TANESCO Company is run by its staff assisted by management team under the guidance of board of directors. Its operations and services are as per national grid code and national standards as monitored by the regulator. Customers pay for services as per authorized tariff by the regulator.

[17] The plant was visited on October 11, 2021.

8.3.15.3 Sustainability

Financial Sustainability

Diesel generation is expensive. Potential for long-term financial sustainability of the Kigoma–Ujiji–Kasulu mini-grid will involve substitution of diesel generation with cheap renewable solar PV generation commissioned in March 2021, connection to the national grid via Tabora to Kigoma 132 kV line under construction slated for end of year 2024, and commission of Malagarasi 49.5 MW hydro plant under construction slated for commission in year 2025. Moreover, TANESCO tariffs need to be cost-reflective.

Technical Sustainability

Diesel generation involves expensive imported fuel and spare parts requiring a lot of foreign currency. TANESCO technicians are experienced in running diesel plants. Often, inadequate supply of spare parts is one of the challenges experienced. Kigoma town is far away from fuel sources in Dar es Salaam, and this sometimes affects fuel supply logistics resulting in disruptive power supply or load shedding.

Air and soil pollution associated with diesel generation is a challenge for environmental sustainability of the diesel mini-grid, if environmental safeguard standards being regularly given by the environmental regulator via regular environmental audits are neglected.

The installed capacity of the diesel 6.25 MW and solar 5 MW hybrid system for Kigoma is in total 11.25 MW against the maximum demand of 8 MW. Load shedding has to be undertaken since the solar plant does not have the battery storage facilities to augment capacity provision during the night.

Affordability

All connected customers are served by TANESCO whereby lifeline tariff category exists for small consumption of less than 75 kWh per month at TSh 100/kWh.

Business Model

TANESCO is a public utility wholly owned by the government. Most of its retail domestic and small commercial customers are on prepayment metering system whereby customers pay upfront for energy services. Large customers are on credit energy metering, billed monthly, and pay for services rendered. TANESCO's energy services are regulated by the regulator. The tariff is set by the regulator.

8.3.15.4 Inclusivity

The diesel plant mini-grid is 100% public. During project development, EIA was undertaken. The communities surrounding the project area were engaged in the project. Gender balance efforts have been exercised during project development and during O&M. Some of the staff employed are female.

During plant erection, a number of people from surrounding community obtained employment.

8.3.16 Kigoma Solar PV–Based Mini-Grid[18]

8.3.16.1 Plant Development

The 5 MW solar PV plant is located at Kigoma Special Economic Zone. It is the first solar SPP in the country that sells power to TANESCO via a decentralized Kigoma–Ujiji–Uvinza mini-grid. The plant is integrated with the 6.25 MW TANESCO diesel plant located at Kigoma town by 11.4 km 33 kV line supplying power to 15,135 customers.

The 5 MW solar PV plant signed an SPPA with TANESCO on January 16, 2013 with expected COD in October 2016. However, construction started on May 17, 2017. Owing to construction loan disbursal timelines, and contractual dispute with the original EPC contractor, an alternate EPC contractor was hired to complete the project. Also, COVID travel restrictions contributed to project construction delays. These events necessitated a renegotiation of the PPA tariff with TANESCO. Commer-

[18] The plant was visited on October 10, 2021.

cial operation started on March 3, 2021, employing a revised PPA with TANESCO.

The 5 MW solar PV plant is wholly owned by NextGen Solawazi Company registered in Tanzania.

The Ministry of Energy via REF allocated TSh 1.4 billion for erection of 11.4 km dedicated 33 kV line from the solar plant to TANESCO substation. The said substation was also upgraded.

8.3.16.2 Governance

The mini-grid was developed on a build–own–operate model. The NextGen Solawazi Company is run by staff assisted by management team under the guidance of a board of directors.

Governance takes place via standardized small power producers' regulatory framework and negotiated power purchase agreement and tariff.

8.3.16.3 Sustainability

Financial Sustainability

All the NextGen Solawazi generated energy is sold to TANESCO mini-grid at the negotiated tariff of USc 9.24/kWh. Potential for long-term financial sustainability of the solar plant exists by selling power to an anchor customer (TANESCO mini-grid) via negotiated tariff. The potential also exists to expand the solar plant so that generation from expensive diesel plant can be further minimized or completely substituted if storage batteries can be installed at the solar plant.

Technical Sustainability

Mini-grid **O&M** is undertaken by local engineers and technicians trained locally and abroad. The local operators are running the solar plant assisted by a resident foreign expert. Spare parts are available.

Environmental sustainability of the mini-grid is maintained by implementing environmental safeguard standards being regularly given by the environmental regulator via regular environmental audits of the mini-

grid. Also, the mini-grid is expected to maintain its social responsibility to the surrounding communities.

The integrated solar–diesel hybrid mini-grid is facing the following challenges:

- The solar plant is a live production plant without storage battery facility; whenever solar insolation level is low, the diesel plant automatically switches on.
- Synchronization of the solar plant with the diesel plant is one of the initial major challenges faced due to problems of lack of experience in proper CT ratings resulting in frequent power interruptions when the solar plant operations began.
- Power supply is inadequate and not reliable; as such, the diesel plant is being expanded with additional 2 × 1.25 MW diesel sets to address the matter.
- Power quality is rather poor, and some customers complain of damaged electrical equipment due to power fluctuations, especially during the day time when the solar plant is running in initial months of solar and diesel plants synchronization.
- The solar and diesel integrated mini-grid capacity cannot meet Kigoma–Ujiji–Uvinza energy demands; hence, load shedding in some portions of the network occurs especially during peak load periods.

Affordability

All connected customers are served by TANESCO whereby lifeline tariff category exists for small consumption at less than 75 kWh per month at TSh 100/kWh.

Business Model

The solar plant employs a private business model with credit energy metering, jointly monitored and read by the solar plant and TANESCO staff once per month for billing and payment offset within specified period as per negotiated PPA. TANESCO is a public utility wholly owned by the government of Tanzania.

8.3.16.4 Inclusivity

The solar plant has not allowed local content in plant ownership. During project development, the communities surrounding the project area have been engaged in the project. Gender balance efforts have been exercised during project development and during O&M. Four out of 10 trained employees are female.

During erection of the solar plant, 170 people from surrounding community obtained employment. Also, solar PV panels' cleaning is done every 3 months by casual laborers from the surrounding community.

TANGA REGION

8.3.17 Mpale Solar–Diesel Hybrid Mini-Grid[19]

8.3.17.1 Plant Development

Mpale Solar–Diesel Hybrid Power System is located at Mpale village, Korogwe District in Kilimanjaro Region. The plant was developed by Ensol Limited and its construction was completed in year 2017. The power plant comprises a 48 kW solar power plant with a total of 192 solar panels, 12P charger controllers, 4 inverters of 32 kVA, and a total of 48 batteries that make a storage capacity of 265 kWh. The power plant generates electricity up to 70 to 80 kWh/day and is backed up with an automatic genset of 50 kVA.

The development of this system was co-financed by different partners at different stages, and 80% of the funding was from the USADF Power Africa, EEP under the Finish government, UNCDF, and Rural Energy Agency (REA), and 20% was a contribution of Ensol in the form of equity.

At the beginning of the operation, only 79 customers were connected, but as awareness and demand increased, the connectivity rose to 256 customers by the time of visit. The plant has potential and capacity to connect up to 500 households. The power plant operates 24/7 on all days of the week. The plant can connect large productive users, but, due to affordability and financial challenges, a few have connected to the mini-grid.

[19] The plant was visited on March 16, 2022.

8.3.17.2 Governance

The power system was developed as a build–own–operate model. Mpale Power System is registered by regulator, but in reality it is not regulated. The payments are prepaid; each customer has a card for making payments. New customer services are installed with load-limiter meters, so there are no monthly service charges paid by customers. The developer and the villagers have agreed on the tariffs structures grouped into categories and levels of households and businesses. Tariff level 1 and level 2 are for households and level 3 and 4 are for businesses. Level 1 tariff is for households which use 275 Wh/day, level 2 uses 276 to 550 Wh/day, level 3 is for businesses which use 1,100 Wh/day, and level 4 uses 1,650 Wh/day.

Due to the government's announcement on the adoption of uniform tariff charges for mini-grid, the operations of the power plant were affected by poor revenue collection, and it was closed for almost a year.

8.3.17.3 Sustainability

Financial Sustainability

The plant is capable of connecting up to 500 customers, but the number of already connected customers is still low, and the majority of customers use electricity for lighting and powering small accessories. This is not a good indication of revenue collection. To ensure financial sustainability, the developer has introduced loan schemes at a small interest rate to encourage customers to avail productive uses of energy. The loan was for equipment such as carpentry tools, compressors, refrigerators, television sets, barber and beauty salons, stationaries, and machinery. Since power supply is reliable, electricity consumption has increased, leading to an increase in revenues. Revenue collection was also a challenge after government ordered on adoption of uniform tariffs used in the national grid; as a result, revenue collection dropped from TSh 2,000,000/month to TSh 280,000–300,000/month.

Technical Sustainability

The Mpale power plant's feasibility study and project design was jointly done by the Spanish experts and Ensol technical team. However, the entire plant installation was done by Ensol experts. Ensol has built an

in-house capacity to handle a range of issues, and this has enabled them to undertake the O&M of the power plant using only technicians hailing from the local village. The operators have Grade I Test Certificates on electrical technology from Vocational Education and Training Authority (VETA). The power plant is located at a hilly area, which is not close to the villagers and also reduces risks of panels being stoned by children or any act of vandalism.

Some spare parts, especially for the load-limiter meters, are expensive; a single unit costs up to €100, and these are not available in the local market. Such meters are often affected by lightning strikes, and it may take up to 2 months to procure them from Spain.

Currently, there appear minimum challenges on the environmental front; the sustainability is well taken care of at Mpale power plant, especially when they are undertaking regular services of the diesel generator. They ensure that there is no contamination to the environment from the lubricating oil or diesel fuel in the process. If the accessories reach the end of their lifetime, the developer plans to sell them to authorized scrap metals dealers.

Affordability

Mpale villagers are farmers, and most of them cannot afford upfront connection costs. Developers got funds from REA, through result-based financing scheme that helped reduce connection cost, which initially was pegged to be between TSh 400,000 and TSh 200,000. Connected customer services included a ready body and a package of four lights as well as a socket for phone charging.

Furthermore, in view of affordability issues, tariffs were developed based on the level of usage at households and businesses. Households were paying TSh 11,000 to 20,000/month, while businesses were paying TSh 32,000 to 44,000/month. The government announcement on the adoption of uniform tariffs of TSh 100/kWh used in the national grid affected revenue collections and mini-grid operations but since Mpale customers already liked and needed the services, they discussed with the developer to ensure that their case was treated differently, whereby they paid TSh 100/kWh and the rest of the charges were treated like regular charges for services.

Business Model

The power plant is owned and privately operated by Ensol Limited. Customers are connected with load-limit meters and are provided with a card that is activated following payment for recharging the electricity units.

8.3.17.4 Inclusivity

The villagers were involved at different stages from the setting up of the project to sustainable and safety uses of electricity. The villagers agreed with the developer during the initial meetings on land provision, types of tariffs and modes of payment with tariffs set based on customers' ability to pay and the kind of electrical appliances they used. They also agreed that there will be no compensations to villagers for infrastructure way leave, but, nevertheless, there would be employment for the local technicians as operators. The local villagers were involved in the construction of distribution networks and the powerhouse. There has not been any community resistance to project activities; rather, political leaders have been using the power system as part of their political campaigns. The supervisor of the entire operation is a woman.

Lessons learned include the following:

- Inclusivity was vividly practiced when villagers decided and agreed to continue paying higher tariffs despite the government's order on adoption of uniform tariffs. This indicated the villagers' high level ownership in the existence of the plant, which was demonstrated with their appreciation for the high-quality services provided to them.
- The power plant has become a learning center for many researchers who come to study various aspects in relation to the mini-grids.
- The in-house technical capacity in the **O&M** of the power system has immensely contributed in reducing the overall operational costs.
- The Mpale power system is oversized, only 40% of its capacity is being utilized, and there is a need to plan for a bigger capacity power plant that can meet the current rise in demand and then expand it later as demand increases.
- Many other villagers are interested in venturing into productive uses, and developer is planning to procure such equipment needed for such purposes and also provide loans to them for financial sustainability.

8.4 Concluding Remarks

The fieldwork led to the following main conclusions:

Technical sustainability: Limited data for design is leading to over-or under-sizing of mini-grids. There is also lack of expertise to design and install mini-grids and to undertake major maintenance. The study team also learned about concerns related to spare parts availability and affordability, difficulties with obtaining operational data, and low mini-grid capacity utilization. These challenges are adversely affecting the technical sustainability of mini-grids in the country.

On environmental sustainability, soil erosion and siltation effects arise from hydropower projects, although water basin authorities and developers educate villagers on these issues. Sewage disposal systems availed by bagasse-based mini-grids raise environmental issues. The performance of solar-powered mini-grids was adversely affected during both monsoon (cloudy) seasons and drought seasons. End-of-life disposal of mini-grid components is a challenge.

Financial sustainability: Mini-grid financing is received through various channels, including through equity, grants, loans, and subsidies; credit facility and risk guarantee are not readily available. Securing financing for local developers is difficult as local developers lack capacity to prepare appropriate documentation required for loan or funding assistance. However, financial sustainability is guaranteed by selling electricity to anchor customers.

Inclusiveness: Due to limited capacity, local communities are side-lined; local communities are rarely involved in tariff-setting process, but gender inclusion in management and operation of mini-grids is observed. Mini-grid developers support social services as part of corporate social responsibility.

On governance, the local government authority at district levels is key to supporting land and water rights permits processing, and there is no decentralization in energy sector at the local level. Political directives have influenced the mini-grids development process, which is a concern to mini-grid developers. There is no example of any developer being compensated to date, and there is lack of coordination between agencies for licenses and permits to establish mini-grids.

PART 3

Mini-Grid Sustainability, Inclusiveness, and Governance Analysis

This part of the book presents frameworks and case studies to analyze sustainability, inclusiveness, and governance of mini-grids in Sub-Saharan Africa. This part contains the following chapters:

Chapter 9 presents the performance analysis of mini-grids using the Data Envelopment Analysis approach. The chapter presents the method and its application using a publicly available dataset.

Chapter 10 presents an indicator-based framework that can be used in contexts where data availability is an issue. The chapter provides a detailed guidance about the framework. The chapter applies the indicator-based framework to a sample of mini-grids in Kenya.

Chapter 11 presents the case of mini-grid governance in Nigeria with a focus on investments for electricity access expansion. It questions the suitability of current electricity regulations, mainly designed for a grid-based electricity system, for supporting electricity access in the country.

Chapter 12 presents a case study of tariff regulation in Tanzania, and Chapter 13 presents a study of household innovation and agency in sustainable energy transition in Kenya.

CHAPTER 9

Mini-Grid Performance Analysis Using Data Envelopment Analysis

Subhes C. Bhattacharyya[1†] and Daniel Kerr[1]
[1]De Montfort University, Leicester, UK
[†]Corresponding author email: Subhes.bhattacharyya@dmu.ac.uk

Abstract

In this chapter, we present the Data Envelopment Analysis (DEA) as an approach for the performance analysis of mini-grids. DEA has been widely used as a performance benchmarking approach but its application to mini-grids is limited until now. We apply the well-established quantitative assessment methodology to the energy access space, specifically for assessing the efficiencies of mini-grids in Sub-Saharan Africa. Our results indicate that mini-grids in developing countries are not operating efficiently and the scale efficiency is low. This suggests most mini-grids are far away from their most-productive-scale-size (MPSS). There is also spatial variation in the performance, as the ownership type influences performance. Going forward, the mini-grid sector in developing countries needs to consider the size of its operation to achieve better performance.

Keywords: Data envelopment analysis, mini-grids, Sub-Saharan Africa, electricity, electricity access

Acronyms

BCC	*Banker, Charnes and Cooper model*
CCR	*Charnes, Cooper and Rhodes model*
DEA	*Data Envelopment Analysis*
DMU	*Decision Making Units*
ESMAP	*Energy Sector Management Assistance Programme*

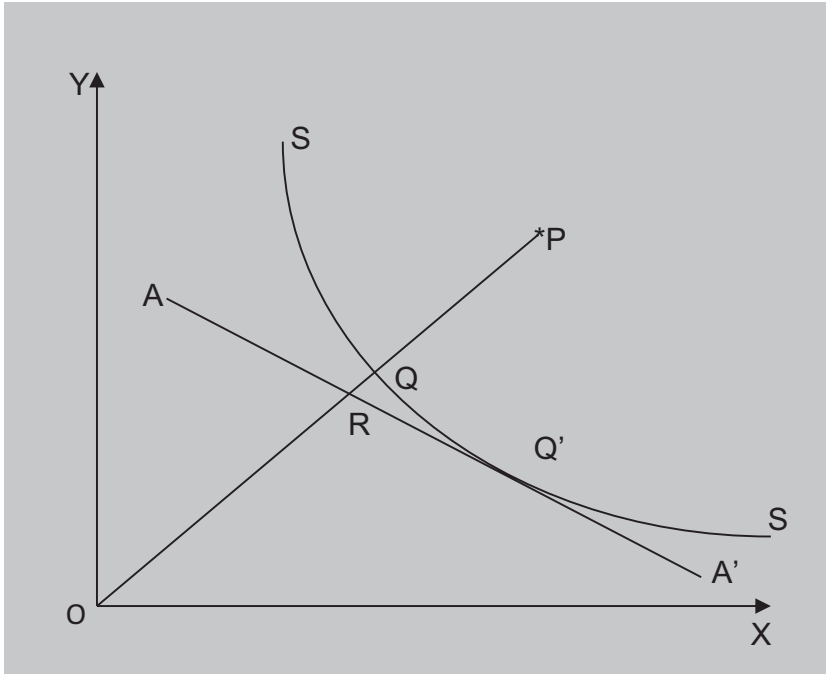
LCOE	*Levelised cost of electricity*
MPSS	*Most productive scale size*
OSDEA	*Open-Source Data Envelopment Analysis*
PPP	*Private Public Partnership*
SBM	*Slack-based measure of efficiency*
SDG	*Sustainable Development Goal*

9.1 Introduction to Productive Efficiency Measurement

Significant progress has been made in recent years toward achieving the UN Sustainable Development Goals and, in particular, SDG7 on clean energy access. However, if the goal of universal access to energy is to be met by 2030, large-scale investment and rapid and significant action are needed. According to the IEA in 2022, approximately 733 million people still lack access to electricity globally (IEA et al., 2022). Electricity access in many low- and middle-income contexts is hampered with reliability issues and supply constraints. Supplies from off-grid and mini-grid solutions are often insufficient for meeting aspirational energy access needs, which results in various challenges to economic development (Bukari et al., 2023; Ulsrud, 2020). While frameworks such as the ESMAP Multi-tier Framework on Energy Access (ESMAP, 2015) have tried to account for variations in reliability, capacity, and service quality, there remains a gap in the assessment of the performance of energy access solutions, in technical, economic, and social terms. The paucity of evidence-based assessment of determinants of project or program success has been cited by Duran and Sahinyazan (2021b). This chapter seeks to apply a well-established quantitative assessment methodology known as Data Envelopment Analysis (DEA), to the energy access space, specifically in assessing the efficiencies of mini-grids in Sub-Saharan Africa. Applications of DEA methodologies to the performance analysis of distributed energy systems are limited in the literature, as are applications looking at electricity access in developing countries. The outcomes of this analysis will be used to propose technical, policy, and economic interventions to improve the efficiency of operation of mini-grids, reduce upfront capital costs, enable more efficient supply regimes, and create better energy access outcomes.

Performance benchmarking has become a common business practice, which is undertaken to understand the current performance of a given unit of production or service compared to its peers. The theoretical idea comes from the concept of economic efficiency, which in simple terms means producing as large an output as possible from a given set of inputs.

Figure 9.1: Measurement of Productive Efficiency



The seminal work of Farrell (1957) introduced the concept of using the "best results observed in practice" to estimate how efficient production function is. This is explained in Figure 9.1 below using a two-input case. This chapter applies the concepts of performance benchmarking to the delivery of electricity services via mini-grids in Sub-Saharan Africa.

Data envelopment analysis was initially proposed as a performance assessment methodology of a set of homogeneous decision-making units (DMUs) in the mid-1970s, through the work of Charnes et al. (1978). The authors presented a linear programming formulation of efficiency measurement that facilitated the development of a data-driven approach of performance measurement.

The main idea of DEA is to measure the relative technical efficiency of DMUs by a ratio of a weighted sum of outputs to a weighted sum of inputs, where the input and output weights are selected in a manner that no DMU can have an efficiency score greater than unity (Charnes et al., 1994).

This work has been expanded on significantly in the following decades. The initial CCR model assumed constant returns-to-scale, leading to Banker et al. (1984) proposing an alternative model for estimating variable returns-to-scale, and a method for determining the most-productive-scale-

size (MPSS) for DMUs. The BCC model assumes a convexity constraint, ensuring that theoretical units are of similar scale sizes to the measured units, enabling the calculation of the MPSS for individual DMUs.

Let us assume that SS' represents the various combinations of two inputs X and Y that an efficient firm uses to produce a unit of output (which in other words is known as the production possibility frontier). If a firm actually uses a combination of inputs represented by the point P, then the firm is using many more inputs compared to an efficient firm. To operate at the efficient level, it would have to use the combination of inputs that lies on the SS' curve. Assuming a constant returns-to-scale,[1] this efficient combination is given by the point Q. This means that the efficient firm would produce (OP/OQ) times more output from the inputs used by the company producing at point P. The ratio OQ/OP gives the measure of technical efficiency. But the firm has to use the inputs in a cost-effective manner as well. If AA' has a slope equal to the ratio of the prices of the two factors, then cost minimization requires that the firm produces where the cost function is tangent to the production possibility frontier (i.e., at Q'). This is different from Q, although both Q and Q' lie on the technically efficient production possibility. Therefore, if the firm chooses the input combinations represented by Q', it will reduce its cost by a factor OR/OQ, which is a measure of its price efficiency.

The overall efficiency is given by the product of technical efficiency and price efficiency (i.e., (OQ/OP) × (OR/OQ) = OR/OP). Had the firm chosen its inputs in a technically efficient and cost-efficient manner, its costs would be only a fraction OR/OP of what they are now.

In practice, the production possibility function of a firm is not known, and Farrell (1957) suggests that such a function can be constructed using observed data. The production possibility is then called the best-practice frontier. The above approach has led to the development of benchmarking as a new field of study that is still used in business analysis and regulatory studies.

Section 9.2 below details our review of literature on Data Envelopment Analysis applications to the performance analysis of renewable energy systems and highlights the limited applications to date in the analysis of mini-grid systems in developing countries. Section 9.3 describes our methodology and how different estimation approaches can be used to determine best-practice frontiers using DEA. Section 9.4 shows an illustrative application of the methodology using an open-access dataset of mini-grids in developing countries from Duran and Sahinyazan (2021b). Section 9.5 discusses the results

[1] Which implies that if inputs are increased by a given factor, the output will also increase proportionately.

of our DEA modeling work on this dataset and highlights the differences in terms of input- and output-oriented models and different returns-to-scale assumptions. Finally, Section 9.6 contains our conclusions from the research and our recommendations for policymakers and future research.

9.2 Literature Review of DEA Applications to Renewable Energy Systems

Several applications of DEA to the productivity benchmarking of renewable energy systems exist in the literature. Agrell et al. (2005) used DEA to develop a benchmarking model to compare regulatory regimes across the Scandinavian electricity networks. Kuosmanen et al. (2013) compared three different assessment methodologies (DEA, stochastic frontier analysis, and stochastic semi-nonparametric envelopment of data) in their analysis of benchmark regulation of the Finnish electricity distribution network. Gouveia et al. (2015) used a value-based DEA method, which links traditional DEA with multiple-criteria-decision analysis to benchmark the performance of maintenance and outages repair for a Portuguese electricity distribution company. Arcos-Vargas et al. (2017) assessed 102 small electricity distributors in Spain using three separate input-oriented DEA models, considering both constant and variable returns-to-scale.

In the renewable energy space, authors have used DEA to investigate grid-scale and national-scale renewable energy installations and renewable sources, as well as benchmarking the performance of specific technologies across multiple installations and, latterly, to assess the efficiency of different renewable energy mini-grid installations. Sueyoshi and Goto (2014) used both input- and output-oriented DEA models with variable returns-to-scale to analyze the performance of 160 grid-tied photovoltaic power plants in the United States and Germany. Wang et al. (2017) used both stochastic frontier analysis and DEA to assess the environment-adjusted operational performance of photovoltaic plants in the United States. Wu et al. (2018) assessed photovoltaic poverty alleviation projects in China using a three-phase model, integrating DEA with Pearson correlation coefficients and a Tobit regression analysis. Indeed, Tobit regressions and DEA are frequently combined in the literature, with Wu et al. (2016) using these combined methods to assess the efficiency of wind farms in China, and Sağlam (2017) using a two-stage DEA–Tobit analysis to assess the productive efficiency of large-scale wind farms in the United

States. Other forms of regression analysis have been combined with DEA in the literature; for example, Barros et al. (2017) used a virtual frontier dynamic range-adjusted DEA model alongside Simplex regression analysis to investigate the efficiency of Angolan hydroelectric power plants. Finally, Aziz and Chowdhury (2021) used a two-stage DEA model with Tobit regression to assess the performance of solar mini-grids in Bangladesh. The authors analyzed the performance of 21 solar PV mini-grids using both the CCR and BCC models, perform a slacks analysis (also referred to as a slacks-based measure of efficiency [SBM]), and use Tobit regression to explore the relationship between dependent variables, efficiency scores from the DEA models, and exogenous factors. Slacks analysis in this instance refers to the assessment of the distance of each decision-making unit that is not on the efficiency frontier from the efficiency frontier. Both models used in Aziz and Chowdhury (2021) were input-oriented, as the total market size of an individual mini-grid is limited, and the objective is to deliver electricity services in the most efficient way.

DEA applications to renewable energy system performance benchmarking have several themes in common across the literature. DEA models used in the literature tend to be mixed, with both constant and variable returns-to-scale models used extensively for different purposes. Different types of returns-to-scale models are also commonly combined to derive different levels of efficiency measure, with pure technical efficiencies being analyzed alongside scale efficiencies and slacks. DEA is also combined with regression analysis quite commonly in the literature. While this is not necessary for the methodology to produce robust results, it can offer some additional insights into the data: DEA in general produces more accurate results, but regression offers greater stability of accuracy of results (Thanassoulis, 1993). While it is common for models in the literature to feature multiple inputs and outputs, which is a strength of the methodology, Sueyoshi and Goto (2014) and Wang et al. (2017), for example, used a more limited set of input and output variables: three input and two outputs in the case of Sueyoshi and Goto (2014) and four input and one output in the case of Wang et al. (2017).

From the review, we have identified a significant gap in the literature relating to performance analysis studies relating to energy and renewable energy in Sub-Saharan African countries. Specifically for mini-grids, we have found only one comparable paper in Aziz and Chowdhury (2021), and for Sub-Saharan African nations, Barros et al. (2017) is the sole comparable study. DEA has been used to an extent in the performance analysis of energy production and distribution in industrialized countries, and

for distributed renewable energy systems, but applications to the problem space of mini-grid performance are limited. This chapter seeks to address that gap by providing an indicative example of the application of the DEA methodology to the global mini-grids sector.

9.3 Estimation Approaches for the Best-Practice Frontiers

In essence, the DEA methodology uses the observed data to identify the subset of DMUs that define the envelopment surface (efficient frontier). Those on this surface are efficient DMUs, and any DMU not lying on the surface is inefficient. The DEA analysis provides information on the sources and amounts of inefficiency. The efficiency scores are relative measures—derived relative to other DMUs in the dataset. This also implies that the efficiency scores will change if the sample size changes or if the assumptions behind the scoring methodology change. In addition, the geometry of the envelopment surface is determined by the model chosen. For example, the CCR model results in a piecewise linear, constant-returns-to-scale envelope surface. The proportionality rule of constant returns-to-scale also implies the efficient DMUs will lie on the rays like the one shown in Figure 9.1. The BCC model, on the other hand, uses a variable returns-to-scale envelope surface (Banker et al., 1984), which relaxes the ray assumption by adding a convexity constraint. Many more models and extensions have been explored in the literature; however, for this study, we are limiting ourselves to CCR and BCC models.

A further distinction is generally made with regards to optimization of inputs or outputs. When the analysis aims to maximize the output for a given set of inputs, the output-oriented model is used. On the other hand, when inputs are maximized to produce a given output, the model is termed as an input-oriented model (Cooper et al., 2007). In this study, we are using both the input-oriented and output-oriented models for comparing the performance of mini-grids.

Three separate aspects of mini-grid performance were considered in this study, namely, technical, economic, and social aspects. Different input and output variables are needed when considering each of these dimensions:

For the technical performance of a mini-grid, we considered output variables such as generation-per-unit capacity, user-per-unit capacity,

given the installed capacity, its renewable energy share, and other available data (such as hours of service and employee-per-unit capacity). Given the constraints on available data to perform this analysis, three technical dimensions were selected to move further with the analysis: capacity-per-person, renewable energy share of the mini-grid system, and system's age.

For the economic analysis, cost-per-unit of output or levelised cost of electricity (LCOE) is a desired output variable. Conventional input variables include installation cost-per-unit of capacity, employee-related costs-per-unit of capacity, fuel-related costs-per-unit of output, and so on; for this analysis, we used cost-per-watt delivered as an economic output variable.

For social performance analysis, data for suitable variables are not easily available. In an output-oriented analysis, in line with the universal electrification target, the share of households gaining access in the community can be considered. Reduced dependence on traditional fuels or percentage of increase in study time could be another desired outcome to consider. The capacity of the mini-grid and its renewable energy share could be the inputs for this dimension. Data availability remains an important challenge in this study. Commonly reported data include capacity, renewable energy share, and number of users. Cost data and social data are more difficult to find. Survey data can provide information at a given point in time, and the dataset can be limited as well. Faced with this challenge, we have kept the analysis simple and exploratory in this study and restricted the analysis to technical and economic dimensions.

9.4 Illustrative Case Applications

Duran and Sahinyazan (2021a) reported a global dataset of mini-grid projects covering both developed and developing countries. The data contain information about project location, year of construction, technology type, capacity, population served, and project cost estimates, among others. The data were used to conduct an econometric analysis of mini-grid projects, which was reported in Duran and Sahinyazan (2021b). This is a rich dataset that is available publicly and is suitable for illustrating the DEA application. This section presents the details of this analysis.

9.4.1 Data Selection for the Application

The above dataset includes mini-grids from developed countries, which are likely to have different characteristics compared to the mini-grids for electricity access being used in developing countries. As a first step, we have removed any project information from the developed countries. This reduced the sample to 83 projects.

We then extracted information relating to ownership type, installation date, installed capacity, renewable energy fraction in the capacity, population served, and installation cost of the project. Each project was identified using a code indicating the country of the project and its identification in the main data file. For example, In-9 implies the project was located in India, and it came from the ninth row of the metadata file. The ownership type was then coded as follows: private as 1, public as 2, public private partnerships (PPP) as 3, and community as 4. The age of each project was identified from the difference between 2020 and the installation date. Using installed capacity and population served, the capacity-per-person was calculated. In the absence of information on power produced from the plant, the cost-per-watt (calculated from the installation cost and installed capacity) is used as a proxy for the cost of generation. This is used as the output variable, and the remaining data were used as input variables, apart from the ownership type, which was used as a noncontrollable variable.

For generation capacity-per-capita, this variable represents the ability of a mini-grid to supply adequate power to the users of the system. The renewable energy share represents the environmental sustainability and low-carbon nature of the system. The age of the facility is used to capture the status of the technology, as older systems are correlated with less clean technologies and lower reliability. The cost-per-watt as an output is used to capture the affordability of the system for developers.

After processing data, it was noticed that two variables were reporting errors due to missing data. Accordingly, these points were removed from the set used for the analysis. The data used for this case are placed in Annex 9.1, which contains data for 81 projects. Ramanathan (2003) suggests that the number of DMUs in a sample dataset, in order for it to be representative, should be greater than three times the sum of input and output variables, or larger than the product of the number of inputs and outputs, both of which are true for this dataset. Table 9.1 presents the variables used in the analysis of this dataset. To perform the analysis, an open-source software package, OSDEA, was employed, and results were further analyzed in MS Excel (OSDEA, 2023).

Table 9.1: Variables Used in the Analysis of Duran and Sahinyazan (2021a)

Variable	*Unit*
Input 1	*Capacity/person (W/capita)*
Input 2	*Renewable Energy Share (0–1)*
Input 3	*Age (integer)*
Noncontrollable Input 1	*Ownership model (1, 2, 3, 4 for private, public, PPP, or community)*
Output 1	*Cost/watt (US$/W)*

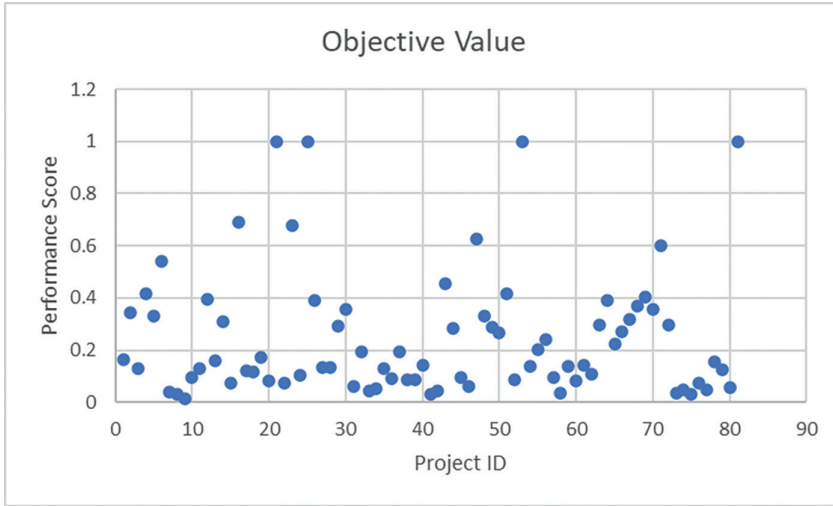
9.4.2 Results from the CCR Analysis

First, we have considered the output-oriented CCR model with cost-per-watt used as the output variable. This model optimizes for increased outputs for a constant level of inputs. The three inputs included were capacity-per-person, RE share, and age of the installation, with ownership type as a fourth, noncontrollable input. Using the above combination of inputs and output, four plants were found to be efficient. Four others received a score between 0.6 and 0.8. Another eight plants received a score between 0.4 and 0.6. The majority of the plants scored below 0.4. The scatter plot of the efficiency scores is presented in Figure 9.2.

As indicated previously, the efficient plants form the best-practice envelope, and, in our case, four plants were on this envelope. All other plants are compared against these efficient plants. Each plant is placed in a peer group composed of one or more of the efficient plants. This peer group represents the plant on the efficiency frontier that the plant in question is most similar to. The frequency of plants under different groups for the CCR analysis is shown in Table 9.2. Nam-104 has the greatest number of peers, followed by the group composed of Col-45 and Nam-104, and the group composed of Col-45 and N-76. This suggests that the greatest number of plants are most similar to Nam-104 in terms of their efficiency.

The closer to 1 the lambda value is for a given plant in relation to its peers, the closer to the peer the efficiency of the plant is, and the less the plant needs to increase its outputs to reach the efficient frontier for this output-oriented model. For the largest peer group, the peers of Nam-104, the highest lambda value reported was 0.5 for Ton-34, In-68, and CV-85, while the lowest non-zero reported value was 0.04, for Ken-58.

Figure 9.2: Scatter Plot of Output-Oriented CCR Efficiency



Slacks, when used in relation to models like CCR and BCC, are the additional improvements in input reduction or output maximization over that which is implied by the gap in efficiency score, which deals with increases in outputs or decreases in inputs equally across all input and output variables. The four efficient plants have no slack available in their input variables, meaning they are operating efficiently across all inputs. Other plants have some slacks, but the level of input slack varies by plant and by input, depending on the magnitude of the input variables. AS-7 illustrates this variance well, with slacks of 2,275.48 W/person in capacity, and 0.5 in terms of renewable energy share. This means AS-7 could maintain its efficiency while dramatically reducing its capacity in terms of watts-per-person, as well as reducing the share of renewable energy in the plant generation mix. This also highlights a limit of the analytical method: Higher renewable energy shares do not necessarily translate to more efficient plants in the analysis, and this needs to be accounted for when analyzing the results. For constant returns-to-scale models like the CCR model, the efficiency scores for the output- and input-oriented variances are the same, as the efficiency frontier does not change with regard to the orientation of the model. The peer groups for this analysis are also identical to the input-oriented model presented in Table 9.3. Examining the lambda values, however, provides additional insight into how the sample of DEAs is performing in relation to the efficiency frontier. For Nam-104 again, the highest lambda value reported was 0.12 for Tuv-53, and the lowest non-zero lambda was 0.0009 for MAU-13.

Table 9.2: Peer Groups and Plant Distribution

Peer Group	*Nam-104*	*N-76*	*Per-41*	*Col-45*	*Col-45 & N-76*	*Col-45 & Nam-104*	*Per-41 & Nam-104*	*Per-41 & N-76*	*Col-45, N-76 & Nam-104*	*Per-41, N-76 & Nam-104*	*All Efficient Mini-Grids*
Mini-Grids in Group	*23*	*1*	*1*	*2*	*17*	*18*	*11*	*4*	*2*	*1*	*1*

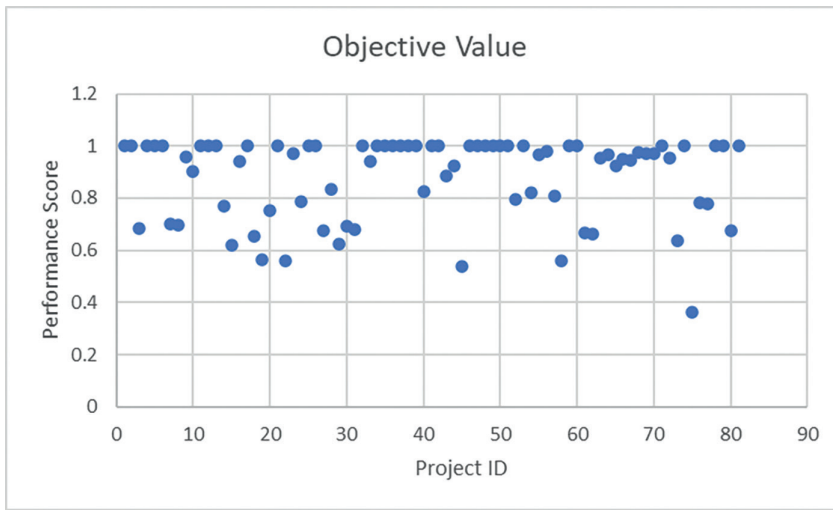
The overall trend of lambda values being smaller (closer to 0) is mirrored in the slacks for input-oriented model. Comparing AS-7 again, the W/person capacity slack is 293.01, and the renewable energy share slack has fallen to 0.06, both reduced dramatically from the output-oriented model. This indicates that, while individual plants themselves may have more to improve under an input-oriented model, and are further away from their peers, they are operating efficiently for their scale size under a constant returns-to-scale assumption.

9.4.3 Results from the BCC Analysis

The Banker–Charnes–Cooper model (BCC) represents an efficiency analysis from a variable returns-to-scale perspective. While the CCR model gives a pure technical efficiency measure, the BCC model accounts for the scale size of individual DMUs, and accounts for efficiency at all scale sizes, allowing for a determination of the MPSS of DMUs. If DMUs are operating at a scale size that is larger or smaller than what would be optimally productive for them, the BCC model accounts for and captures this inefficiency.

As many as 34 plants achieved an efficiency score of 1 in the input-oriented BCC analysis; however, only 14 of these plants are defined as efficient in the software output (Fig. 9.3). This is due to the presence of output slacks for the plants with perfect efficiency scores: an example of

Figure 9.3: Scatter Plot of Input-Oriented BCC Efficiency



this is H-6, which has a BCC efficiency of 1, but has input slacks in plant age, and output slacks in cost-per-watt delivered. Input-oriented BCC efficiency scores are significantly higher than those for the CCR analysis, which is consistent with the variable returns-to-scale assumptions inherent in the BCC model. The majority of plants score above 0.6 in this analysis, with some outliers: the worst-performing plant, Tan-98, has an efficiency score of 0.36.

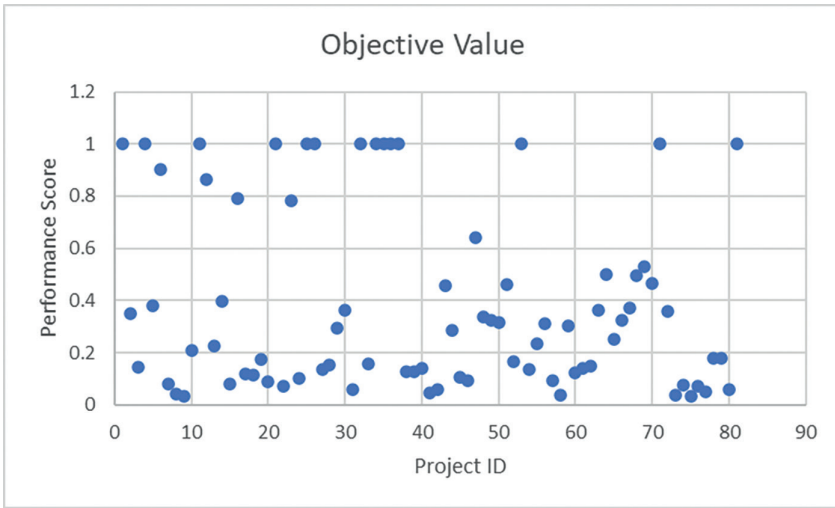
Compared to the CCR model, which had 11, the input-oriented BCC analysis has 39 separate peer groups. The largest peer group was for Per-41, which has 16 peers, followed by a combined peer group of Per-41, Ken-57, and MM-94. A total of 27 of these 39 peer groups had a single member, indicating a greater overall spread of peers on the efficiency frontier under the variable returns-to-scale assumption.

For Per-41, with the largest peer group, 16 plants had a lambda value of 1, indicating they were equally as efficient, while the largest non-zero lambda was 0.03. The 32 plants with non-zero lambda values to Per-41 exhibited an even spread across the range.

Fourteen plants are classed as efficient under the output-oriented BCC analysis (Fig. 9.4). No plants in this analysis have perfect efficiency scores but are not classed as efficient, indicating no output slacks for efficient plants at these scale sizes.

There are 33 peer group combinations for different plants in this analysis. Per-41 again has the largest peer group, with 16 peers, followed by a

Figure 9.4: Scatter Plot of Output-Oriented BCC Efficiency



group of Col-45 and Nam-104 together, with 7.23 of these 33 peer groups have a single member. Of the non-zero, non-one lambda values for Per-41, the largest is 0.96, with the smallest being 0.006. Seven plants have a lambda value of 2/3 (0.667).

9.4.4 Scale Efficiency of Mini-Grids

Using the CCR and BCC model outputs, we can now calculate the scale efficiency of the sampled mini-grids. Constant returns-to-scale efficiency scores, such as the outputs of the CCR models, represent the overall efficiency of the mini-grid, including both technical efficiency and scale efficiency. Variable returns-to-scale models, such as the outputs of the BCC models, represent the pure technical efficiency of the mini-grid, regardless of their current scale size. If we therefore calculate the ratio of CCR efficiency to BCC efficiency, we can determine the scale efficiency of the mini-grids, and investigate the MPSS for the assessed mini-grids. The results for the input-oriented scale efficiency and output-oriented scale efficiency analysis are presented in Figures 9.5 and 9.6 below:

In these analyses, the higher the scale efficiency score, the closer the plant is to operating at its MPSS.

Figure 9.5: Scatter Plot of Input-Oriented Scale Efficiency

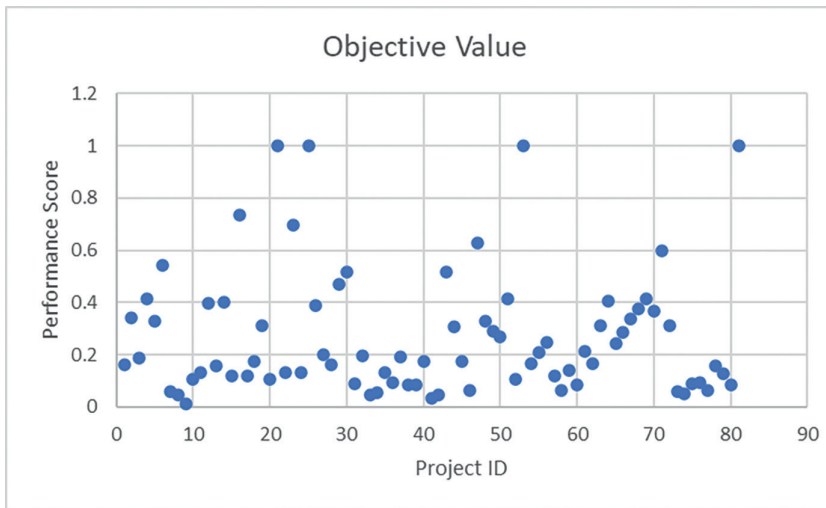


Figure 9.6: Scatter Plot of Output-Oriented Scale Efficiency

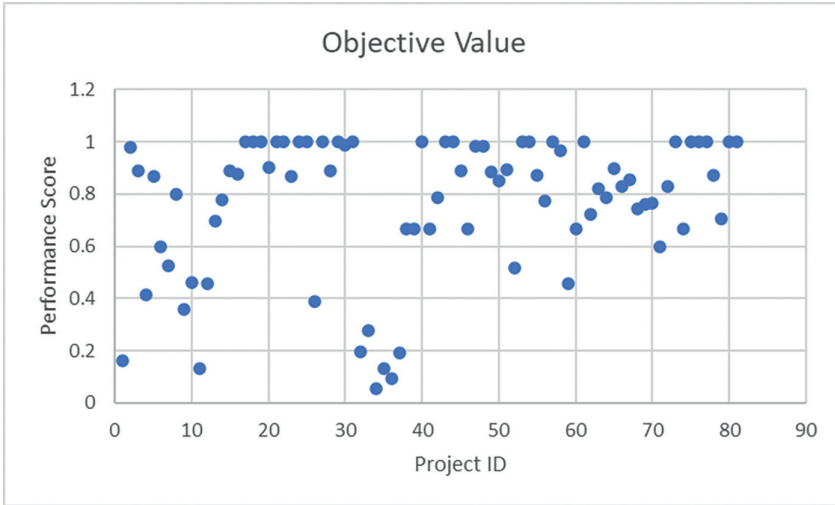


Table 9.3 presents the full results of the analysis, including CCR efficiency, input- and output-oriented BCC efficiency, and scale efficiency for the 81 mini-grids analyzed.

9.5 DEA and Mini-Grid Performance Benchmarking: Discussion

For the selected set of mini-grid DMUs from Duran and Sahinyazan (2021a), the CCR and BCC model results above provide some insights into how the productive efficiency of mini-grids can be improved. There are also interesting differences in performance depending on the geographic region the mini-grid is located in, as well as the ownership model that the mini-grid uses.

9.5.1 CCR, BCC, and Scale Efficiency Discussion

The CCR analysis produced only four efficient DMUs out of the sample of 81, which is a significantly smaller number than the number produced in the BCC analysis, which produced 14 efficient DMUs. While this is expected, the scale of inefficiency in mini-grids in the CCR model was not: The majority of plants scored below 0.4 in the CCR model, with only 12 of the 81 managing to score above this. This indicates that the

Table 9.3: Full DEA Results

Mini-Grid	*CCR Efficiency*	*BCC—Input Efficiency*	*BCC—Output Efficiency*	*Scale Efficiency—Input*	*Scale Efficiency—Output*
H-5	*0.162*	*1.000*	*0.162*	*0.162*	*1.000*
H-6	*0.342*	*1.000*	*0.342*	*0.342*	*0.349*
AS-7	*0.129*	*0.683*	*0.189*	*0.129*	*0.145*
In-8	*0.415*	*1.000*	*0.415*	*0.415*	*1.000*
In-9	*0.330*	*1.000*	*0.330*	*0.330*	*0.381*
In-10	*0.541*	*1.000*	*0.541*	*0.541*	*0.903*
Ma-11	*0.042*	*0.702*	*0.060*	*0.042*	*0.080*
CV-12	*0.033*	*0.699*	*0.047*	*0.033*	*0.041*
MAU-13	*0.012*	*0.960*	*0.013*	*0.012*	*0.034*
Per-16	*0.097*	*0.902*	*0.107*	*0.097*	*0.210*
Niu-17	*0.131*	*1.000*	*0.131*	*0.131*	*1.000*
H-20	*0.396*	*1.000*	*0.396*	*0.396*	*0.866*
In-21	*0.158*	*1.000*	*0.158*	*0.158*	*0.227*
Ch-24	*0.309*	*0.768*	*0.403*	*0.309*	*0.398*
Ton-34	*0.072*	*0.620*	*0.117*	*0.072*	*0.081*
Ton-36	*0.693*	*0.943*	*0.735*	*0.693*	*0.792*
Ind-37	*0.120*	*1.000*	*0.120*	*0.120*	*0.120*
Gua-38	*0.115*	*0.656*	*0.176*	*0.115*	*0.115*
Dom-Hai-39	*0.175*	*0.563*	*0.310*	*0.175*	*0.175*
Col-40	*0.081*	*0.751*	*0.107*	*0.081*	*0.090*
Per-41	*1.000*	*1.000*	*1.000*	*1.000*	*1.000*
Ecu-42	*0.073*	*0.559*	*0.130*	*0.073*	*0.073*
Mex-43	*0.676*	*0.972*	*0.696*	*0.676*	*0.781*
Col-44	*0.103*	*0.785*	*0.131*	*0.103*	*0.103*
Col-45	*1.000*	*1.000*	*1.000*	*1.000*	*1.000*
Chil-46	*0.389*	*1.000*	*0.389*	*0.389*	*1.000*
Nica-47	*0.136*	*0.674*	*0.201*	*0.136*	*0.136*

(*Continued*)

Mini-Grid	*CCR Efficiency*	*BCC—Input Efficiency*	*BCC—Output Efficiency*	*Scale Efficiency—Input*	*Scale Efficiency—Output*
Per-48	*0.135*	*0.834*	*0.162*	*0.135*	*0.152*
Fij-52	*0.293*	*0.623*	*0.471*	*0.293*	*0.293*
Tuv-53	*0.359*	*0.695*	*0.516*	*0.359*	*0.363*
Van-54	*0.061*	*0.678*	*0.089*	*0.061*	*0.061*
Ken-55	*0.196*	*1.000*	*0.196*	*0.196*	*1.000*
Ken-56	*0.044*	*0.942*	*0.047*	*0.044*	*0.159*
Ken-57	*0.054*	*1.000*	*0.054*	*0.054*	*1.000*
Ken-58	*0.131*	*1.000*	*0.131*	*0.131*	*1.000*
Ken-59	*0.093*	*1.000*	*0.093*	*0.093*	*1.000*
Ken-60	*0.192*	*1.000*	*0.192*	*0.192*	*1.000*
In-61	*0.086*	*1.000*	*0.086*	*0.086*	*0.128*
In-62	*0.086*	*1.000*	*0.086*	*0.086*	*0.128*
Ma-63	*0.142*	*0.823*	*0.173*	*0.142*	*0.142*
In-64	*0.031*	*1.000*	*0.031*	*0.031*	*0.047*
In-65	*0.046*	*1.000*	*0.046*	*0.046*	*0.058*
In-66	*0.456*	*0.885*	*0.515*	*0.456*	*0.456*
In-67	*0.284*	*0.925*	*0.307*	*0.284*	*0.284*
In-68	*0.094*	*0.540*	*0.174*	*0.094*	*0.106*
In-69	*0.062*	*1.000*	*0.062*	*0.062*	*0.093*
N-70	*0.628*	*1.000*	*0.628*	*0.628*	*0.639*
N-71	*0.329*	*1.000*	*0.329*	*0.329*	*0.335*
N-72	*0.288*	*1.000*	*0.288*	*0.288*	*0.325*
N-73	*0.267*	*1.000*	*0.267*	*0.267*	*0.314*
N-74	*0.415*	*1.000*	*0.415*	*0.415*	*0.463*
Fij-75	*0.086*	*0.794*	*0.108*	*0.086*	*0.166*
N-76	*1.000*	*1.000*	*1.000*	*1.000*	*1.000*
CN-77	*0.136*	*0.820*	*0.166*	*0.136*	*0.136*
Ken-78	*0.203*	*0.968*	*0.210*	*0.203*	*0.233*

Mini-Grid	*CCR Efficiency*	*BCC—Input Efficiency*	*BCC—Output Efficiency*	*Scale Efficiency—Input*	*Scale Efficiency—Output*
Ken-79	*0.241*	*0.981*	*0.246*	*0.241*	*0.313*
Ug-80	*0.095*	*0.810*	*0.117*	*0.095*	*0.095*
Ug-81	*0.035*	*0.562*	*0.061*	*0.035*	*0.036*
Ug-82	*0.139*	*1.000*	*0.139*	*0.139*	*0.304*
Ug-83	*0.082*	*1.000*	*0.082*	*0.082*	*0.123*
Ug-84	*0.142*	*0.668*	*0.212*	*0.142*	*0.142*
CV-85	*0.108*	*0.661*	*0.164*	*0.108*	*0.150*
MM-86	*0.298*	*0.955*	*0.312*	*0.298*	*0.363*
MM-87	*0.393*	*0.966*	*0.407*	*0.393*	*0.501*
MM-88	*0.226*	*0.924*	*0.244*	*0.226*	*0.251*
MM-89	*0.270*	*0.952*	*0.284*	*0.270*	*0.325*
MM-90	*0.319*	*0.943*	*0.338*	*0.319*	*0.373*
MM-91	*0.368*	*0.976*	*0.377*	*0.368*	*0.495*
MM-92	*0.402*	*0.972*	*0.414*	*0.402*	*0.529*
MM-93	*0.356*	*0.971*	*0.366*	*0.356*	*0.466*
MM-94	*0.599*	*1.000*	*0.599*	*0.599*	*1.000*
MM-95	*0.297*	*0.953*	*0.312*	*0.297*	*0.358*
Tan-96	*0.037*	*0.638*	*0.059*	*0.037*	*0.037*
Tan-97	*0.050*	*1.000*	*0.050*	*0.050*	*0.075*
Tan-98	*0.032*	*0.363*	*0.088*	*0.032*	*0.032*
Tan-99	*0.073*	*0.781*	*0.093*	*0.073*	*0.073*
Tan-100	*0.051*	*0.776*	*0.065*	*0.051*	*0.051*
Tan-101	*0.156*	*1.000*	*0.156*	*0.156*	*0.179*
Tan-102	*0.126*	*1.000*	*0.126*	*0.126*	*0.179*
Tan-103	*0.058*	*0.676*	*0.086*	*0.058*	*0.058*
Nam-104	*1.000*	*1.000*	*1.000*	*1.000*	*1.000*

majority of the mini-grids analyzed are operating inefficiently, assuming constant returns-to-scale. The BCC analysis with its variable returns-to-scale assumption indicates that more mini-grids are operating efficiently, particularly in an input-oriented analysis, where the majority of mini-grids are above 0.6 efficiency rating. This indicates output efficiency is good among the corpus; however input efficiency, as shown by the output-oriented model, is worse overall, with the majority of plants scoring below 0.4. This indicates further input efficiency is needed, to minimize inputs for the specified output levels. More efficient DMUs being present in a variable returns-to-scale model is expected due to the model accounting for variable returns-to-scale.

The scale efficiency results, however, show that there are significant efficiencies to be found in operating at the level of MPSS. The output-oriented models suggest that overall scale efficiency across the corpus is acceptable, but there remain 33 DMUS with scale efficiencies below 0.8. With an input-oriented perspective, no DMUs, apart from the four DMUs on the efficiency frontier in the CCR model, have a scale efficiency above 0.8, indicating that scale size issues are the driver of inefficiency in these mini-grids. In terms of slacks also, both input and output slacks exist for the orientations of the two models used. Input slacks are most common in the capacity-per-person of the mini-grids, and output slacks exist for the cost-per-watt delivered in both input-oriented models. This indicates that even if mini-grids were operating at their MPSS, there are further efficiency improvements to be found in optimizing the capacity-per-customer-served in mini-grids.

9.5.2 Geographic Differences in Mini-Grid Performance

Of the mini-grids on the efficiency frontier in the CCR model, two are African mini-grids and two are Latin/South American or Caribbean mini-grids. Specifically, one mini-grid from Nigeria and Namibia and one mini-grid from Peru and Colombia are on the efficiency frontier under the CCR model, with no Asia-Pacific mini-grids being fully efficient. However, efficiency scores under the CCR model are higher in the Asia-Pacific mini-grids, with greater numbers of poorly performing mini-grids in the other two global regions. Overall, however, CCR efficiency scores are low globally.

For the BCC results, input- and output-oriented models will be considered separately and exhibit different results. Nine out of the 31 Afri-

can mini-grids exhibit input-oriented BCC efficiency scores of below 0.8, with 17 being on the efficiency frontier, the best-performing region in this analysis. Eleven of the 34 Asia-Pacific mini-grids are efficient under the input-oriented BCC model, with 8 out of the 34 having scores below 0.8, meaning overall efficiency scores are higher than African mini-grids but peak scores are lower. Five out of the 16 Latin/South American and Caribbean mini-grids are efficient under BCC-input, with 7 of the 16 having scores below 0.8.

Similarly to the CCR analysis, output-oriented BCC scores are low for the majority of mini-grids; however, all regions have some mini-grids on the efficiency frontier. Seven of the 31 African mini-grids are efficient under this analysis, compared to 3 of the 34 Asia-Pacific mini-grids and 4 of the 16 Latin/South American and Caribbean mini-grids. Percentage-wise, Latin/South America and the Caribbean perform best; however, the Asia-Pacific mini-grids have the greatest number above 0.4, and between 0.2 and 0.4, while the majority of African mini-grids score below 0.2, and all other Latin/South American and Caribbean mini-grids score below 0.4, with 8 of 16 below 0.2. This indicates that, globally, output-oriented efficiency under the BCC model is low, with the Asia-Pacific region having a slight advantage, but all global regions assessed have room for improvement.

9.5.3 Ownership Models and Mini-Grid Performance

The original dataset also allows us to perform some analysis of the relative efficiencies of different mini-grids by ownership model. Four different ownership models are represented in the sample–mini-grids privately owned, publicly owned, community-owned, and under public-private partnerships. PPPs are the least well-represented in the dataset, with just five mini-grids under this ownership model, but otherwise the sample contains 21 publicly owned mini-grids, 24 privately owned, and 31 community-owned. Overall, community-owned mini-grids and privately owned mini-grids perform best under the CCR model, with publicly owned mini-grids performing less well overall. Under an input-oriented BCC model, privately owned mini-grids perform the best, with every example in the sample being on the efficiency frontier under this orientation. Publicly owned mini-grids also performed very well in this orientation, and while the overall performance of community mini-grids is still good, it was the

worst-performing out of the three ownership types with sufficient sample sizes. However, community-owned mini-grids performed the worst in the output-oriented BCC model, with publicly owned mini-grids performing the best.

In terms of scale efficiency, a notable result is that community-owned mini-grids operate at their MPSS much more frequently than other ownership types under an output-oriented configuration, with 23 of the 31 sampled operating at above 0.8 scale efficiency and 18 at the MPSS. This compares to 1 of 24 private mini-grids operating at their MPSS, and 3 of 21 public mini-grids. For an input-oriented configuration, scale efficiencies are low throughout, but community-owned mini-grids again show a performance advantage in terms of scale size. Nineteen of 31 community-owned mini-grids have a scale efficiency measure of 0.2 or above, compared to 12 of 24 privately owned mini-grids and just 5 of 21 publicly owned mini-grids.

9.6 Conclusions

This chapter has used the open-access dataset from Duran and Sahinyazan (2021b) to perform a Data Envelopment Analysis, determining the relative production efficiencies of mini-grids in developing countries across the world. Data for 81 mini-grids were extracted, and two separate Data Envelopment Analysis models were used to analyze the dataset. The Charnes–Cooper–Rhodes (CCR) model offered an analysis under a constant returns-to-scale assumption, while the Banker–Charnes–Cooper (BCC) model offered an analysis with a variable returns-to-scale assumption. This allowed for the determination of the MPSS for the mini-grids analyzed, by comparing the pure technical efficiency given by the BCC model with the technical and scale efficiency of the CCR model. Four inputs and one output variable were considered for this analysis, with the capacity-per-person-served by the mini-grid, the renewable energy share of the mini-grid, and the age of the mini-grid being used alongside a code for the ownership model of the mini-grid as inputs, and the cost-per-watt delivered as the single output.

This analysis has shown that there are significant issues present with the productive efficiency of mini-grids in developing countries. Compared to their peers in the dataset, the majority of mini-grids are inefficient, with a large number of mini-grids being very inefficient compared to their peers.

The input-oriented models in particular highlight this inefficiency: Input-oriented scale efficiency is low across the corpus, indicating that the majority of mini-grids are operating far away from their MPSS. Moving forward, the mini-grid sector in developing countries needs to assess the scale of their operations and determine whether increasing or decreasing returns-to-scale are present to expand or diversify their operations as appropriate.

DEA as a methodology shows promise in the analysis of productive efficiency in the mini-grids sector. Few articles in the literature have addressed this topic to date, the notable exception being Aziz and Chowdhury (2021). Access to reliable quantitative data is a challenge: Aziz and Chowdhury (2021) addressed this barrier by investigating a context where a public utility is the primary developer of mini-grids and, thus, has access to data as required to complete the analysis. Our secondary data analysis had to optimize for the data that were available; the diversified public sector and private sector developer contexts, such as much of Sub-Saharan Africa, present a challenge to the collection of reliable quantitative data. This presents barriers for implementing DEA as a methodology for productive efficiency analysis going forward, which need to be addressed if the sector is to become more efficient, deliver energy services on a more cost-effective and productive basis, and achieve the UN Sustainable Development Goals (SDGs) for energy access by 2030.

References

Agrell, P. J., Bogetoft, P., & Tind, J. (2005). DEA and dynamic yardstick competition in Scandinavian electricity distribution. *Journal of Productivity Analysis*, *23*(2), 173–201.

Arcos-Vargas, A., Núñez-Hernández, F., & Villa-Caro, G. (2017). A DEA analysis of electricity distribution in Spain: An industrial policy recommendation. *Energy Policy*, *102*, 583–592.

Aziz, S., & Chowdhury, S. A. (2021). Performance evaluation of solar mini-grids in Bangladesh: A two-stage data envelopment analysis. *Cleaner Environmental Systems*, *2*, 100003.

Banker, R., Charnes, A., & Cooper, W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science*, *30*, 1078–1092.

Banker, R. D., Chames, A., & Cooper, W. W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science*, *30*(9), 1078–1092.

Barros, C. P., Wanke, P., Dumbo, S., & Manso, J. P. (2017). Efficiency in Angolan hydro-electric power station: A two-stage virtual frontier dynamic DEA and simplex regression approach. *Renewable and Sustainable Energy Reviews*, *78*, 588–596.

Bukari, D., Hatamimarbini, A., Bhattacharyya, S. C., Kerr, D., Baker, L., Onsongo, E., Sesan, T., Sawe, E. N., & Pueyo, A. (2023). On the technical sustainability of mini-grids in developing countries: A comprehensive review of literature (Working paper 2). Sustainability, Inclusiveness and Governance of Mini-Grids in Africa (SIGMA) Project.

Charnes, A., Cooper, W. W., Lewin, A. Y., & Seiford, L. M. (1994). *Data envelopment analysis: Theory, methodology and application*. Springer Science-Business Media.

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research*, *2*(6), 429–444.

Cooper, W. W., Seiford, L. M., & Tone, K. (2007). *Data envelopment analysis: A comprehensive text with models, applications, references and DEA-solver software* (Vol. 2, p. 489). Springer.

Duran, A. S., & Sahinyazan, F. G. (2021a). Meta-analysis data of 104 renewable mini-grid projects for rural electrification. *Data in Brief*, *34*, 106739, https://doi.org/10.1016/j.dib.2021.106739

Duran, A. S., & Sahinyazan, F. G. (2021b). An analysis of renewable mini-grid projects for rural electrification. Socio-economic Planning Sciences, *77*, 100999. https://doi.org/10.1016/j.seps.2020.100999

ESMAP. (2015). Beyond connections: Energy access redefined. ESMAP Technical Report 008/15. Retrieved November 14, 2013, from https://openknowledge.worldbank.org/entities/publication/a896ab51-e042-5b7d-8ffd-59d36461059e

Farrell, M. J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society Series A (General)*, *120*(3), 253–290.

Gouveia, M. C., Dias, L. C., Antunes, C. H., Boucinha, J., & Inácio, C. F. (2015). Benchmarking of maintenance and outage repair in an electricity distribution company using the value-based DEA method. *Omega*, *53*, 104–114.

IEA, IRENA, UNSD, World Bank, and WHO. (2022). Tracking SDG 7: The Energy Progress Report 2022. World Bank. Retrieved November 14,

2013, from https://www.iea.org/reports/tracking-sdg7-the-energy-progress-report-2022

Kuosmanen, T., Saastamoinen, A., & Sipiläinen, T. (2013). What is the best practice for benchmark regulation of electricity distribution? Comparison of DEA, SFA and StoNED methods. *Energy Policy*, *61*, 740–750.

OSDEA. (2023). About Open Source DEA. Retrieved November 15, 2013, from https://opensourcedea.org/about/

Ramanathan, R. (2003). *An introduction to data envelopment analysis: A tool for performance measurement*. Sage Publications India.

Sağlam, Ü. (2017). Assessment of the productive efficiency of large wind farms in the United States: An application of two-stage data envelopment analysis. *Energy Conversion and Management*, *153*, 188–214.

Sueyoshi, T., & Goto, M. (2014). Photovoltaic power stations in Germany and the United States: A comparative study by data envelopment analysis. *Energy Economics*, *42*, 271–288.

Thanassoulis, E. (1993). A comparison of regression analysis and data envelopment analysis as alternative methods for performance assessments. *Journal of the Operational Research Society*, *44*(11), 1129–1144.

Ulsrud, K. (2020). Access to electricity for all and the role of decentralized solar power in sub-Saharan Africa. *Norsk Geografisk Tidsskrift - Norwegian Journal of Geography*, *74*(1), 54–63.

Wang, Z., Li, Y., Wang, K., & Huang, Z. (2017). Environment-adjusted operational performance evaluation of solar photovoltaic power plants: A three stage efficiency analysis. *Renewable and Sustainable Energy Reviews*, *76*, 1153–1162.

Wu, Y., Hu, Y., Xiao, X., & Mao, C. (2016). Efficiency assessment of wind farms in China using two-stage data envelopment analysis. *Energy Conversion and Management*, *123*, 46–55.

Wu, Y., Ke, Y., Zhang, T., Liu, F., & Wang, J. (2018). Performance efficiency assessment of photovoltaic poverty alleviation projects in China: A three-phase data envelopment analysis model. *Energy*, *159*, 599–596.

Annex 9.1: Mini-Grid Data Extracted from the Meta-Analysis Dataset

DMU-ID	Ownership	Installation Date	Capacity (W)	RE Share	Cost (US$ 2020)	Population	Capacity/ Person (W)	RE Share	Age	Ownership	Cost/W (US$ 2020)
H-5	Private	2015	400	0.5	2,100,000	5,500	72.72727273	0.5	5	1	5.25
H-6	Private	2016	2.7	1	19,902	250	10.8	1	4	1	7.371111
AS-7	Public	2016	1,400	1	8,600,000	600	2333.333333	1	4	2	6.142857
In-8	Private	2014	1.2	1	9,341	375	3.2	1	6	1	7.784167
In-9	Private	2014	1	1	6,906	110	9.090909091	1	6	1	6.906
In-10	Private	2014	1.2	1	12,721	220	5.454545455	1	6	1	10.60083
Ma-11	Public	2012	2,612	0.48	6,800,000	3,746	697.2770956	0.48	8	2	2.603369
CV-12	PPP	2011	24,290	0.24	25,000,000	84,229	288.3804865	0.24	9	3	1.02923
MAU-13	Public	2010	13,400	0.08	1,700,000	37,000	362.1621622	0.08	10	2	0.126866
Per-16	Public	2014	11.5	0.57	49,147	255	45.09803922	0.57	6	2	4.273652
Niu-17	Public	2018	3,000	0.2	8,400,000	1,624	1847.29064	0.2	2	2	2.8
H-20	Private	2015	123	0.76	1,500,000	2,790	44.08602151	0.76	5	1	12.19512
In-21	Private	2014	100	1	492,819	2,200	45.45454545	1	6	1	4.92819
Ch-24	Community	2010	175	0.14	982,419	105	1666.666667	0.14	10	4	5.613823
Ton-34	Public	2013	512	1	2,400,000	3,000	170.6666667	1	7	2	4.6875
Ton-36	Public	2017	550	1	16,000,000	7,212	76.26178591	1	3	2	29.09091
Ind-37	Community	2018	1,200	1	8,800,000	1,840	652.173913	1	2	4	7.333333
Gua-38	Community	2014	90	1	872,246	804	111.9402985	1	6	4	9.691622

DMU-ID	Ownership	Installation Date	Capacity (W)	RE Share	Cost (US$ 2020)	Population	Capacity/ Person (W)	RE Share	Age	Ownership	Cost/W (US$ 2020)
Dom-Hai-39	Community	2008	1,300	1	17,000,000	20,000	65	1	12	4	13.07692
Col-40	Public	2015	191	1	823,345	1,853	103.0760928	1	5	2	4.310707
Per-41	Private	2017	20.55	1	445,199	1,850	11.10810811	1	3	1	21.66418
Ecu-42	Community	2012	12.27	1	85,399	80	153.375	1	8	4	6.959984
Mex-43	PPP	2013	187.5	1	3,600,000	30,000	6.25	1	7	3	19.2
Col-44	Community	2016	8	1	59,896	76	105.2631579	1	4	4	7.487
Col-45	Community	2018	7.85	1	480,675	250	31.4	1	2	4	61.23248
Chil-46	Private	2000	27	0.56	340,601	213	126.7605634	0.56	20	1	12.61485
Nica-47	Community	2007	220	1	1,900,000	5,900	37.28813559	1	13	4	8.636364
Per-48	Public	2016	20	1	129,054	200	100	1	4	2	6.4527
Fij-52	Community	2013	20	1	443,198	300	66.66666667	1	7	4	22.1599
Tuv-53	Public	2009	46	1	962,501	600	76.66666667	1	11	2	20.92393
Van-54	Community	2014	75	1	327,092	1,300	57.69230769	1	6	4	4.361227
Ken-55	PPP	2015	46.8	0.85	304,924	4,000	11.7	0.85	5	3	6.51547
Ken-56	Public	2011	3,400	0.15	2,900,000	41,000	82.92682927	0.15	9	2	0.852941
Ken-57	Public	2013	3,460	0.1	2,400,000	50,400	68.65079365	0.1	7	2	0.693642
Ken-58	Public	2011	260	0.04	176,430	1,350	192.5925926	0.04	9	2	0.678577

(*Continued*)

DMU-ID	Ownership	Installation Date	Capacity (W)	RE Share	Cost (US$ 2020)	Population		Capacity/ Person (W)	RE Share	Age	Ownership	Cost/W (US$ 2020)
Ken-59	Public	2013	570	0.09	616,382	2,520		226.1904762	0.09	7	2	1.081372
Ken-60	Public	2012	860	0.07	1,500,000	6,890		124.8185776	0.07	8	2	1.744186
In-61	Private	2006	43	1	119,476	336		127.9761905	1	14	1	2.778512
In-62	Private	2006	150	1	416,777	178		842.6966292	1	14	1	2.778513
Ma-63	Community	2005	5	1	34,777	300		16.66666667	1	15	4	6.9554
In-64	Private	2010	50	1	50,478	436		114.6788991	1	10	1	1.00956
In-65	Private	2012	32	1	40,492	989		32.35591507	1	8	1	1.265375
In-66	Public	2002	2	1	35,233	179		11.17318436	1	18	2	17.6165
In-67	Public	2010	4.5	1	45,430	587		7.666098807	1	10	2	10.09556
In-68	Public	2005	120	1	730,016	1,029		116.6180758	1	15	2	6.083467
In-69	Private	2012	32	1	64,787	553		57.86618445	1	8	1	2.024594
N-70	Private	2013	6	1	83,100	480		12.5	1	7	1	13.85
N-71	Private	2015	9	1	65,341	720		12.5	1	5	1	7.260111
N-72	Private	2015	34	1	239,583	1,600		21.25	1	5	1	7.046559
N-73	Private	2015	40	1	272,254	1,600		25	1	5	1	6.80635
N-74	Private	2015	24	1	240,909	1,180		20.33898305	1	5	1	10.03788
Fij-75	Public	1997	290.6	0.31	1,000,000	2,000		145.3	0.31	23	2	3.441156

DMU-ID	Ownership	Installation Date	Capacity (W)	RE Share	Cost (US$ 2020)	Population	Capacity/ Person (W)	RE Share	Age	Ownership	Cost/W (US$ 2020)
N-76	Public	2006	3	1	106,268	5,000	0.6	1	14	2	35.42267
CN-77	PPP	2003	31.05	1	206,575	1,800	17.25	1	17	3	6.652979
Ken-78	Community	2012	13.5	1	75,885	3,000	4.5	1	8	4	5.621111
Ken-79	Community	2014	21.9	1	119,389	5,000	4.38	1	6	4	5.451553
Ug-80	Community	2015	13.5	1	73,509	500	27	1	5	4	5.445111
Ug-81	PPP	2012	32	1	91,623	172	186.0465116	1	8	3	2.863219
Ug-82	Private	2016	288.8	0.79	1,300,000	2,000	144.4	0.79	4	1	4.501385
Ug-83	Private	2006	250	1	668,013	470	531.9148936	1	14	1	2.672052
Ug-84	Community	2014	40	1	424,306	615	65.04065041	1	6	4	10.60765
CV-85	Public	2012	60	0.67	421,584	450	133.3333333	0.67	8	2	7.0264
MM-86	Community	2016	9.76	1	80,659	977	9.989764585	1	4	4	8.264242
MM-87	Community	2016	9.76	1	96,683	1138	8.576449912	1	4	4	9.906045
MM-88	Community	2016	4.88	1	39,469	336	14.52380952	1	4	4	8.08791
MM-89	Community	2016	13	1	100,673	1,237	10.50929669	1	4	4	7.744077
MM-90	Community	2016	10.8	1	106,018	925	11.67567568	1	4	4	9.816481
MM-91	Community	2016	6	1	50,047	836	7.177033493	1	4	4	8.341167
MM-92	Community	2016	7.2	1	68,624	931	7.733619764	1	4	4	9.531111

(*Continued*)

DMU-ID	Ownership	Installation Date	Capacity (W)	RE Share	Cost (US$ 2020)	Population		Capacity/ Person (W)	RE Share	Age	Ownership	Cost/W (US$ 2020)
MM-93	Community	2016	12.96	1	110,018	1,654		7.835550181	1	4	4	8.489043
MM-94	Community	2016	8.7	1	88,583	2,170		4.00921659	1	4	4	10.18195
MM-95	Community	2016	6.48	1	54,667	625		10.368	1	4	4	8.436265
Tan-96	Community	2012	300	1	762,522	6,199		48.3949024	1	8	4	2.54174
Tan-97	Private	2015	500	1	816,761	3,789		131.9609396	1	5	1	1.633522
Tan-98	Community	2001	250	1	968,469	1,390		179.8302403	1	19	4	3.873876
Tan-99	Community	2006	10	1	38,738	460		21.73913043	1	14	4	3.8738
Tan-100	Community	2015	210	1	668,013	5,896		35.61736771	1	5	4	3.181014
Tan-101	Private	2013	44	1	170,387	1,950		22.56410256	1	7	1	3.872432
Tan-102	Private	2013	35.2	1	136,310	800		44	1	7	1	3.872443
Tan-103	Community	2013	8.8	1	34,078	200		44	1	7	4	3.8725
Nam-104	Community	2006	1.6	1	207,337	8		200	1	14	4	129.5856

CHAPTER 10

Mini-Grid Sustainability Framework and Its Application to Selected Mini-Grids in Kenya

Mourice Wambua Kausya,[1] Rosebella Nyumba,[1,2] Elsie Khakasa Onsongo,[1] Daniel Kerr[3] and Subhes C. Bhattacharyya[3†]

[1]Nuvoni Centre for Innovation Research, Nairobi, Kenya
[2]Bergische Universität Wuppertal, Wuppertal, Germany
[3]De Montfort University, Leicester, UK
[†] Corresponding author e-mail: Subhes.bhattacharyya@dmu.ac.uk

Acronyms

UN SDG	*United Nations Sustainable Development Goals*
PV	*Photovoltaic*
IFC	*International Finance Corporation Kakuma Kalobeyei Chal-lenge Fund (KKCF),*

Abstract

This chapter presents an indicator-based framework for the sustainability analysis of mini-grids and applies this to a selection of mini-grids in Kenya. Although various frameworks exist, they have been criticized for lack of attention to long-term perspectives, high data needs, prescriptive nature of the attributes, and limited user-friendliness. Considering that data availability is a major concern and that data available are qualitative in nature, this chapter proposes a set of indicators and a scoring system that can be used with a broad qualitative understanding of the sustainability attributes of the mini-grids. The chapter first presents the framework and the scoring system and applies this to the data gathered from the fieldwork in Kenya. The results indicate significant variations in

sustainability performance of the mini-grids covered and their relatively poor performance in social, institutional, and environmental dimensions.

Keywords: sustainability indicators, mini-grids, qualitative data, performance comparison

10.1 Introduction

The interest in mini-grids for electrification has grown in recent years, particularly after 2015 when the UN Sustainable Development Goals (SDGs) were launched. According to the Tracking SDG 7 report, the number of people connected to mini-grids has more than doubled to 11 million people in 2019, from 5 million in 2010 (IEA et al., 2021). The World Bank however indicates that 47 million people across 134 countries are currently connected to 19,000 mini-grids (World Bank, 2019). It further suggests that 490 million people will be cost-effectively electrified by 210,000 mini-grids across the globe for the attainment of universal access by 2030.

Although the mini-grid sector is growing, their desirability as a long-term solution is collectively determined by the ability of these technologies to support long-term prospects in technical, economic, social, environmental, and governance terms. Depending on how they manage to negotiate these challenges, the long-term sustainability of mini-grids may either fall into what has been characterized as virtuous or vicious cycles. These cycles can emerge from different foundational perspectives; technical, socioeconomic, governance/regulatory, and environmental.

In our review of technical sustainability, we have presented the following definition of mini-grid sustainability (Bukari et al., 2023): *a mini-grid intervention to be sustainable if it is a technically feasible, safe, and reliable option that meets the needs of the present generation and that of the future generations, economically viable and affordable, socially acceptable and leaves no one behind, environmentally sound and institutionally manageable*. Our review has also indicated various sustainability measurement frameworks developed by various authors (e.g., Ilskog & Kielstrom, 2008; Katre & Tozzi, 2018; Manali & Silveira, 2015, Rahmann et al., 2016). The index-based approaches retained in these studies differ in their choice of indicators, their coverage, and the weighting used for different dimensions.

However, several concerns and criticisms have been raised against the existing frameworks. These include:

Lack of attention to long-term perspectives: For example, the indicators do not consider the ability of the systems to meet future needs. The absence of any consideration for the future generations' ability to meet the needs goes against the basic requirement of a sustainable solution.

Information requirement: Many frameworks require a large volume of data, which are either nonexistent or are difficult to obtain from the owners of mini-grids. Our fieldwork confirms that mini-grid owners/operators are reluctant to share financial information. Quantitative data for social conditions are also not easily available, and users of mini-grids can only offer qualitative views of the relevance and performance of mini-grids.

In addition, some frameworks have been criticized for the prescriptive nature of the attributes used. For example, there is often a presumption that a higher quantity of energy use is better, without realizing that such an assumption can go against the environmental desirability of a solution and that the quality of the provision may be more important than quantity.

Concerns were also raised about redundancy of indicators, their ambiguity and fit for purpose.

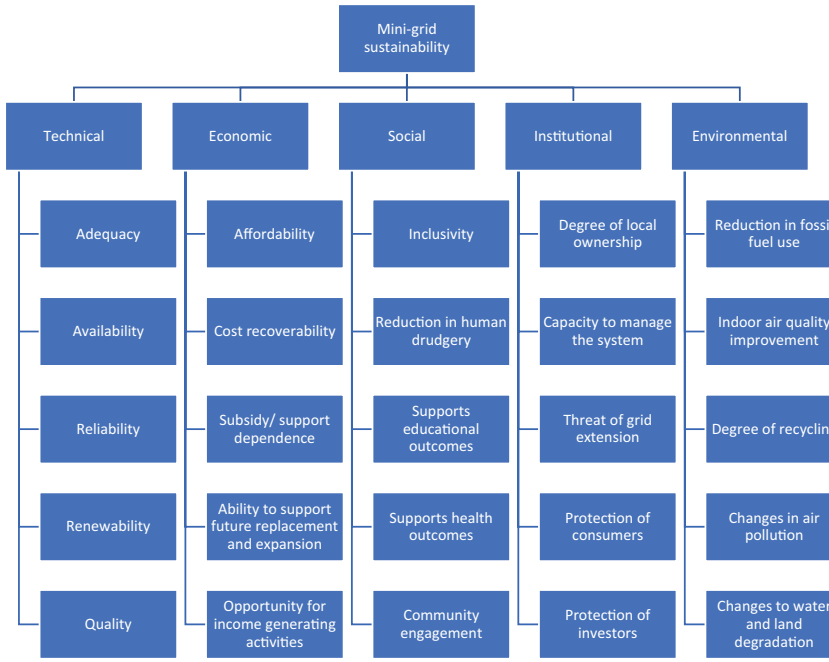
User-friendliness of the frameworks has also been commented upon: Frameworks are often complex, with stringent data requirements, or are opaque in their descriptors of sustainability dimensions.

The purpose of this chapter is to present a simple framework that captures the sustainability of mini-grids so that the idea can be applied to the data gathered from the fieldwork in the different countries covered by this project. The idea presented in chapter 2 is extended to include social, economic, institutional, and environmental dimensions so that an overall picture of a mini-grid performance can be arrived at. Due to the qualitative nature of the data gathered, the framework would provide a perception of the sustainability performance of a given mini-grid at the time of the fieldwork and would allow a simple comparison across multiple mini-grids within a country and across countries.

10.2 Framework Design

Figure 10.1 presents the five dimensions of the framework proposed, namely technical, economic, social, institutional, and environmental. Under each dimension, five indicators are being considered to capture

Figure 10.1: Framework for Mini-Grid Sustainability Assessment



the state of play of a mini-grid. These indicators will be assessed using a qualitative scale of low, medium, and high level of compliance with a given indicator. A low level of performance will get a score of 1, the medium performance will be given 3, and strong performance will get a score of 5. The maximum score can be 125, and the lowest score can be 25. The details of the performance measures are presented in Table 10.1.

The technical indicators are similar to what has been proposed in Bukari et al. (2023). The economic indicators capture the affordability of the users, reliance on support (such as grants and subsidies), cost recoverability, integration of productive use of energy, and the ability to support future expansion. The indicators for the social dimension include inclusivity, changes in terms of human drudgery, health and educational outcomes, and the level of community engagement. The indicators for the institutional dimension include local ownership, local capacity to manage the system, threat of grid extension, and availability of consumer and investor protection arrangements. Finally, the indicators for the environmental dimension include fossil fuel reduction, indoor air pollution reduction, improvements in air and water pollution, and the level of recycling. These indicators follow from

S'Table 10.1: Description of the Framework Components and Measures

Dimension	*Indicator*	*Measure Capturing the Indicator*	*Description of Performance Level*		
			Low (1 point)	*Medium (3 points)*	*High (5 points)*
Technical	*Adequacy 1 (50%)*	*How likely is the system to meet users' needs now?*	*Barely meets the demand*	*Regularly meeting the demand*	*Always meeting the demand*
	Adequacy 2 (50%)	*How likely is the system to meet the demand in the future?*	*Unlikely*	*Quite likely*	*Most likely*
	Availability	*Duration of supply: limited, fixed time, or uninterrupted*	*Limited, short duration (2–3 hours)*	*Fixed duration (6–8 hours)*	*Uninterrupted supply*
	Reliability	*How reliable is the supply?*	*Unreliable*	*Moderately reliable*	*Highly reliable*
	Renewability	*Share of renewable energy mix*	*Low mix (<20%)*	*Medium level (20–50%)*	*High (>50%*
	Quality	*Stable or unstable supply?*	*Unstable*	*Generally stable, with some fluctuations*	*Highly stable, with low levels of fluctuations*

(Continued)

Table 10.1: (*Continued*)

Dimension	*Indicator*	*Measure Capturing the Indicator*	*Description of Performance Level*		
Economic	*Affordability*	*Can users bear the tariff charges?*	*Weak (many reporting difficulty)*	*Generally affordable (few reporting difficulty)*	*Highly affordable (no complaints)*
	Cost recoverability	*Is the system recovering costs?*	*Inadequate (costs > income)*	*Breaking even or low margin*	*Generating sufficient profit margin*
	Subsidy/support dependence	*Degree of dependence on support*	*High dependence on capital and operating cost subsidies*	*Dependence on capital grant/subsidy but covers operating costs*	*Low dependence on subsidies*
	Ability to support future replacement/ expansion	*Is the plant likely to support replacement and expansion?*	*Unable*	*Marginally able*	*Confidently able*
	Income-generating opportunities	*To what extent has the project supported any economic activities?*	*No or very limited evidence*	*Modest level (with evidence of some regular activities)*	*High (supporting a wide range of activities)*

Table 10.1: (*Continued*)

Dimension	*Indicator*	*Measure Capturing the Indicator*	*Description of Performance Level*		
Social	*Inclusivity*	*Is the access reaching all potential users?*	*No, only who can afford to or are able to pay*	*Mostly, except those unwilling to join*	*All inclusive*
	Reduction in human drudgery	*Extent of reduction*	*Limited evidence*	*Modest evidence*	*Strong evidence*
	Educational outcomes	*Extent of improvement*	*Weak evidence*	*Moderate evidence*	*Strong evidence*
	Health outcomes	*Extent of improvement*	*Weak or no change*	*Some evidence of improvement*	*Strong evidence of improvement*
	Community engagement	*Level of engagement*	*Poor (hardly any consultation or participation)*	*Some consultation and participation*	*Strong, inclusive participation*

(Continued)

Table 10.1: (*Continued*)

Dimension	*Indicator*	*Measure Capturing the Indicator*	*Description of Performance Level*		
Institutional	*Degree of local ownership*	*Share of local ownership*	*No or very low local ownership (<20%)*	*Moderate level of local ownership (20–50%)*	*Majority local ownership (>50%)*
	Local capacity to manage the system	*Extent of local ability to manage the system*	*Poor evidence of any local capacity*	*Some evidence of local capacity*	*Strong evidence of local capacity*
	Threat of grid extension	*Extent of the threat and potential for stranded assets*	*Strong (imminent)*	*Some threats (in less than 5 years)*	*Limited or no threat*
	Consumer protection	*Procedures and capacity to protect consumers*	*None or poorly developed*	*Some protection available*	*Robust protection system*
	Investor protection	*Procedures and capacity to protect investors*	*No protection*	*Some protection*	*Strong, formalized protection*

Table 10.1: (*Continued*)

Dimension	*Indicator*	*Measure Capturing the Indicator*	*Description of Performance Level*		
Environmental	*Reduction in fossil fuel use*	*Extent of fossil fuel replacement*	*Low or no reduction*	*Moderate reduction (20–50%)*	*Strong reduction (>50%)*
	Indoor air quality improvement	*Degree of improvement*	*Low or no change*	*Moderate change*	*Significant improvement*
	Changes in air pollution	*Degree of improvement*	*Low or no change*	*Modest change*	*Strong change*
	Degree of recycling	*Extent of recycling*	*Low or no change*	*Some recycling evidence*	*Strong recycling measures embedded*
	Changes to water pollution and land degradation	*Level of improvement*	*Low or no change*	*Some evidence of improvement*	*Strong evidence of improvement*
Overall	*Overall score for the mini-grid*				

our extensive literature reviews and are measured in terms of their degree of contribution. A high value of 5 is used when the mini-grid is making or likely to make a strong contribution to the dimension, whereas a low value of 1 is used when the mini-grid is making or likely to make limited or weak contribution. An intermediate value of 3 is used for other cases. Note that the qualitative description in Table 10.1 reflects the nature of the indicator under consideration. For example, a mini-grid that heavily depends on subsidies or grants is considered to be weak in terms of economic sustainability and is given a score of 1. Cases should be examined carefully and scores assigned based on their performance in each sub-indicator.

The advantage of the framework is that it can be implemented using records of field visits where the researchers managed to gain a good understanding of the mini-grid operation at a given location, but in some cases there was reluctance to share quantitative information due to confidentiality or other local reasons. The framework uses a simple scoring system to ensure its ease of application, and all dimensions are given equal weights to allow equal importance to all factors.

10.3 Application to the Mini-Grids Visited in Kenya

The above framework was applied to the mini-grids visited in Kenya as part of the SIGMA fieldwork, and, based on the information gathered from the sites visited, a qualitative evaluation was performed to determine the sustainability of these mini-grids. A separate report provides the details of the fieldwork through which data were collected (see Onsongo et al., 2023). Data for 15 mini-grids were used in this study to present an evaluation of their sustainability.

The details are presented in the Annex 10.1, and the summary of the results by dimension is presented in Table 10.2 (in descending order). The highest score is 78 (for Kalobeyei Settlement mini-grid), whereas the lowest score is 41 (Oloika plant). The lowest score is about 32% of the maximum possible score, whereas the highest score is about 62% of the maximum possible score. The table also suggests that a majority of the mini-grids in the Kenyan sample lie between 50 and 60% of the maximum score. This implies that most of the plants are performing somewhere in between and there is potential for significant improvement in terms of sustainability.

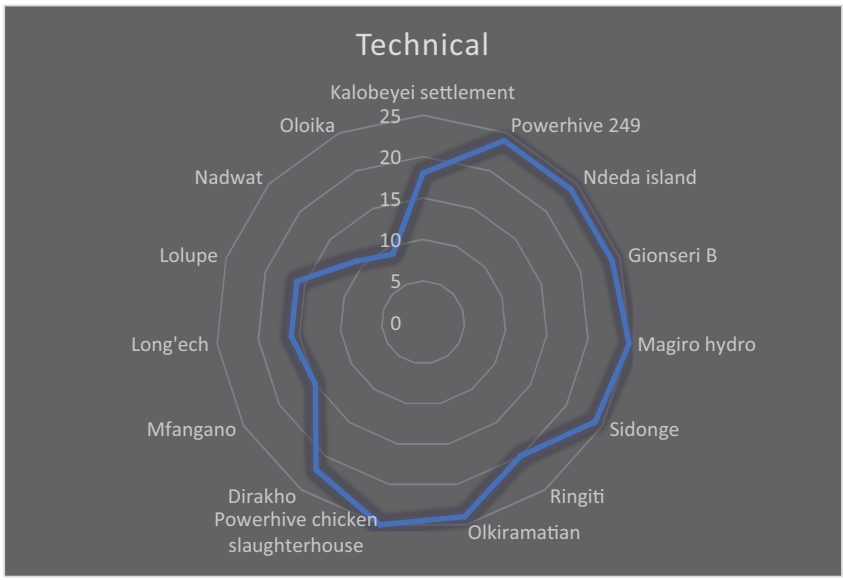
Figures 10.2 to 10.7 capture the comparative position for different plants for different dimensions. The scores are out of 25 for each dimension, but it can be seen that most of the scores are much lower than the maximum

Table 10.2: Summary of Sustainability Evaluation of Mini-Grids in Kenya (for Selected Cases)

Plants	*Technical*	*Economic*	*Social*	*Institutional*	*Environmental*	*Total*
Kalobeyei settlement	*18*	*21*	*13*	*15*	*11*	*78*
Powerhive 249	*24*	*15*	*15*	*11*	*11*	*76*
Ndeda island	*24*	*17*	*13*	*15*	*7*	*76*
Gionseri B	*24*	*15*	*15*	*11*	*11*	*76*
Magiro hydro	*25*	*15*	*15*	*11*	*9*	*75*
Sidonge	*24*	*17*	*17*	*11*	*5*	*74*
Ringiti	*20*	*15*	*15*	*15*	*7*	*72*
Olkiramatian	*24*	*17*	*11*	*13*	*7*	*72*
Powerhive chicken slaughterhouse	*25*	*17*	*5*	*19*	*5*	*71*
Dirakho	*22*	*15*	*15*	*13*	*5*	*70*
Mfangano	*15*	*15*	*15*	*19*	*5*	*69*
Long'ech	*16*	*15*	*9*	*17*	*5*	*62*
Lolupe	*16*	*9*	*13*	*15*	*5*	*58*
Nadwat	*11*	*9*	*7*	*15*	*5*	*47*
Oloika	*9*	*7*	*9*	*11*	*5*	*41*

possible score, except for the technical dimension. Several mini-grids are performing at the highest technical level of sustainability; however, there were also some mini-grids that have demonstrated poor performance.

Figure 10.2: Technical Sustainability Scores

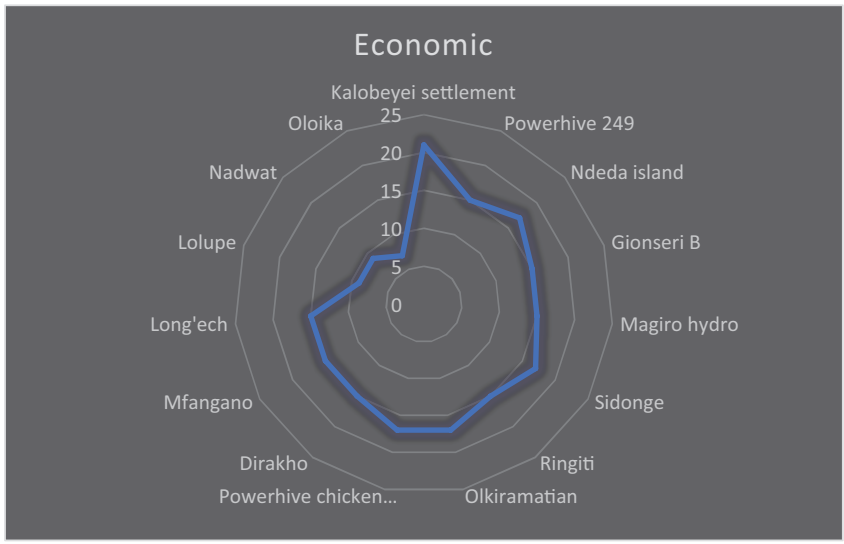


On the economic dimension, most of the plants have scored between 50 and 60% of the maximum score, suggesting the difficulties faced by mini-grids in economic terms. The dependence on subsidies, limited income-generation opportunities, limited affordability, and low level of cost recoverability are contributing to the low scores for this dimension.

In the social dimension, the performance remains mediocre, with a majority of the plants scoring between 50 and 60% of the maximum possible score. A few plants are performing at a much lower level—indicating their limited contribution to inclusiveness and other social outcomes.

The scores for the institutional dimension vary widely. Only one plant has scored above 70% of the maximum, with six plants averaging a score of 60%. The majority of the plants have received scores in the 40% range. The rest have performed weakly and received lower scores. Limited local capacity, low consumer and investor protection arrangements, and the threat of grid extension have contributed to the institutional weakness.

Figure 10.3: Economic Sustainability Scores



Mini-grids relying on renewable energy technologies reduce fossil fuel dependence, but the contribution of mini-grids to the environmental dimension can be limited due to limited use of electricity for cooking and heating purposes, whereas biomass use for such needs still remains high. The low scores in this dimension arise from these weaknesses.

Figure 10.4: Social Sustainability Scores

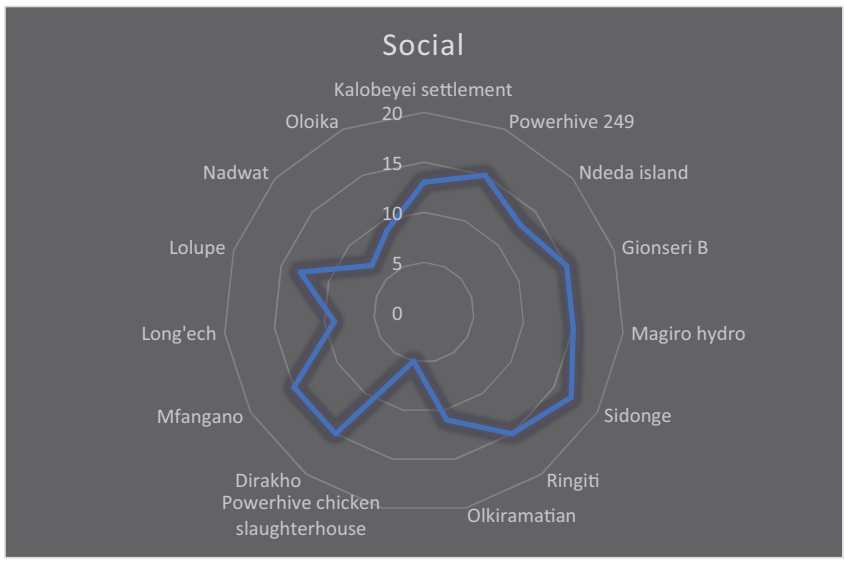
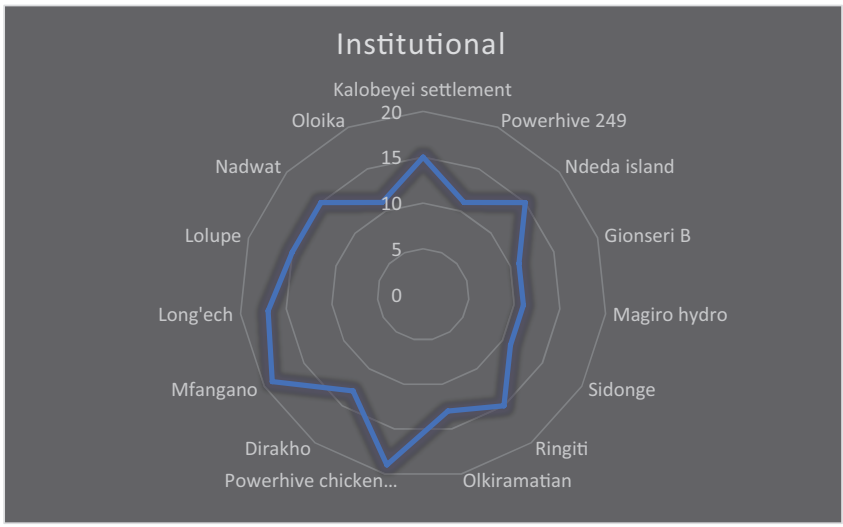


Figure 10.5: Institutional Sustainability Scores



10.4 Discussion

Kalobeyei Settlement mini-grid, which is a solar mini-grid, has received the highest score in this study. This plant was commissioned by Renewvia, with support from EnDev, and offers electricity at rates comparable to those of the national utility, Kenya Power, thanks to substantial subsidies from donors. Following an expansion funded by the Kakuma Kalobeyei Chal-

Figure 10.6: Environmental Sustainability Scores

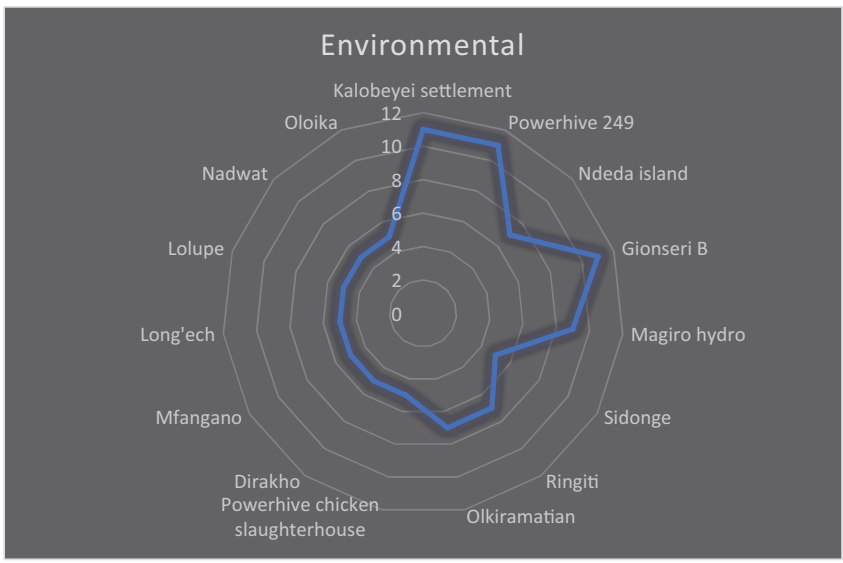
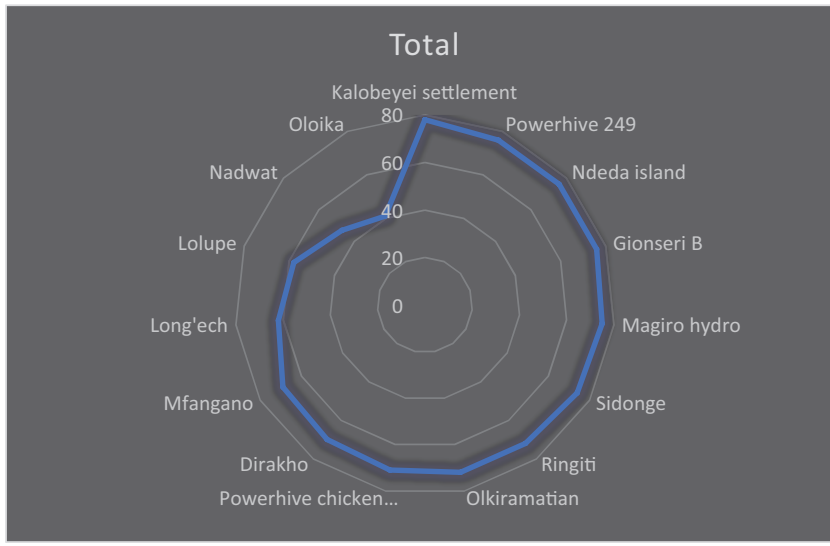


Figure 10.7: Total Sustainability Scores



lenge Fund (KKCF), a program facilitated by the International Finance Corporation (IFC), the mini-grid has now become the largest in East Africa, catering to nearly 2,500 households, businesses, health facilities, schools, and international organizations located within the refugee settlement.

The lowest score went to the Oloika plant. The plant is not operating optimally due to technical issues, specifically battery failures and aging battery installations. The plant is currently operating without any storage, which implies no electricity at night when users need it most. The local cooperative managing the project has no relationship with the country administration, and, consequently, the plant is not benefitting from technical assistance from the government. The financial resource management remains weak, and the initial benefits realized through the electrification process could not be sustained. This is an example of the sustainability challenges being faced by mini-grids promoted by international agencies.

The diesel–solar hybrid plant in Mfangano Island (the Mfangano mini-grid) deserves a special mention here. The plant is owned by the national utility company Kenya Power. The tariff charged is the same as what the rest of the country pays, which was way lower than what other solar photovoltaic (PV) mini-grids charge. The mini-grid boasts significant capacity, efficiently supplying electricity to the entire island. The mini-grid serves the entire island supporting a variety of businesses, such as an ice-making plant, fish farm, salons, barbershops, entertainment venues, and tourist

hotels. The power is stable, reliable, and they rarely experience any outages unless there are delays in the delivery of the diesel to the island.

Community involvement during the construction phase was substantial, with local volunteers contributing their time and effort to assist in equipment off-loading. Moreover, the community played a pivotal role in determining the mini-grid's location. Operational and maintenance responsibilities are efficiently managed by dedicated Kenya Power staff stationed within the area. External assistance is only sought for major repair works like the repair of faulty transformers or destroyed power lines. Despite relying mainly on diesel, the mini-grid is supporting the local island community very strongly.

Similarly, the only hydro-based mini-grid in the sample (Magiro Mini-grid) coexists harmoniously with the main grid. The mini-grid reports no instances of conflict with Kenya Power. On the contrary, it is actively expanding its operations within the region. Their tariffs are lower than other solar PV mini-grids, even cheaper than the Kenya Power tariffs. This affordability has positioned the mini-grid as the preferred electricity source for many households in the area. The electricity is stable, reliable, and the hydro plant has enough capacity; hence, it is preferred by households over the Kenya Power electricity, which is rather unstable in that area. Most of the households use electricity from the Magiro Mini-grid, and Kenya Power electricity serves as a backup.

The electricity provided by this mini-grid supports many kinds of end-use and has been able to support a wide range of businesses, schools, and other institutions. The founder and some HydroBox (the external investor) staff are based in the area, and they train interns from a nearby polytechnic to increase the local capacity. They heavily involved the community in the construction phase, and some of the workers and the founder are from the area. This again shows the importance of active local engagement in the sustainability of mini-grids.

10.5 Conclusions

This chapter has presented a simple indicator-based framework for sustainability evaluation of mini-grids. The evaluation using this framework can be performed using qualitative information gathered from the projects through field visits, stakeholder interactions, and any secondary information available on the project. Five dimensions were identified for the sustainability analysis, namely technical, economic, social, institutional, and environmental, and each dimension has received equal weight. All dimensions are evaluated using five indicators, except for the technical

dimension where six indicators have been used, with two indicators given equal weighting, keeping the overall distribution between dimensions the same.

A scoring system using a three-point scale has been developed to capture the different levels of sustainability: low, intermediate, and high. The maximum possible score for each dimension is 25, and the total maximum possible score is 125. The scoring system allows for visualization and comparison of performance across different plants at a given time.

The framework has been applied to 15 mini-grids visited by the team in Kenya. The application clearly captures the relative performance of mini-grids. The results indicate that high-scoring mini-grids are all performing very well technically and they have supported economic activities well. These plants have also managed to offer affordable and somewhat inclusive supply. But there are weaknesses in institutional and environmental dimensions for most plants. Those receiving low scores have not ensured long-term technical performance, and, consequently, they have demonstrated weaknesses in terms of income-generating activities, social outcomes, as well as environmental and institutional performances.

Although the framework is easy to use and can capture the sustainability performance well, the scoring process remains inherently subjective. However, this is a criticism that remains true for any qualitative ranking methodology. As long as the methodology is used with care and is supported by evidence, the subjectivity is unlikely to affect the outcomes significantly.

References

Bukari, D., Hatamimarbini, A., Bhattacharyya, S. C., Kerr, D., Baker, L., Onsongo, E., Sesan, T., Sawe, E. N., & Pueyo, A. (2023). On the technical sustainability of mini-grids in developing countries: A comprehensive review of literature (Working paper 2). Sustainability, Inclusiveness and Governance of Mini-Grids in Africa (SIGMA) Project.

IEA, IRENA, UNSD, World Bank, WHO. (2021). *Tracking SDG7: The Energy Progress Report*. World Bank. https://www.irena.org/publications/2021/Jun/Tracking-SDG-7-2021

Ilskog, E., & Kjellstrom, B. (2008). And they lived sustainably ever after? Assessment of rural electrification cases by means of indicators. *Energy Policy*, *36*, 2674–2684.

Katre, A., & Tozzi, A. (2018). Assessing the sustainability of decentralised renewable energy system: A comprehensive framework with analytical methods. *SustainabilitySustainability \i , 10*, 1058. https://doi.org/10.3390/su10041058

Mainali, B., & Silveira, S. (2015). Using a sustainability index to assess energy technologies for rural electrification. *Renewable and Sustainable Energy Reviews*, *41*, 1351–1365.

Onsongo, E., Okoko, A., Onjala, B., Nyumba, R., & Kausya, M. (2023). *SIGMA Project: Kenya Fieldwork Report* (SIGMA Project Team, University of Surrey.).

Rahmann, C., Nunez, O., Valencia, F., Arrechea, S., Sager, J., & Kammen, D. (2016). Methodology for monitoring sustainable development of isolated mini-grids in rural communities. *Sustainability, 8*, 1163. https://doi.org/10.3390/su8111163

World Bank. (2019). *Mini-grids for half a billion people: Market outlook and handbook for decision makers*. World Bank. https://openknowledge.worldbank.org/handle/10986/31926.

Annex 10.1: *Details of Sustainability* Scores

			Mini-grids from Kenya															
Dimension	Indicator	Measure Capturing the Indicator	Oloika	Olkiramatian	Ndeda Island	Ringiti	Mfangano	Powerhive Chicken Slaughterhouse	Powerhive 249	Gionseri B	Sidonge	Dirakho	Long'ech	Lolupe	Nadwat	Kalobeyei Settlement	Magiro Hydro
Technical	Adequacy 1 (50%)	How likely is the system to meet the needs now?	1	5	5	3	5	5	5	5	5	5	3	3	1	3	5
	Adequacy 2 (50%)	How likely is the system to meet the demand in the future	1	3	3	1	5	5	3	3	3	3	1	1	1	5	5
	Availability	Duration of supply: limited, fixed time or uninterrupted	1	5	5	5	3	5	5	5	5	5	3	3	3	3	5
	Reliability	How reliable is the supply?	1	5	5	5	3	5	5	5	5	3	3	3	1	3	5
	Renewability	Share of renewable energy mix	5	5	5	5	1	5	5	5	5	5	5	5	5	5	5
	Quality	Stable or unstable supply?	1	5	5	3	3	5	5	5	5	5	3	3	1	3	5
Economic	Affordability	Can users bear the tariff charges?	1	3	3	3	5	5	3	3	3	1	1	1	1	5	5
	Cost recoverability	Is the system recovering costs?	1	3	3	3	1	3	3	3	3	3	3	1	1	5	3
	Subsidy/ support dependence	Degree of dependence on support	1	3	3	3	1	1	3	3	3	3	3	1	1	1	1
	Ability to support future replacement/ expansion	Is the plant likely to support replacement and expansion?	3	5	5	3	3	3	3	3	5	5	3	3	3	5	3
	Income generating opportunities	To what extent has the project supported any economic activities?	1	3	3	3	5	5	3	3	3	3	5	3	3	5	3
Social	Inclusivity	Is the access reaching all potential users?	1	3	3	5	3	1	3	3	3	3	1	3	1	3	3
	Reduction in human drudgery	Extent of reduction	1	1	1	1	1	1	3	3	1	1	1	1	1	1	3
	Educational outcomes	Extent of improvement	1	1	3	3	3	1	3	3	5	3	3	3	1	3	3
	Health outcomes	Extent of improvement	3	3	3	3	3	1	1	1	3	3	1	3	1	3	3
	Community engagement	Level of engagement	3	3	3	3	5	1	5	5	5	5	3	3	3	3	3
Institutional	Degree of local ownership	Share of local ownership	3	1	1	1	3	1	1	1	1	1	5	5	5	1	3
	Local capacity to manage the system	Extent of local ability	1	1	3	3	3	3	3	3	3	3	1	1	1	3	3
	Threat of grid extension	Extent of the threat and potential for stranded asset	5	5	5	5	5	5	1	1	1	3	5	3	3	3	1
	Consumer protection	Procedures and capacity to protect	1	3	3	3	3	5	3	3	3	3	3	3	3	3	3
	Investor protection	Procedures and capacity to protect	1	3	3	3	5	5	3	3	3	3	3	3	3	5	1
Environmental	Reduction in fossil fuel use	Extent of fossil fuel replacement	1	3	3	3	1	1	3	3	1	1	1	1	1	3	3
	Indoor air quality improvement	Degree of improvement	1	1	1	1	1	1	3	3	1	1	1	1	1	3	1
	Changes in air pollution	Degree of improvement	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1
	Degree of recycling	Extent of recycling	1	1	1	1	1	1	3	3	1	1	1	1	1	1	3
	Changes to water pollution and land degradation	Level of improvement	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Technical			9	24	24	20	15	25	24	24	24	22	16	16	11	18	25
Economic			7	17	17	15	15	17	15	15	17	15	15	9	9	21	15
Social			9	11	13	15	15	5	15	15	17	15	9	13	7	13	15
Institutional			11	13	15	15	19	19	11	11	11	13	17	15	15	15	11
Environmental			5	7	7	7	5	5	11	11	5	5	5	5	5	11	9
Total			41	72	76	72	69	71	76	76	74	70	62	58	47	78	75

CHAPTER 11

Harnessing Mini-Grid Regulation and Investment for Rural Electrification in Nigeria: Challenges and Prospects

Temilade Sesan,[1] Unico Uduka,[2] Lucy Baker,[3] Okechukwu Ugwu,[2] Ewah Eleri[2] and Subhes Bhattacharyya[4]

[1]Centre for Petroleum, Energy Economics and Law, University of Ibadan, Ibadan, Nigeria
[2]International Centre for Energy, Environment and Development, Central Business District, Abuja, Nigeria
[3]Faculty of Arts and Social Sciences, The Open University, Milton Keynes, UK
[4]De Montfort University, Leicester, UK

Acronyms

SDG	*Sustainable Development Goals*
UN	*United Nations*
GenCos	*Generation Companies*
EPSRA	*Electric Power Sector Reform Act*
NEP	*Nigeria Electrification Project*
ESMAP	*Energy Sector Management Assistance Programme*
REA	*Rural Electrification Agency*
REF	*Rural Electrification Fund*
DISREP	*Distribution Sector Recovery Programme*
NESI	*Nigerian Electricity Supply Industry*

Abstract

About 140 million people across Africa are expected to gain access to electricity from mini-grids by 2040. Nigeria, with the least dependable electricity supply on the continent, stands to benefit significantly from this boon. Accordingly, the government has put in place clear regulations to

incentivize private investment and drive market growth. While the techno-economic dimensions of the growing mini-grid sector and the broader electricity industry have been extensively studied, less attention has been paid to analyzing the impacts of the regulatory framework on the achievement of rural electrification and universal energy access goals. Drawing on qualitative data obtained from key regulatory and market actors in the Nigerian mini-grid sector, this chapter interrogates the premise of pursuing widespread rural electrification through a regulatory framework that is primarily geared toward increasing market efficiency. The study finds that, while the current framework has enabled growth in the sector, complementary mechanisms are required to achieve equitable distribution of access, especially among the mainly rural populations dwelling on the fringes of mainstream electricity markets. The findings are instructive for practitioners and policymakers seeking evidence-informed approaches to achieving the goal of universal energy access in Africa.

Keywords: Africa, electricity governance, energy access, mini-grids, Nigeria, rural electrification

11.1 Introduction

Significant progress has been realized in recent years toward fulfilling UN Sustainable Development Goals' (SDGs) SDG 7 ("affordable and clean energy") and the UN Sustainable Energy for All mandate to achieve universal energy access by 2030. According to the International Energy Agency (IEA), there are 770 million people who do not have access to electricity—a statistic that, despite having fallen consistently since 2013, still sees nearly half of the population in sub-Saharan Africa (around 580 million people) being in that category (IEA, 2019). Moreover, the COVID-19 pandemic has hampered progress toward universal access in recent years, further reducing the likelihood of meeting the goal under business-as-usual scenarios (Cozzi et al., 2020)[1].

It is widely agreed that closing the energy access gap in sub-Saharan Africa requires a socio-technical transition in which decentralized and off-grid renewable electricity generation, including mini-grids, will play a critical role (Odarno et al., 2017; Peters et al., 2019). The IEA projects that, by 2040, an estimated 140 million rural Africans might be supplied by 100,000 to 200,000 mini-grids and an additional 80 million people

could be reached by off-grid solutions (IEA, 2019). It is envisaged that these new technologies will replace, or at least compete with, the centralized power generation, transmission, and distribution infrastructure, which is mostly dependent on traditional thermal and large hydroelectric sources (Ockwell & Byrne, 2016).

Nigeria, with a population of around 206 million people, is expected to become the world's third-most-populated country by 2050 (UNDESA, 2017). According to Power Africa (2022), around 60% of the country's population has access to electricity, with 86% of these living in urban areas and 34% living in rural areas. The country has the least dependable electricity supply on the continent, according to BloombergNEF (2019), with only a quarter of its installed capacity of 16,000 MW being utilized for generation, mostly from thermal and large hydropower sources (Edomah et al., 2021; Power Africa, 2022). Consequently, a large portion of the nation's electricity consumers—whether residential, commercial, or industrial—rely on pricey self-generation from small-l and medium-scale diesel generators (Saifuddin et al., 2016). On the other hand, periodic increases in electricity tariffs are frequently met with public and labor union opposition, reflecting partly the majority's poor purchasing power and also public opinions of the power sector as being corrupt and overly bureaucratic (Edomah et al., 2021; Pallavi, 2020; Roche et al., 2020).[1]

In response to these challenges, the Nigerian government has announced plans to raise power production to 30,000 MW by 2030 and increase the share of renewables in the energy mix to 30% by that same year (Federal Ministry of Power, n.d.). Concrete developments on the ground seem to indicate some progress toward those targets. The country's off-grid solar sector is expanding, especially for solar home systems (ACE-TAF, 2022), and it has been named a "frontier" country in the sector due to the thoroughness of its mini-grid regulations, which cover matters like licensing, retail tariff-setting, and preparations for the grid's arrival (ESMAP, 2019).

According to Roche et al. (2020), solar–diesel hybrid mini-grids and solar home systems will likely replace a substantial portion of the country's diesel generators, potentially providing electricity to as many as 42.9 million people, or about a fifth of the country's population (ESMAP,

[1] In a recent development, the nongovernmental organisation Socio-economic Rights and Accountability Project sued the federal government over what it described as latter's failure to "reverse the illegal, unfair, and arbitrary increase in electricity rate and to investigate the spending of public funds as 'investments and bailouts' to DisCos (Distribution Companies) and GenCos (Generation Companies) since 2005." (Vanguard Newspapers Editorial, 2023).

2022). Taken together, these developments suggest that mini-grids have the potential to revolutionize the field of affordable, pro-poor, low-carbon, universal electrification in Nigeria (Sesan, 2020). Pedersen (2016, p. 1) describes mini-grids as "a third alternative to rural electrification, coming between the option of large-scale grid extension and pico-scale stand-alone solutions like solar home systems or solar lanterns." From an electricity planning perspective, these systems have particular appeal for historically hard-to-reach populations like those in informal settlements, dispersed locations, and/or remote locations where the cost of connection to the centralized national grid can be prohibitive. Mini-grids can, in principle, help bridge the energy access gap by enabling locally generated and distributed renewable electricity tailored to the needs of local populations.

Notwithstanding these optimistic narratives, however, the deployment of mini-grids poses significant governance, regulatory, and socioeconomic challenges. Indeed, mini-grid development has frequently occurred in the absence of regulation rather than as a result of it, and countries with low levels of electricity access and/or significant levels of inequality—many of them in sub-Saharan Africa—either lack defined rules for such integration or are still developing and revising them (Antonanzas-Torres et al., 2021; Baker et al., 2022). This can create a situation in which the benefits of mini-grids are unevenly distributed among different social groups, with those in the lower socioeconomic classes unable to access the electricity generated due to poverty or lack of resources.

Against this background, our chapter sets out to unpack the governance and regulatory context within which the mini-grid sector in Nigeria is developing. Through this study, we respond to calls from development and energy geographers for a more "refined categorisation and contextualisation" of the decentralization of electricity (Rothfuß & Boamah, 2020, p. 165), and a deeper understanding of the evolving conflict and coexistence between the extension of the national electricity grid and decentralized and off-grid systems (Jaglin, 2019; Jaglin & Guillou, 2020). These calls are, in turn, a response to existing scholarship on rural electrification and energy access in low- and middle-income countries, which has been dominated by perspectives from engineering and economics and tended to privilege technological and financial enablers and barriers. Such perspectives have often focused on narrow definitions of "business models" (Muchunku et al., 2018; cf. Pedersen, 2016) rather than considering the political, economic, and sociocultural complexities of regulation and governance. As a result, and as Ahlborg (2017, 2018) argues, energy access interventions are too

often framed as neutral welfare schemes when, in fact, they are inherently political. This is because in many cases, these interventions introduce large-scale changes to existing energy production and consumption patterns, which can often lead to power imbalances between social groups or classes.

In engaging with these debates, the chapter asks the following questions: What governance and regulatory frameworks exist for the development of mini-grids in Nigeria, and how do they combine with preexisting frameworks for grid electricity to reconfigure patterns of access and distribution? In particular, to what extent have mini-grids in the context enabled rural electrification, and what key governance challenges need to be addressed for more equitable access?

The chapter is structured as follows. Section 11.2 situates mini-grids within the broader context of the electricity sector, highlighting the changing orthodoxies within sub-Saharan Africa over time with regard to ownership and governance structures. Section 11.3 describes the approach taken to empirical research into the governance of mini-grids in Nigeria, while Section 11.4 presents the findings from the fieldwork conducted. Section 11.5 presents conclusions and policy implications of the study.

11.2 Mini-Grids in the Context of Electricity Sector Governance

As a large-scale networked infrastructure and a complex, interconnected, and interactive system of artifacts and technologies (Hughes, 1983; Rip & Kemp, 1998; Smith et al., 2005), electricity is not easily governed. Electricity is subject to vested interests and uncertainty in the adoption of new technologies, and it is influenced by factors such as the nature of domestic, industrial, agricultural, and residential electricity demand, national varieties of capitalism, and national and subnational governance systems (Baker et al., 2021).

In the first half of the twentieth century, the electricity sector, in countries where it was established, was generally a state-owned, vertically integrated monopoly. This gave the government complete control over the production and distribution of electricity, including price regulation, aimed at preventing exploitation and promoting the role of governments as guardians of the welfare state (Sandmo, 1998). However, by the 1980s and 1990s, the "standard model" of power sector reform was established as a global

blueprint, in keeping with the neoliberal economic orthodoxy of the time. In developing countries, this model was promoted by the World Bank and related consultants and endorsed by other multilateral lending institutions as part of loan and debt relief conditionalities under structural adjustment programs (Baker et al., 2022). The model was informed by the experiences of a small group of countries including the United States, UK, Norway, and Chile and followed the assumption that state ownership was unable to meet the high levels of investment required by the electricity sector (Gratwick & Eberhard, 2008). According to such an assumption, state-owned utilities should therefore be unbundled into private generation, distribution, and transmission companies, with a significant role for wholesale markets and, ultimately, retail competition (Sen, 2014). The creation of a strong independent regulator to "regulate the monopoly prone parts" of the industry was also prescribed (Victor & Heller, 2007, p. 7).

Despite the apparent simplicity of the standard model, its implementation was more complex in practice, resulting in various forms of failure, partial implementation, and stranded assets from surplus generation capacity. Given the role of the centralized electricity sector as a strategic source of "revenue, political power, and influence," these donor-driven power sector reforms have often faced resistance from various government departments (Godinho & Eberhard, 2019, p. 10). The model has also been criticized for making broad assumptions about the state's ability to implement it and attract investment, regardless of country context (Sen, 2014). In addition, national regulators have rarely been as empowered per the model's prescriptions, have faced significant political challenges, and have struggled to negotiate the complex contractual and regulatory terms of power sector liberalization (Baker et al., 2021). This implies that the centralized standard model of electricity sector reform is not a one-size-fits-all solution but requires a nuanced approach, acknowledging the geographical, political, and social contexts in which the reform will take place (Foster & Rana, 2020).

While many principles of electricity liberalization remain influential, other socio-technical dynamics have come into play in recent years, not least the deployment of renewable electricity at multiple scales, including that of mini-grids.[2] This deployment has been accompanied by the emergence of new players and the reconfiguration of old ones; changes in national electricity policy, planning, and regulation; and shifting trends

[2] The term mini grid refers to a low-voltage or medium-voltage generation and electricity distribution network which can operate in isolation from the main grid, but also connect to it should the network expand.

in global investment and technological innovation, all of which are fundamentally reshaping the electricity sector (Baker et al., 2022). Developments in decentralized and off-grid renewable systems in particular mean that electricity can now be generated and accessed without the centralized mediation of the transmission or distribution grid (Brisbois, 2020). Debates over the governance of electricity have therefore gone beyond the simplified dichotomy of state versus market to include competition and coexistence between different scales and configurations of centralized and decentralized electricity (Baker & Phillips, 2019).

In many sub-Saharan African countries, there are growing tensions between, on the one hand, incumbent utilities (state-owned and otherwise) largely dependent on conventional technologies, and, on the other hand, new institutions and actors in the renewable energy space that are often private sector–led. The latter largely embody a shift to solar-powered or "third-generation" mini-grids (ESMAP, 2019, p. 26), as distinct from the large hydro and diesel-powered mini-grid schemes from earlier generations led by utilities in countries like Kenya and Tanzania. This shift toward decentralized renewable mini-grids, which began in Kenya in 2011, is now evolving elsewhere on the continent (Pedersen & Nygaard, 2018).

Mini-grids have been conceptualized as a "disruptive innovation" (Verbong & Geels, 2010), given their potential to radically change the way electricity is produced, consumed, purchased, regulated, financed, and paid for and owned. Because they are technologically flexible and modular, mini-grids can cater to needs at multiple scales, from basic services such as lighting, mobile phone charging, and small appliances, for example, fans and radios; to productive uses such as grain milling, water purification, and fish drying; to institutional electricity needs, for example, schools, clinics, and businesses.

Indeed, the potential of third-generation mini-grids is often discursively pitted by the mini-grid industry against that of the aging, indebted, corrupt, capital-intensive, inefficient, vertically integrated, state-owned utility, supplying an increasingly expensive and unreliable source of electricity, from coal, gas-fired, or large hydroelectricity, to a low-consuming user base (AMDA, 2020; Trimble et al., 2016). Such a discourse is accompanied by the assumption that the dynamism of the private sector (New Climate Economy, 2018) and the creative financing that dismantles market constraints (Wohlgemuth & Painuly, 1999) can push forward the roll-out of renewable electricity generation and distribution at scale.

Some of these dynamics are at work in Nigeria, where extensive electricity sector reforms resulted in the unbundling of the erstwhile state-owned grid utility into generation companies (GenCos), distribution companies (DisCos), and a national transmission company by the 2005 Electric Power Sector Reform Act (EPSRA) (Edomah, 2018). Much of the literature on the governance of the sector focuses on the structure of this large-scale networked system, with little reference to what obtains outside the grid (Babatunde et al., 2023; Chukwujindu et al., 2021; Edomah et al., 2016, 2021; Nwozor et al., 2021; Pavanelli et al., 2023). The studies that do explore mini-grid development in areas unserved by the national grid largely focus on issues related to the optimization of power generation, auction systems, and market development (Arowolo et al., 2019; Azimoh & Mbohwa, 2019; Lane et al., 2018; Yakubu et al., 2018), with little reference to the governance context that defines the remit of actors in the sector.

The dearth of literature on the governance of mini-grids in Nigeria is incongruent with the reality of the country's status as a leading market for mini-grids in Africa, having developed frameworks to support private sector investment and prescribe grid-compatible technical standards (ESMAP, 2019). These frameworks are encapsulated in the much-lauded Regulation for Mini-Grids 2016, which sets clear guidelines for deploying mini-grids of varying sizes (up to 1 MW) and configurations (i.e., isolated or interconnected with the national grid) (Regulation for Mini-Grids, 2016, 2017).[3] The perceived market-friendliness of the regulatory climate has spurred a flurry of activity on the ground: According to ESMAP (2022), 2,700 third-generation mini-grids were planned for the country as of that year.

The underrepresentation of mini-grids in the discourse on electricity regulation is consequential in universal access terms, not least because it has largely obscured the primary role of the Rural Electricity Agency (REA)—an implementation arm created by the same power sector liberalization process that established the commercially oriented GenCos and DisCos—in expanding access to unserved and underserved areas. In light of the complexity of institutional arrangements in the sector, it is essential to scrutinize the roles and interests of key actors, with a view to understanding how they converge or diverge to shape the realities of mini-grid expansion and access for local populations.

Drawing on data from qualitative research conducted in Nigeria, our chapter interrogates aspects of the governance and regulatory landscape

[3] The regulation was ratified by the Nigerian Electricity Regulatory Commission in 2017.

as they have enabled the development of the mini-grid sector in some ways and constrained it in others. Importantly, the disparity between the capabilities of DisCos, the substantive "last-mile" operators per the provisions of the 2005 EPSRA, and the constraints highlighted by relevant provisions of the 2016 Regulation for Mini-Grids will be discussed, as will the implications of the status quo for rural electrification in Nigeria. First, though, we describe the approach we took to framing our inquiry and conducting fieldwork in-country.

11.3 Methods

This study relied on both secondary and primary sources of data. Secondary data were obtained through an in-depth review of the academic and gray literatures, including reports published by international institutions such as the World Bank, the United States Agency for International Development, the International Renewable Energy Agency, and the IEA; national policy and other government documents; civil society reports; and national and international media sources.

Primary data were gathered mainly through key informant interviews. A total of 15 in-depth interviews were conducted between March and September 2022 with government officials, the independent electricity regulator, mini-grid developers, representatives of distribution companies, and development finance experts. Interviewees were selected purposively, based on their role in their respective institutions and their positioning in the Nigerian Electricity Supply Industry more broadly.

Detailed interview guides were prepared for each interviewee category. With the exception of one case that allowed for a face-to-face interview, all the interviews were conducted virtually and audio-recorded. All the interviews were fully transcribed—a process that assert, is crucial for gathering accurate data because it encourages greater conversation with the interviewee, improves data quality, better listening and concentration, and the ability to resist the urge to omit or edit out some essential information. This is especially important if, as in our case, the interviewer is familiar with the situation and is therefore prone to assuming that certain details are "known" (Rutakumwa et al., 2020).

The data were coded and analyzed using a structured and rigorous collaborative qualitative analysis approach (Richards & Hemphill, 2018). First, the interview transcripts were studied in detail to enable a fuller grasp

of the data as a whole. Following this, a preliminary "global" codebook with themes, codes, and corresponding definitions was produced from the literature review conducted in earlier phases of the study. This codebook was then iteratively refined to emerge with a grounded version that more adequately reflected the granularity of the primary data gathered. The codes that were generated for the governance and political economy theme through this process included: political context; institutional and regulatory context; macroeconomic conditions; global trade and supply chain issues; public/private/community ownership; tariff-setting; technical standards; grid compatibility; and licensing regulations. It is worth noting that our analysis does not engage with individual provisions of the regulatory code, given that the focus of the chapter is on the dynamic interplay between the regulatory regime and the market environment it has created, rather than on linking particular provisions to specific market outcomes. The latter would be a fruitful subject for further inquiry.

The findings reported below have been anonymized to protect interviewees' confidentiality. Where direct quotes are used, the attribution is just sufficient to establish the context of each quote without revealing any identifying information about the interviewee involved.

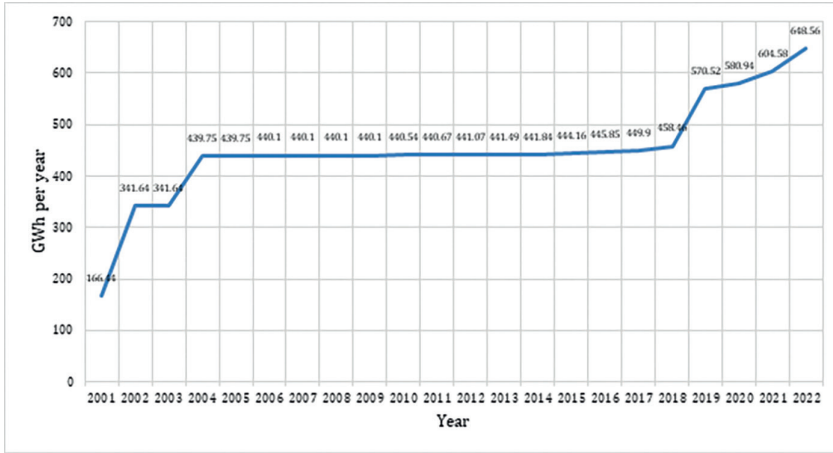
11.4 The Intersection of Mini-Grid Regulation and Market Development in Nigeria

"The market mechanism is as good as the company it keeps."—Sen (2015, p. 126)

This section discusses empirical findings from our inquiry into the regulation and governance of mini-grid development in Nigeria. The findings show how the local mini-grid market has grown alongside, but not necessarily in tandem with, regulatory activity in the sector, with developments in both areas converging and diverging at different points along the way. In particular, Figure 11.1 shows the growth in electricity supply from third-generation mini-grids, typically powered by renewable sources (solar, wind, hydro, biodiesel, and biogas)—with backup provided by fossil fuels—from 2017 to 2022. This is distinct from an earlier spike between 2001 and 2005 that was fueled by the installation of high-capacity gas-powered plants in a handful of states in the country.

While the valorization of private sector investment and ownership models for the acceleration of third-generation mini-grids has turned out to have some merit in the Nigerian case, this growth has occurred under specific conditions, and challenges remain that indicate the need for a

Figure 11.1: Growth in Power Output from Operational Mini-Grids in Nigeria, 2001–2022



Source: Dataset compiled by authors.

more holistic and integrated regulatory response. Three key points stand out for our analysis:

- The growth of the mini-grid market in Nigeria predates regulation and associated development finance, but it has subsequently been shaped by these factors.
- The advent of regulation and investment has helped to accelerate the activities of market actors, but winners and losers have emerged in the process.
- The premise of electrifying last-mile communities through improved regulation and investment for mini-grid expansion is not aligned with institutional and financial realities.

11.4.1 The Growth of the Mini-Grid Market in Nigeria Predates Regulation and Associated Development Finance, but It Has Subsequently Been Shaped by These Factors

In recent times, the Nigerian mini-grid sector has experienced an increase in interest from various stakeholders, including development finance insti-

tutions, donors, investors, and local entrepreneurs. This increase has been driven by a combination of policy changes, technological advances, and greater national commitment to rural electrification.

The development of the local mini-grid market began in the mid-1990s when international companies such as German multinational Siemens began installing solar PV systems in Lagos, Nigeria's commercial capital. These companies brought in the funding and technology needed to create a mini-grid market, increasing the viability of solar energy options locally. Indigenous companies soon began to follow suit and quickly garnered substantial shares of the local market. These indigenous companies, mainly startups launched by a handful of enterprising individuals, were key to the early domestication and spread of the technology, at least for niche uses:

> *Then, it was only Siemens in Oshodi and a few others that were doing solar in Nigeria. Siemens and Solarmate at Yaba. Solarmate started in 1996. So, he was like a father to us. We converged there to buy materials in 1997, 1998 and 2000. In 2004, we incorporated as a limited liability company because most of those Siemens businesses pulled out of Nigeria. So, they subcontracted most of us and what we did was to incorporate so they could give us a maintenance contract. In those days the places you see solar panels are either in NGO-run hospitals or [telephone-company] base stations. There are these [telephone-company] base stations that have solar panels and that is part of the projects we did then.*
>
> *Project Developer_Company 1_CEO*

While the element of cooperation between international and local companies was conducive to early market penetration, it was the entrepreneurial drive of the latter that led to the expansion of the market and helped foreground the economic and social development opportunities presented by solar energy technologies.

In particular, local entrepreneurs, by dint of experience and foresight, were quick to see the value proposition of deploying solar energy technologies in off-grid rural areas. The combination of technical expertise and knowledge of the context put them in a position to adapt existing technologies to the realities of local conditions. Early community-scale projects implemented with the support of development partners such as GIZ

revealed the need to build delivery models that encouraged cost recovery and therefore had a higher chance of achieving financial sustainability:

> *We pioneered mini-grids with meters in 2010 in Onitsha with UNDP where we did the first mini-grid that was metered. They found out that the market was large but the bottleneck was energy to automate production. So, there is a lot of [animal] hide coming from Kaduna, there are willing hands to work, there is demand, but they can't produce at pace and that is where the idea came up to do a mini-grid. Then a sustainable plan beyond UNDP came up. How do we run it in a sustainable way? It means someone had to pay for it so that the money could be used to run the system. That is how we started talking about how to meter the system. So early in those days, there were no mini grids and that is how we started mini grids.*
>
> *Project Developer_Company 1_CEO*

The market ambled along with very little support until the ratification of the Regulation for Mini-Grids by the independent Nigerian Electricity Regulatory Commission in 2017, at which point the economic incentive to invest in mini-grids increased significantly. The regulation provides a legal framework for local developers and investors to accelerate the provision of mini-grid electricity to rural areas not served by the national grid. Importantly, it clearly outlines terms and requirements for the participation of all the actors involved. For example, it stipulates varying degrees of accreditation and compliance for different levels of investment in a bid to lower barriers to entry for smaller electricity generators. This approach enables developers to set cost-reflective tariffs and ensures that they do not take advantage of their customers by charging higher tariffs than is necessary.

Provisions like this encouraged local developers, including some of the early comers to the market, to scale up their investment in mini-grids in the aftermath of the regulation. On the whole, developers agree that the regulation has provided clarity on the roles and responsibilities of stakeholders, set the rules for the operation and management of mini-grids, and helped create an enabling environment for private sector investment, even if areas of uncertainty remain:

> *We are coming full circle where we have given this permit and we are testing the waters with coming to see the quality of the regulatory environment*

> *because investors come in and do their due diligence; that is where you put those documents to test. So, we are having a lot of tweaking, here and there, trying to adjust the documents to suit investors' appetite so that it can be a broadly accepted document, not just locally but within. But with some untested provisions…. There are still some grey areas that need to be worked out to align with what investors would be comfortable with.*
>
> *Project Developer_Company 1_CEO*

Concurrently with the introduction of the Regulation for Mini-Grids, the Nigerian government secured major development financing for the sector in the form of a joint US$550 million loan from the World Bank and the African Development Bank. Termed the Nigeria Electrification Project (NEP) and launched in 2018, the intervention extended technical advice and credit to the country's REA, which, in turn, awarded performance-based grants to private companies for the development of off-grid electrification projects in rural areas.[4] A key goal of the project was to prime the pump investment-wise and consequently catalyze the growth of the mini-grid market in the country. The NEP funding was closely tied to the development of the Regulation for Mini-Grids, in which the World Bank played a major role:

> *You recall the regulator, five or six years ago, approved the Mini-grid Regulation, so that was actually the work that we did behind the scenes to support that process…we came in and advised on how to expand access more efficiently, which is by categorising these customers to unserved and the underserved, and then try to see those customers that are not within the coverage of the distribution companies, and then work possibly on what the regulation can actually do to create this framework that would allow mini-grid developers to extend access to them. Those were the contributions we made.*
>
> *DFI_World Bank_Energy Specialist*

According to ESMAP (2022), the NEP constitutes the largest mini-grid program in Africa with a target of 850 projects and an approximate capacity of 3,000 MW across 250 sites by 2025. Market orthodoxy has featured strongly in the design and implementation of the NEP—an

[4] More details on NEP can be found here: https://projects.worldbank.org/en/projects-operations/project-detail/P161885

unsurprising outcome given the neoliberal underpinnings of the development finance institutions supporting the scheme. So far, the project's hopes of encouraging market growth through initial seed investments appear to have materialized to a degree, at least according to some developers:

> *Then, for the NEP, we have well over 20 projects. We have signed a grant agreement for 14. We have completed 6 and 8 are under construction at the moment. So that is where we are. Out of the 6 projects, 4 are here in Abuja and 2 are in Niger State. This is for the completed projects. We are building 8 more and out of 8, 2 are currently at an advanced stage so we are at different levels of construction and operation under the NEP projects.*
>
> *Project Developer_Company 1_CEO*

> *I think to date we have four projects operational and by the end of this month we will be commissioning an additional 26, making the total mini-grids we have in the country to about 30, serving about 200,000 people across those 30 communities…. Last year, we closed about $4.6 million to build the additional 26 projects which we are about completing.*
>
> *Project Developer_Company 3_CEO*

The upshot of the above is that the regulatory environment has helped to grow the mini-grid market, with small- and medium-scale developers moving from simple Engineering, Procurement, and Contracting models in the early days to relatively sophisticated micro-utility models that are more conducive to financial and technical sustainability. As the chapter goes on to show, however, this market growth has not occurred evenly, with implications for the country's ability to meet the goal of expanding electricity access to rural areas.

11.4.2 The Advent of Regulation and Investment Has Helped to Accelerate the Activities of Market Actors, but Winners and Losers Have Emerged in the Process

The previous section showed how the Nigerian mini-grid market grew from the efforts of a handful of bootstrapping entrepreneurs to become a burgeoning sector supported by a robust regulatory framework and development financing over the course of two decades. This section elab-

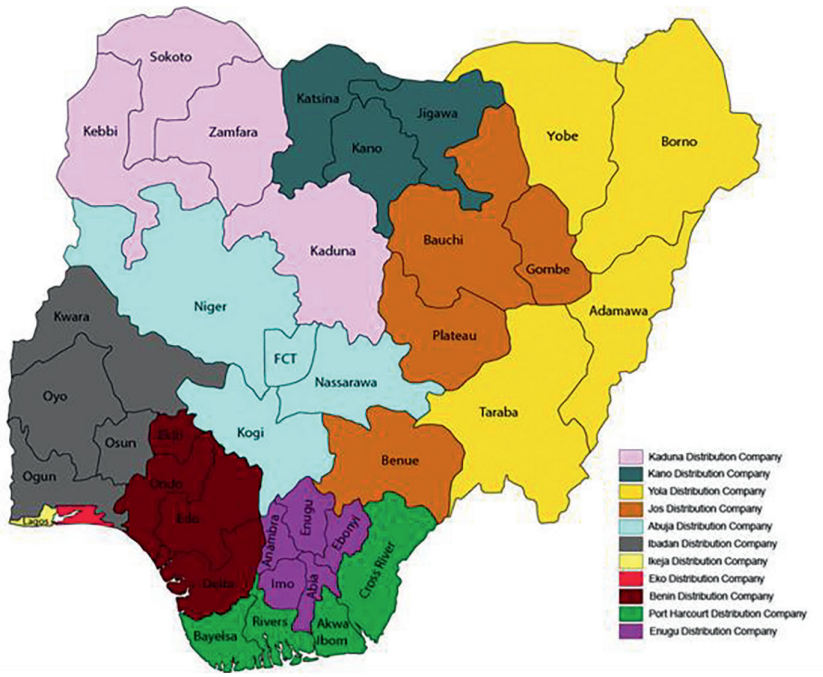
orates on how the gains resulting from this process have not been distributed as evenly as may be required to achieve the kind of broad market participation envisaged by regulatory and finance actors in the context.

Mini-grid investments in the Nigerian context are generally perceived as risky and challenging due to a host of unfavorable macroeconomic factors. These factors include a weakening local currency, fluctuating exchange rates of the Naira against other currencies, rising inflation, and lack of clarity over tax regulation. These issues are particularly consequential for the mini-grid sector because it is heavily reliant on imported components, from the photovoltaic panels used for solar energy generation, to the batteries used for storage and the smart meters that enable transparent billing. In the absence of affordable local credit, many developers take on debt in foreign currency—usually US dollars—and find their loan amounts doubling or tripling in real terms over the space of a few years due to a steep decline in the value of the Nigerian naira, which is the currency in which their transactions are denominated (Oladipo & Ndigwe, 2022). In this kind of macroeconomic environment, only the most resilient developers survive—and these include several local companies (such as the ones referenced above) that struck out early and were well positioned to seize the opportunity presented by the regulatory and financial incentives introduced to catalyze growth in the mini-grid market.

The drawback to this development is that it has essentially created a rather narrow pool of legacy "winners" who may be more concerned about protecting their advantage in the market than they are about expanding opportunities for others in the sector:

> *So, I came up with, okay, let's develop a site selection criteria framework, whereby any new entrant that comes into the business will not make the same mistake the pioneer developers made…. So we did that and we spoke to everybody. But what we saw was the big guys would say no, that they already knew these things. I said, "yes, fine you guys are the big guys, but there are new people coming into the sector, they have not experienced what you've experienced. They will need a guide or a tool or something that will help them know." So yes, there will always be people that will think that a generic [framework] is not the best idea, because when I spoke with some developers, they did not want to share theirs. They felt it was their intellectual property.*
>
> *Business Developer_Company 1_Consultant*

Figure 11.2: Coverage Area of Electricity Distribution Companies in Nigeria



Source: https://nerc.gov.ng/index.php/contact/discos.

On the other hand, there is the broader question of why the DisCos, with their assumed power of incumbency and wide geographical coverage (see Fig. 11.2), have not played a more prominent role in the current mini-grid era.

There are several factors that might warrant an expectation of the opposite: the World Bank's Energy Sector Management Assistance Programme (ESMAP), for example, argues that mini-grids, whether they are interconnected or isolated, generally achieve higher levels of reliability for their customers than DisCos in Nigeria do through the national grid. ESMAP further asserts that mini-grids that interconnect with the distribution grid will create positive economic outcomes for DisCos, mini-grid operators, and customers alike (ESMAP, 2022). In the same vein, Howard (2022) states that DisCos in the Nigerian context play "a key role in a value chain that relies on their ability to provide last-mile connections and generate revenue." Notwithstanding these positive prognoses regarding the utility of DisCos for expanding electricity access in Nigeria, however, they have been largely missing from efforts to reach last-mile communities with mini-grid electricity.

A closer look at the broader regulatory environment beyond the 2016 Regulation for Mini-Grids sheds some light on the reasons for the seeming discrepancy between DisCos' apparent relevance and their diminished role in the mini-grid sector. It would appear that the 2005 EPSRA, which unbundled the state-owned utility into 7 generation companies, 11 distribution companies and a national transmission company predetermined what is possible and/or profitable for each of those entities to do in the mini-grid regime that followed a decade later.

As such, by design, there are limited incentives for DisCos to invest in mini-grid development. Crucially, the remit of DisCos, as spelled out in the 2005 EPSRA, is limited to electricity distribution and does not extend to generation, which is a defining attribute of mini-grid operation. DisCo officials acknowledged in interviews that it is possible, at least in theory, for the companies to incorporate subsidiary entities that can invest independently in mini-grid electricity generation. In practice, however, this is not an option that many DisCos are willing to contemplate given that their current operations are hobbled by low technical and financial capacity. The option to partner with smaller developers on interconnected mini-grid schemes is potentially more appealing;[5] again, however, this is a nascent sector that the generally risk-averse DisCos approach with caution.

The DisCos' financial problems persist despite the recent infusion of development finance (to the tune of US$1.743 billion) into the sector under the World Bank–supported Nigeria Distribution Sector Recovery Programme (DISREP) launched in 2021.[6] A key objective of DISREP is to provide DisCos with funding for capital expenditure and infrastructure improvements, with a view to enhancing electricity distribution, reducing technical losses and consequently increasing revenue generation (Federal Ministry of Power, 2020). Given this background, many DisCos are not interested in taking on mini-grid development within their jurisdiction, as this seems guaranteed to increase their transaction costs without assuring them of profit. The current strategy for most DisCos is therefore to focus on consolidating their financial position with their existing grid customer base:

> *The DisCos are more concerned about reducing losses from the existing networks and not looking out to create islands where they have to worry.*
>
> *Utility_Benin DisCo_Regulatory Affairs*

[5] Interconnected mini-grids can boost supply in underserved areas. Although private developers were expected to partner with DistCos for the deployment, only a handful of DistCos have welcomed collaboration with developers.
[6] More details can be found here: https://projects.worldbank.org/en/projects-operations/project-detail/P172891

The subtext in the above assertion is that the rural areas that the 2005 EPSRA and 2016 Regulation for Mini-Grids conceive of as being the primary beneficiaries of isolated mini-grids are not profitable for DisCos, a point that comes across more clearly in the following quotes:

> *Priority will be given to expanding the [DisCo] networks to where the returns vis-a-vis the endeavour will be substantial, and that is why network expansions are more likely to be in the areas where there are high cluster industrial areas than in communities that are just going to return pennies.*
>
> *Utility_Benin DisCo_Regulatory Affairs*

> *The DisCos will never go to the rural areas because it is not economical for them. The value of going there is zero.*
>
> *Business Developer_Company 1_Consultant*

This raises the question of how sound the premise of electrifying rural areas through improved regulation and financing for mini-grid expansion is. On the one hand, the small- and medium-scale developers that have benefitted from the existing regulations do not have the economies of scale to expand access to rural areas at competitive costs. On the other hand, the DisCos that have the required institutional and geographical reach do not find the idea of extending their services to rural customers a worthwhile proposition. The following section discusses the implications of this tension for electricity access expansion in more detail.

11.4.3 The Premise of Electrifying Last-Mile Communities Through Improved Regulation and Investment for Mini-Grid Expansion Is Not Aligned with Institutional and Financial Realities

At the time of the privatization of the Nigerian Electricity Supply Industry (NESI), about 90 million people nationwide were not connected to the main grid (Onaguruwa, 2011). A core objective of the 2005 EPSRA was to bridge this access gap by extending electricity to hitherto unserved populations around the country, the majority of them in rural areas. The institution mandated by the Act to achieve this objective of last-mile electrification was the REA and the associated Rural Electrification

Fund (REF), both established in 2006 (Baker et al., 2022). Underlying the creation of a dedicated institution to administer rural electrification initiatives was a recognition that the commercial model envisaged for the newly established DisCos and GenCos would necessarily differ from that for customers in poorer rural areas who exist on the periphery of mainstream electricity markets.

Importantly, the provisions made for rural electrification in the EPSRA encompass a broad range of delivery mechanisms, including the expansion of both grid and off-grid systems, and involving contributions from both public and private sector actors. In other words, the mandate of rural electrification in the country predated the current focus on off-grid solutions and was agnostic with regard to the means for achieving the goal of universal access. Since the arrival of mini-grids on the national scene, however, the REA has de-emphasized alternative solutions, leaving private sector–led—albeit publicly subsidized—mini-grid deployment (and, to a lesser extent, stand-alone solar systems) as the dominant model for rural electrification.[7] The widespread appeal of this model notwithstanding, the uneven dynamics of market participation observed in the wake of the 2016 Regulation for Mini-Grids suggest that its valorization of a commercial approach to mini-grid development needs to be weighed against its ability to serve the rural poor in way that helps achieve, in the words of the EPSRA, "more equitable regional access to electricity" (Electric Power Sector Reform Act, 2005, p. A.120).

The Regulation for Mini-Grids has, in many ways, enabled the REA to approach its mandate with greater transparency and legitimacy. In particular, stringent donor requirements guiding the allocation and disbursement of NEP funds have helped the agency sidestep pressure from other arms of government to implement politically motivated projects that almost invariably lack technical or economic merit[8]. The penchant for undue political influence has been a bane of rural electrification projects in the past[9] (see also Osunmuyiwa et al., 2018), with change only coming from recent reforms championed by the REA:

> *Part of the budget emanates from us and the rest comes from the National Assembly, and they have the power to even change what we present to them.…*

[7] All REA initiatives are geared towards boosting commercial viability of off-grid schemes implemented by private developers.
[8] More details on NEP projects can be found here: https://nep.rea.gov.ng/
[9] Stories of corruption are reported regularly in the national press. An example can be found here: https://guardian.ng/news/court-jails-five-rea-ex-directors-over-n5-2b-project-fraud/

> *They have, as we say in Nigerian parlance, they have the yam and the knife. But we try to employ stakeholder management before the budget is passed… we're there to advise them technically, professionally as to, for instance, what it would cost to provide a transformer, as opposed to doing it arbitrarily, and how much it would cost to extend a grid from a certain community to the other, and what technology should even be considered—should it be solar, SHS, or whatever. This has been yielding some fruit.*
>
> *Government Department_REA_Official* 1

However, while the recent successes recorded by the REA under the auspices of the 2016 Regulation for Mini-Grids and the NEP have enabled a significant boost in technical, institutional, and financial capacity, there remain real limitations to the agency's ability to deliver on its mandate of ensuring equitable distribution of electricity access under the current regulatory regime. This is because, even with capital subsidies that are available to private mini-grid developers under the NEP, the electricity arrives in rural areas at a cost that is typically unaffordable for the average household or business. The costs are even higher for mini-grid projects that do not have access to these publicly funded subsidies, resulting in tariffs that are several times higher than those for grid-connected populations and exacerbating the inequities in electricity access between rural and urban areas:

> *According to the mini grid regulatory framework, that framework allows mini-grid developers to charge what we call a cost-reflective tariff. Now, typically, across most mini grids…tariff ranges from about 130 per kilowatt hour to about 180 per kilowatt hour. Now, you may want to argue that it is relatively high compared to what those of us in the urban area pay, you know, 50 to 60 naira, but the truth is that as of today Nigerians don't pay the true cost of electricity.*
>
> *Project Developer_Company 3_CEO*

In sum, our findings indicate that a more holistic assessment of the role of mini-grids in Nigeria's rural electrification outlook is required, one that prioritizes the goal of equitable access alongside that of regulatory efficiency. The chapter concludes with recommendations for how to achieve this.

11.5 Conclusions and Policy Implications

This chapter has analyzed the regulatory framework governing mini-grid development in Nigeria within the context of broader developments in the NESI. Our analysis goes further than the majority of existing studies on the NESI that, to the extent that they explore the dynamics of mini-grid development in the country, tend to do so from a largely techno-economic perspective. Our findings highlight the wins that the country has recorded in mini-grid regulation and investment especially in the last half-decade; at the same time, our findings highlight also the challenges of access evinced by these strides and their implications for the achievement of the national and global goals of rural electrification and universal energy access, respectively. Crucially, we argue that contradictions in the overall regulatory landscape restrict the ability of various actors to leverage the opportunities presented not just by mini-grids but also by other potential solutions (including conventional grid options), and these need to be resolved if electricity is to be accessible for the majority of rural dwellers.

The chapter has shown how the "standard model" of electric sector governance has led to underwhelming outcomes in Nigeria, creating a cohort of generation and distribution companies that mostly lack the institutional capacity to supply reliable power to customers on the national grid. The status quo represents a case of stalled liberalization in many respects: The state has had to keep subsidizing the private investors that took over the grid utility in the wake of the EPSRA (Akintayo, 2022), and, according to recent media reports, the state maintains 40% ownership of all DisCos to ward off potential liquidation of the companies (The Nation Editorial, 2022). Furthermore, many of the companies are heavily indebted to Nigerian commercial banks, partly because they continue to struggle with revenue collection and infrastructure maintenance—which, in turn, are occasioned by operational difficulties such as persistent metering gaps and electricity theft.

It is against this background that smaller and more dynamic developers have emerged on the national mini-grid scene. For isolated mini-grids in rural areas of the country at least, the tensions observed by Baker and Phillips (2019) between legacy utilities and newer decentralized actors in other country contexts is not apparent, as the latter have seemingly stepped into a lacuna resulting from the interplay of technical, financial, and regulatory factors in the broader electricity industry. Indeed, the

activities of these smaller developers—as well as the regulation governing them—are viewed as a relatively quick fix for lingering problems in the electricity sector that can be traced back to earlier regulatory regimes. Our analysis has shown that the current regulatory era, while it has boosted the efficiency of decentralized electricity markets, has had limited effectiveness in terms of its ability to substantially reconfigure unequal patterns of electricity distribution, with the most disadvantaged populations remaining poor rural dwellers at the last mile. The following recommendations emerge from our analysis as being potentially relevant for enhancing regulation and financing that are more responsive to the needs of those populations.

Harmonize the regulatory environment. Much attention has been paid to the 2016 Regulation for Mini-Grids by public and private actors alike given its apparent relevance for the growth of the sector. Attempts to improve on the regulation tend to be forward-looking: A review process was recently launched, for instance, and the National Assembly has proposed a new piece of legislation targeting renewable energy more broadly. Our findings, however, indicate that progress can also be facilitated by looking back to the 2005 EPSRA and revising provisions that are out of step with current realities, such as restrictions on the size of mini-grids and protections that make DisCos impermeable to competition even when they fail to deliver power to their customers.[10]

Situate mini-grid development within the broader framework of rural electrification policy. More than 30,000 Nigerian households and businesses have gained access to electricity from mini-grids to date,[11] signaling that the technology has an important role to play in the country's electrification strategy. However, this still represents a fraction of the population, and, considering the challenges of affordability faced by rural dwellers, progress on this front will likely be slow. Consequently, mini-grids are perhaps better viewed as one of several possible means of achieving the overall policy goal of rural electrification. Broadening the perspective in this way will allow for the consideration of a range of regulatory and financing mechanisms, including the commitment of significant public funding that has historically enabled the electrification of poor rural populations (Karekezi & Majoro, 2002).

[10] The Electricity Act 2023has introduced liberalisation of the power sector and provides a framework for prevention of anti-competitive behaviour. The impact of this act on mini-grids remains to be seen however.

Institutionalize mechanisms for transparent governance of the sector. The mini-grids implemented under the NEP have exhibited a high degree of transparency, largely due to the provisions of the Regulation for Mini-Grids and stringent donor requirements for administering program funds. While this is a win, it falls short of what is required to institutionalize mechanisms for allocating and disbursing funds for rural electrification at the national level. In particular, attention needs to be paid to strengthening the autonomy of the REA to make technical decisions with minimal influence from political actors.

Review regulatory provisions to unlock latent subsidies for rural electrification. The REF set up by the 2005 EPSRA makes provision for the cross-subsidization of tariffs between urban and rural dwellers, a mechanism that enables the latter to pay relatively low rates for electricity (Azimoh, 2016). However, the overall subsidy amount available is undermined by low rates of electrification in urban areas—a situation that can be improved by increasing electricity supply to those wealthier areas, including through opening up existing DisCos to competition from isolated mini-grids. Future reviews of the EPSRA and the Regulation for Mini-Grids should integrate provisions that allow for greater complementarity between different segments of the electricity market so that the needs of all can be met.

Acknowledgments

This study was conducted as part of the "Sustainability, Inclusiveness and Governance of Mini grids in Africa" (SIGMA) project funded by the UK Global Challenges Research Fund, Grant Number ES/T006684/ 1 and 2.

The authors are grateful to Anna Pueyo, Dramani Bukari, Shukuru Meena, Elsie Onsongo, Muyiwa Oyinlola, Estomih Sawe, Yuri Handem, Beryl Onjala, and Maneno Katyega for their comments on an earlier version of the paper.

References

ACE-TAF. (2022). *State Off-Grid Solar – Nigeria*. Africa Clean Energy Technical Assistance Facility. https://www.ace-taf.org/wp-content/uploads/2022/07/State-Off-Grid-Solar-Policy-Brief-NIGERIA-2.pdf

Ahlborg, H. (2017). Towards a conceptualization of power in energy transitions. *Environmental Innovation and Societal Transitions*, *25*, 122–141. https://doi.org/10.1016/j.eist.2017.01.004

Ahlborg, H. (2018). Changing energy geographies: The political effects of a small-scale electrification project. *Geoforum*, *97*, 268–280. https://doi.org/10.1016/j.geoforum.2018.09.016

Akintayo, O. (2022). Should Nigeria reverse nine-year power privatisation? *Punch Newspapers*. https://punchng.com/should-nigeria-reverse-nine-year-power-privatisation/

AMDA. (2020). *Benchmarking Africa's Mini Grids*. Africa Minigrid Developers Association. https://africanpowerplatform.org/resources/2458-benchmarking-africa-s-minigrids.html

Antonanzas-Torres, F., Antonanzas, J., & Blanco-Fernandez, J. (2021). State-of-the-art of mini grids for rural electrification in West Africa. *Energies*, *14*(4), 990. https://doi.org/10.3390/en14040990

Arowolo, W., Philipp Blechinger, C. C., & Perez, Y. (2019). Seeking workable solutions to the electrification challenge in Nigeria: Minigrid, reverse auctions and institutional adaptation. *Energy Strategy Reviews*, *23*, 114–141. https://doi.org/10.1016/j.esr.2018.12.007

Azimoh, C. L. (2016). *Sustainability and development impacts of off-grid electrification in developing countries: An assessment of South Africa's rural electrification program*. Mälardalen University Press.

Azimoh, C. L., & Mbohwa, C. (2019). Optimized solution for increasing electricity access with mini-grid technology in Nigeria. *Journal of Sustainable Development*, *12*(1), 156. https://doi.org/10.5539/jsd.v12n1p156

Babatunde, O., Buraimoh, E., Tinuoye, O., Ayegbusi, C., Davidson, I., & Ighravwe, D. E. (2023). Electricity sector assessment in Nigeria: The post-liberation era. *Cogent Engineering*, *10*(1), 2157536. https://doi.org/10.1080/23311916.2022.2157536

Baker, L., Hook, A., & Sovacool, B. K. (2021). Power struggles: Governing renewable electricity in a time of technological disruption. *Geoforum*, *118*, 93–105. https://doi.org/10.1016/j.geoforum.2020.12.006

Baker, L., & Phillips, J. (2019). Tensions in the transition: The politics of electricity distribution in South Africa. *Environment and Planning C: Politics and Space*, *37*(1), 177–196. https://doi.org/10.1177/2399654418778590

Baker, L., Sesan, T., Bhattacharyyra, S., Pueyo, A., Bukari, D., Meena, S., Onsongo, E., Oyinlola, M. T., Sawe, E., Otu-Eleri, E., Uduka. U., Handem, Y., Onjala, B., & Katyega, M. (2022). *Of monopolies and mini grids: Case studies from Kenya, Tanzania, Nigeria and Senegal* (SIGMA Working Paper 1). https://static.s123-cdn-static-d.com/uploads/3093860/normal_62f3d6304c7b0.pdf

BloombergNEF. (2019). *Solar for businesses in Sub-Saharan Africa*. https://data.bloomberglp.com/professional/sites/24/BNEF_responsAbility-report-Solar-for-Businesses-in-Sub-Saharan-Africa.pdf

Brisbois, M. C. (2020). Shifting political power in an era of electricity decentralization: Rescaling, reorganization and battles for influence. *Environmental Innovation and Societal Transitions*, *36*, 49–69. https://doi.org/10.1016/j.eist.2020.04.007

Chukwujindu, O., Ukeje, I., Ekwunife, R., & Nwangbo, S. (2021). Management innovation and power sector governance in Nigeria. In Ali Farazmand (Ed). *Global Encyclopedia of Public Administration, Public Policy, and Governance* (pp. 1–13). Springer.

Cozzi, L., Contejean, A., Samantha, J., Dasgupta, A., Rouget, A., & Arboleya, L. (2020). *The Covid crisis is reversing progress on energy access in Africa*. International Energy Agency.

Edomah, N. (2018). Historical drivers of energy infrastructure change in Nigeria (1800–2015). In S. Gokten & G. Kucukkocaoglu (Eds.), *Energy management for sustainable development*. IntechOpen. https://doi.org/10.5772/intechopen.74002

Edomah, N., Foulds, C., & Jones, A. (2016). Energy transitions in Nigeria: The evolution of energy infrastructure provision (1800–2015). *Energies*, *9*(7), 484. https://doi.org/10.3390/en9070484

Edomah, N., Ndulue, G., & Lemaire, X. (2021). A review of stakeholders and interventions in Nigeria's electricity sector. *Heliyon*, *7*(9), e07956. https://doi.org/10.1016/j.heliyon.2021.e07956

Electric Power Sector Reform Act, Pub. L. No. 6, A77. (2005). https://nerc.gov.ng/resources/electric-power-sector-reform-act-2005/

ESMAP. (2019). *Mini grids for half a billion people: Market outlook and handbook for decision makers (2019)* (Technical Report No. 014/19). Energy Sector Management Assistance Program.

ESMAP. (2022). *Mini grids for half a billion people: Market outlook and handbook for decision makers*. Energy Sector Management Assistance Program. https://documents1.worldbank.org/curated/en/099635009232259510/pdf/P1751510dd4ab407e083a6098d1905fa94f.pdf

Federal Ministry of Power. (n.d.). *Nigeria SE4All: Mini-grids*. https://nigeriase4all.gov.ng/mini-grids

Federal Ministry of Power. (2020). *Nigeria Distribution Sector.* Recovery Program (DISREP) Environmental and Social Management Framework.

Foster, V., & Rana, A. (2020). *Rethinking power sector reform in the developing world*. International Bank for Reconstruction and Development/The World Bank.

Godinho, C., & Eberhard, A. A. (2019). *Learning from power sector reform experiences: The Case of Kenya'*. http://documents.worldbank.org/curated/en/451561555435655366/Learning-from-Power-Sector-Reform-The-Case-of-Kenya

Gratwick, K. N., & Eberhard, A. (2008). Demise of the standard model for power sector reform and the emergence of hybrid power markets. *Energy Policy*, *36*(10), 3948–3960. https://doi.org/10.1016/j.enpol.2008.07.021

Howard, M. (2022). Between Aso Rock and a hard place: Nigerian disco privatisation's very public problems. *Africa Energy*. https://www.africa-energy.com/news-centre/article/between-aso-rock-and-hard-place-nigerian-disco-privatisations-very-public

Hughes, T. P. (1983). *Networks of power: Electrification in Western Society, 1880–1930*. Johns Hopkins University Press.

IEA. (2019). *Access to electricity*. International Energy Agency. https://www.iea.org/reports/sdg7-data-and-projections/access-to-electricity

Jaglin, S. and Guillou, E. (2020) 'Decentralized electricity solutions: Innovation in essential services is no substitute for policy', The Veolia Institute Review – FACTS Reports, 22, pp. 58–63. Available at: https://journals.openedition.org/factsreports/6326

Jaglin, S. (2019). *Off-grid Electricity in sub-Saharan Africa: From rural experiments to urban hybridisations*. https://shs.hal.science/halshs-02078148

Jaglin, S. and Guillou, E. (2020) 'Decentralized electricity solutions: Innovation in essential services is no substitute for policy', The Veolia Institute Review – FACTS Reports, 22, pp. 58–63. Available at: https://journals.openedition.org/factsreports/6326

Karekezi, S., & Majoro, L. (2002). Improving modern energy services for Africa's urban poor. *Energy Policy*, *30*(11–12), 1015–1028. https://doi.org/10.1016/S0301-4215(02)00055-1

Lane, J., Hudson, W., Walley, L., & Hamden, Y. L. (2018). *Mini-Grid Market Opportunity Assessment: Nigeria*. SE4ALL Africa Hub & African Development Bank. https://greenminigrid.afdb.org/sites/default/files/minigrid_market_opportunity_assessment_nigeria_june_2018.pdf

Muchunku, C., Ulsrud, K., Palit, D., & Jonker-Klunne, W. (2018). Diffusion of solar PV in East Africa: What can be learned from private sector delivery models? *WIREs Energy and Environment*, *7*(3). https://sdgs.un.org/publications/publication-unlocking-inclusive-growth-story-21st-centuryaccelerating-climate-action

New Climate Economy. (2018). *Unlocking the inclusive growth story of the 21st century: Accelerating climate action in urgent times*. https://newclimateeconomy.report/2018/

Nwozor, A., Oshewolo, S., Owoeye, G., & Okidu, O. (2021). Nigeria's quest for alternative clean energy development: A cobweb of opportunities, pitfalls and multiple dilemmas. *Energy Policy*, *149*, 112070. https://doi.org/10.1016/j.enpol.2020.112070

Ockwell, D., & Byrne, R. (2016). *Sustainable Energy for All: Innovation, technology and pro-poor green transformations* (1st ed.). Routledge. https://doi.org/10.4324/9781315621623

Odarno, L., Sawe, E., Swai, M., Katyega, M. J. J., & Lee, A. (2017). *Accelerating mini-grid deployment in Sub-Saharan Africa: Lessons from Tanzania*. World Resources Institute. https://files.wri.org/d8/s3fs-public/accelerating-mini-grid-deployment-sub-saharan-africa_1.pdf

Oladipo, O., & Ndigwe, C. (2022). Solar eludes electricity-starved Nigerians on FX crisis. *BusinessDay Newspapers*. https://businessday.ng/energy/article/solar-eludes-electricity-starved-nigerians-on-fx-crisis/

Onaguruwa, B. (2011). *A presentation to the West African Power Industry Convention*. https://www.esi-africa.com/conference-papers/west-african-power-industry-convention-wapic-conference-program-2011/

Osunmuyiwa, O., Biermann, F., & Kalfagianni, A. (2018). Applying the multi-level perspective on socio-technical transitions to rentier states: The case of renewable energy transitions in Nigeria. *Journal of Environmental Policy & Planning*, *20*(2), 143–156. https://doi.org/10.1080/1523908X.2017.1343134

Pallavi, R. (2020). *The potential of small and medium enterprises: Off-grid solutions to corruption in Nigeria's electricity sector*. Anti-Corruption Evidence Research Consortium. https://ace.soas.ac.uk/publication/the-potential-of-small-and-medium-enterprises-off-grid-solutions-to-corruption-in-nigerias-electricity-sector/

Pavanelli, J. M. M., Sang, E. V., de Oliveira, C. E., dos Reis Campos, F., Lazaro, L. L. B., Edomah, N., & Igari, A. T. (2023). An institutional framework for energy transitions: Lessons from the Nigerian electricity industry history. *Energy Research & Social Science*, *97*, 102994. https://doi.org/10.1016/j.erss.2023.102994

Pedersen, M. B. (2016). Deconstructing the concept of renewable energy-based mini-grids for rural electrification in East Africa. *WIREs Energy and Environment*, *5*(5), 570–587. https://doi.org/10.1002/wene.205

Pedersen, M. B., & Nygaard, I. (2018). System building in the Kenyan electrification regime: The case of private solar mini-grid development.

Energy Research & Social Science, *42*, 211–223. https://doi.org/10.1016/j.erss.2018.03.010

Peters, J., Sievert, M., & Toman, M. A. (2019). Rural electrification through mini-grids: Challenges ahead. *Energy Policy*, *132*, 27–31. https://doi.org/10.1016/j.enpol.2019.05.016

Power Africa. (2022). *Nigeria Power Africa Fact Sheet*. https://www.usaid.gov/powerafrica/nigeria (this website has been discontinued by the US administration in 2025).

Regulation for Mini-grids 2016. (2017). https://minigrid.nerc.gov.ng/assets/documents/20160323%20NERC%20Draft%20Mini-Grid%20Regulations%202016.html

Richards, K. A., & Hemphill, M. A. (2018). A practical guide to collaborative qualitative data analysis. *Journal of Teaching in Physical Education*, *37*(2). https://doi.org/10.1123/jtpe.2017-0084

Rip, A., & Kemp, R. (1998). Technological change. In S. Rayner & E. L. Malone (Eds.), *Human choice and climate change: Vol. II, Resources and technology* (pp. 327–399). Batelle Press.

Roche, M. Y., Verolme, H., Agbaegbu, C., Binnington, T., Fischedick, M., & Oladipo, E. O. (2020). Achieving sustainable development goals in Nigeria's power sector: Assessment of transition pathways. *Climate Policy*, *20*(7), 846–865. https://doi.org/10.1080/14693062.2019.1661818

Rothfuß, E., & Boamah, F. (2020). Politics and (self)-organisation of electricity system transitions in a Global North–South perspective. *Politics and Governance, 8*(3), 162–172. https://doi.org/10.17645/pag.v8i3.3636

Rutakumwa, R., Mugisha, J. O., Bernays, S., Kabunga, E., Tumwekwase, G., Mbonye, M., & Seeley, J. (2020). Conducting in-depth interviews with and without voice recorders: A comparative analysis. *Qualitative Research*, *20*(5), 565–581. https://doi.org/10.1177/1468794119884806

Saifuddin, N., Bello, S., Fatihah, S., & Vigna, K. R. (2016). Improving electricity supply in Nigeria: Potential for renewable energy from biomass. *International Journal of Applied Engineering Research*, *11*, 8322–8339.

Sandmo, A. (1998). The welfare state: A theoretical framework for justification and criticism. *Swedish Economic Policy Review*, *5*, 11–33.

Sen, A. (2014). *Divergent paths to a common goal?: An overview of challenges to electricity sector reform in developing versus developed countries*. Oxford Institute for Energy Studies. https://www.oxfordenergy.org/publications/divergent-paths-to-a-common-goal-an-overview-of-challenges-to-electricity-sector-reform-in-developing-versus-developed-countries/

Sen, A. K. (2015). Sharing the world: Interdependence and global justice. In In Sen, AK, 2015. *The country of first boys and other essays* (pp. 115–126). Oxford University Press.

Smith, A., Stirling, A., & Berkhout, F. (2005). The governance of sustainable socio-technical transitions. *Research Policy*, *34*(10), 1491–1510. https://doi.org/10.1016/j.respol.2005.07.005

The Nation Editorial. (2022). *Fed Govt holds 40% equity stake in all DisCos*. https://thenationonlineng.net/fed-govt-holds-40-equity-stake-in-all-discos/

Trimble, C., Kojima, M., Arroyo, I. P., & Mohammadzadeh, F. (2016). *Financial viability of electricity sectors in Sub-Saharan Africa: Quasi-fiscal deficits and hidden costs* (Policy Research Working Paper Series). The World Bank Group.

UNDESA. (2017). *World Population Prospects: The 2017 Revision, Key Findings and Advance Tables* (Working Paper No. ESA/P/WP/248). United Nations, Department of Economic and Social Affairs, Population Division.

Verbong, G. P. J., & Geels, F. W. (2010). Exploring sustainability transitions in the electricity sector with socio-technical pathways. *Technological Forecasting and Social Change*, *77*(8), 1214–1221. https://doi.org/10.1016/j.techfore.2010.04.008

Victor, D. G., & Heller, T. C. (Eds.). (2007). *The political economy of power sector reform: The experiences of five major developing countries* (1st ed.). Cambridge University Press. https://doi.org/10.1017/CBO9780511493287

Wohlgemuth, N and J.P. Painuly, 1999, Promoting private sector financing of commercial investments in renewable energy technologies, presented at the 5th Expert Group Meeting on Finance for Sustainable Development, 01-04 December, 1999, Nairobi. https://orbit.dtu.dk/en/publications/promoting-private-sector-financing-of-commercial-investments-in-r/

Wohlgemuth, N., & Painuly, J. (1999). Promoting private sector financing of commercial investments in renewable energy technologies. *Finance for Sustainable Development: Testing New Policy Approaches*. https://www.un.org/esa/sustdev/documents/16wohl.PDF

Yakubu, A., Ayandele, E., Sherwood, J., Olu, A. O., & Graber, S. (2018). *Mini grid Investment Report: Scaling the Nigerian Market*. The Nigerian Economic Summit Group.

CHAPTER 12

Regulatory Framework and Tariff Aspects of Electricity Mini-Grids in Tanzania

E. Sawe [1], M.J.J. Katyega [1], S. Meena[1] and M. Butije [1]

[1]TaTEDO- Sustainable Energy Services Organization (TaTEDO-SESO), Dar-es-Salam, Tanzania

Abstract

Tanzania is implementing its Sustainable Energy for All Action Agenda 2030, which embraces the acceleration of the country's modern energy access to meet UN Sustainable Development Goal (SDG) 7. As of the year 2021/2022, national electricity access increased to 45.8% up from 39.9% in 2019/2020 and 32.8% in 2016/2017. The figures indicate that Tanzania has low levels of electrification; thus, much effort is needed to address the matter. Low electrification level is attributed to different aspects, including the large distances involved, low incomes, and complex geographical features, which make distribution and connectivity to the national grid expensive. Decentralized grids may be a more cost-effective solution in the interim until full grid coverage is achieved. In this regard, it is a fact that electrification by mini-grids will continue to be an option for connecting remote areas located far from the national grid, and for villages located in islands. The current strategy is for the private sector to complement the government's efforts in electrification of the country. In that regard, the Tanzanian government has put in place a conducive and innovative environment for Small Power Producers (SPPs) and Very Small Power Producers (VSPPs) to participate in the electrification of rural areas of the country by mini-grids. In 2008, the country introduced a renewable-energy electrification by SPP regulatory framework, which incorporated a tariff-setting mechanism for mini-grids to sell power to the national and isolated grids owned by the public utility. The framework

is governed by the National Energy Policy, various acts, regulations, and rules that have improved it over the years of its existence.

The SPP framework was responsible for the accelerated deployment of mini-grids between 2008 and 2015. Beyond 2015, the framework, in particular tariff-related aspects, seemed not to work as earlier expected due to political interventions given by government leaders who saw a number of mini-grids that closed their operations, a halt to a number of projects under development, and decreased electrification by mini-grids. Due to such circumstances, the withdrawal of funding by some development partners was experienced.

In this chapter, regulatory framework and tariff aspects of electricity mini-grids in Tanzania are analyzed based on a cross-section survey involving 18 purposive selected mini-grids. The study used interviews and focus group discussions to collect qualitative data from mini-grid stakeholders—operators, investors, government policy implementers, regulators, and various categories of energy end-users. Applying the thematic analysis approach using ATLAS.ti software, the study found that transparent regulations play a crucial role in achieving national electrification goals through renewable mini-grids. The key aspects include multistep project approval processes and the significance of adhering to established rules for grid compatibility, interconnection, and technical standards. In addition, the study found that electricity tariff–related aspects in Tanzania are a sensitive and controversial issue, with diverse viewpoints that are challenging to reconcile. To comprehend the problem, one needs to review the tariff-setting methodology, prevailing tariff types, and levels used by different business models. The study recommends that the Tanzanian government consider subsidizing VSPP operators to address the controversy surrounding both very highly regulated VSPP tariffs and the unregulated VSPP tariffs. This subsidy would align their tariffs with prevailing rates in the national grid and some SPP mini-grids, addressing social and equity considerations.

Keywords: *electrification, mini-grid regulation, sustainability, inclusiveness, governance*

Acronyms/Abbreviations

AMR	Automatic Meter Reader
BoT	Bank of Tanzania
CBOs	Community-Based Organizations

CT	Current Transformer
ESIA	Environmental and Social Impact Assessment
EWURA	Energy and Water Utilities Regulatory Authority
FIT	Feed-In Tariff (Standardized Small Power Purchase Tariff)
GDP	Gross Domestic Product
GWh	Giga Watt Hour
IPP	Independent Power Producer
kVA	Kilo Volt Ampere
kW	Kilo Watt
kWh	Kilo Watt Hour
LED	Light-emitting diode
MFP	Multifunction Platform
MoE	Ministry of Energy
MW	Mega Watt
MWh	Mega Watt Hour
NBS	National Bureau of Statistics
NEMC	National Environment Management Company
NGOs	Nongovernment Organizations
PPA	Power Purchase Agreement
PV	Photo Voltaic
REA	Rural Energy Agency
REF	Rural Energy Fund
RERE	Renewable Energy for Rural Electrification
SDG	Sustainable Development Goal
SEforAll	Sustainable Energy for All Action
SMEs	Small and Medium Enterprises
SPP	Small Power producers
SPPA	Standardized Power Purchase Agreement
SPPT	Standardized Small Power Projects Tariff
SREP	Scaling up Renewable Energy Program
TANESCO	Tanzania Electric Supply Company
TANWAT	Tanganyika Wattle Company
TaTEDO-SESO	TaTEDO Sustainable Energy Services Organization
TBS	Tanzania Bureau of Standards
TEDAP	Tanzania Energy Development and Access Expansion Project
TIC	Tanzania Investment Centre
TPC	Tanganyika Planting Company

TSh	Tanzanian Shilling
URT	United Republic of Tanzania
USc	US Cent
US$	United States Dollar
V	Volt
VAT	Value-Added Tax
VSPP	Very Small Power Producers
Wh/d	Watt Hours per Day

12.1 Background

This section sets the scene for the work by indicating the purpose of the study, research questions, country context and the background information on electricity regulation in Tanzania (Ahlborg & Hammar, 2011; SEforAll, 2010; URT, 2017, 2020).

12.1.1 Objectives, Research Questions, and Paper Organization

Since 2008, Tanzania has been privileged with a comprehensive regulatory framework for small power projects, including mini-grids, which has significantly expedited the deployment of mini-grids across the country (Odarno et al., 2017). Accelerated deployment of mini-grids has supplemented grid extension in the electrification of the country and has stood out as an option for the electrification of remote rural areas located far from the national grid and islands in the country. The primary aim of this research is to establish an evidence-based study regarding the performance of Tanzania's mini-grid regulatory framework concerning sustainability, inclusivity, and governance. The research focuses on two main questions: (a) the driving and hindering forces influencing the proliferation and adoption speed of mini-grids in Tanzania and (b) the evaluation of the governance, regulatory, and policy framework for decentralized electricity systems in the country and its level of success.

To address these questions, the chapter is organized into sections covering the country's context, policy and regulatory framework, a comprehensive literature review, and the methodology employed for on-site mini-grid visits and stakeholder interviews to collect relevant data, data analysis, findings discussion, and concluding remarks.

Additionally, the research extends its scope beyond Tanzania, incorporating a broader perspective by including East and West Africa in certain research questions. Specifically, the chapter poses questions related to the drivers and inhibitors of mini-grid proliferation and adoption speed in these regions, considering the roles played by national/international public and private sector entities, as well as civil society actors. It also explores how the geographic allocation of grid or mini-grid projects is determined during the planning stage, the targeting mechanisms for communities, the implications of grid arrival on existing mini-grids, and the factors influencing the implementation of decentralized electricity provision in the case study countries. Furthermore, the research delves into the viability of a private sector-led model of electrification through mini-grids in Sub-Saharan Africa, examining the circumstances under which this model proves successful.

The chapter also investigates the governance, regulatory, and policy frameworks for decentralized electricity provision in each case study country, assessing their level of success and variations. Additionally, it explores the nature of financing and ownership of mini-grid systems, considering whether they are privately owned, community-driven, state-supported, or involve public-private partnerships (PPPs).

12.1.2 Country Context

Tanzania is in East Africa between 1.0°S–11.7°S and 29.2°E–40.7°E. It is bounded by Kenya and Uganda to the north; Rwanda, Burundi, and the Democratic Republic of Congo to the west; Zambia, Malawi, and Mozambique to the south; and the Indian Ocean to the east with Comoros and Seychelles as neighbor countries. The country stretches about 945,087 km^2 and engulfs significant proportions of the East African great lakes of Victoria, Tanganyika, and Nyasa, as such portions of the country are in the Nile, Congo, and Zambezi River basins.

The country's peculiar topography includes Mount Kilimanjaro, the highest free-standing mountain in the world, and also the highest mountain in Africa, and there is the Great African Rift Valley that crosses the country in the middle from the north to the south including the southern highlands and also stretches along the country's western border including Lake Tanganyika and Lake Nyasa. There exists a vast central plateau with sizable stretches of forests and grassland accommodating several national parks, including the world-famous Serengeti National Park. Annually, portions of the country receive rainfall that varies from 550 mm in the

central part of the country to 3,690 mm in southwestern highlands. These locational and topographical features contribute to the country's enormous renewable energy resources. The rift valley is a wind tunnel with the potential for harnessing wind power resources; it is dotted by a number of geothermal sources and varied terrains that exhibit many rivers with substantial hydropower resources for electrification. The central plateau exhibits solar energy radiation intensity of 4 to 7 kWh/m^2 suitable for small- to large-scale solar power generation.

According to the August 2022 population census, Tanzania's population was 61.9 million with an annual population growth of 3.06% (URT, 2022). The rural population contribution to the total population is about 35%, and its distribution is uneven. Population density is high in the Lake Victoria area, Kilimanjaro region, southern highlands, coastal areas, and islands of Zanzibar and Pemba. In 2022, the country registered a GDP of about US$ 77.06 billion and 2021/22 annual GDP growth rate of 4.7% (BoT, 2023). During 2020, the country was elevated to a low-middle-income-country economic status.

In terms of country's primary energy consumption, 85% of energy is biomass in the form of wood, charcoal, and agricultural residues; petroleum products 9.3%; electricity 4.5%; and coal and renewable energy 1.2% (EWURA, 2016). As of June 30, 2022, Tanzania had an installed capacity of 1,740.77 MW, of which 1,489.56 MW was owned by TANESCO, and 189 MW was owned by IPP (EWURA, 2023), Further data compilation by authors indicates that 31.29 MW was traded SPPs, 28.74 MW nontraded SPPs, and 2.18 MW was traded VSPPs.1 Table 12.1 provides an inventory of mini-grids and embedded generators connected to a medium-voltage network of 11 and 33 kV. The generation mix for the national grid in terms of installed generating capacity in 2022 was 68.44% natural gas, 31.37% hydro, and 0.19% heavy fuel oil. Maximum demand for the national grid in the same year was 1,340.68 MW and annual demand growth stood at 11.63% (EWURA, 2023). The total number of electricity customers in the country was 3,864,974, of which 99.4% were served by TANESCO, 0.2% by SPPs that are also distribution network operators, and 0.4% by VSPPs networks. During the same year, annual generation and imports totaled 9,150.33 GWh, which translates to a consumption per capita of about 150 kWh, a figure that can be

[1] The provided mini-grid figures exclude mini-grids owned by the national utility.

considered as low consumption for middle-income countries estimated of 490 kWh PSMPU 2020 (MoE, 2020).

Table 12.1: Summary of Mini-Grids and Distributed Types, Numbers, Capacities, and Number of Connections

Mini-Grid Type/Source	*Number*	*Capacity in kW*	*No. of Connections*
Mini Hydro	*57*	*33,484.9*	*14,279*
Biomass	*25*	*48,886.0*	*561*
Solar	*75*	*7,347.0*	*82,147*
Wind	*1*	*2,400.0*	*-*
Hybrid	*4*	*216.8*	*781*
Diesel and Gas	*14*	*68,332.0*	*181,951*
Total	*176*	*160,666.7*	*279,719*

Source: Authors compilation.

12.1.3 Evolution of Regulatory Framework

A background to the evolution of the Small Power Project framework that incorporates Standardized Power Purchase Agreement (SPPA) and Standardized Power Purchase Tariff/Feed-In Tariffs (SPPT/FIT) policies in Tanzania dates to 2006, when TANWAT signed a negotiated PPA with TANESCO and started selling electricity to the Njombe, Makamabako, and Uwemba decentralized network, supplied by diesel and mini-hydro-integrated system. A TANWAT wood-fired combined heat and power projects substituted expensive TANESCO diesel-generated power. In 2008, the Njombe, Makambako, and Uwemba integrated mini-grid was

connected to the national grid following the commissioning of the 220/33 kV substation at Makambako. Subsequently, TANESCO and TANWAT engaged in a lengthy and unsuccessful renegotiation for a lowered tariff; as such, TANESCO suspended power imports from TANWAT as it was considered more expensive than grid-supplied power.

Another unsuccessful PPA negotiation experience involved the TPC bagasse-fired plant that during 2004 to 2006 undertook retrofit and expansion of their combined heat and power plant that established a surplus capacity of about 9 MW that could be exported to the national grid (Tenenbaum et al., 2014). Similarly, the proposed tariff for the TPC plant to be sold to TANESCO was higher than the national-grid average-generation costs; as such, TANESCO denied purchasing TPC electricity.

In 2008, the World Bank via the TEDAP Project developed the Renewable Energy Small Power Producers (SPP) Framework incorporating SPPA and SPPT/FIT for Tanzania. The SPPTs were developed and set by EWURA. TANWAT was the first SPP followed by TPC to sign an SPPA with TANESCO and start selling power to the national grid at the prevailing SPPT. In view of the above, the SPP Framework was developed to address barriers that discouraged commercial/quasi-commercial mini-grid development (Odarno et al., 2017).

The SPPA is nonnegotiable and lasts 15 to 25 years depending on the generation framework. SPPTs are reviewed annually and are capped both upward (price ceiling) and downwards (price floor), making it possible for the project developer/sponsor to undertake a feasibility study and business plan to assess if the project is going to be financially viable during the tenure of the SPPA. Following consultations with the distribution network operator (DNO) and obtaining a letter of intent for the development of the project, the developer can obtain a provisional generation and distribution license for 3 years so that they can conduct a feasibility study, environmental and social impact assessment (ESIA), and business plan, solicit financing, and build the plant. After the commission of the plant, the developer can obtain a final license.

12.1.3.1 First-Generation SPP Framework

Adopted in 2008, the first-generation SPP framework established SPPAs and SPPTs or generation feed-in tariffs for SPPs of capacity 1 to 10 MW that opted to sell to TANESCO grid or their isolated mini-grids. The feed-in tariffs were developed based on avoided costs of TANESCO in

the grid or isolated mini-grid. The feed-in tariffs were technology neutral; however, they proved unattractive for solar and wind projects that had higher upfront costs. The feed-in tariffs in the TANESCO national grid were lower than in isolated mini-grids. As such, when an SPP supplying a TANESCO-isolated mini-grid was connected to the grid, a lower approved tariff was applied by TANESCO, thereby affecting the financial viability of the mini-grid and increasing financial risks for the developer (EWURA, 2020).

12.1.3.2 Second-Generation SPP Framework

The second-generation SPP framework was introduced in 2015 with different feed-in tariffs for the development of hydro, biomass, wind, and solar energy projects of capacity 0.1 to 10 MW. To benefit from falling prices of solar and wind, a competitive bidding process was introduced for solar and wind projects of capacity 1 to 10 MW. As such, solar and wind SPPTs were project-site-specific. Solar and wind projects of less than 1 MW that opted to sell to a DNO were not subject to competitive bidding. However, their tariff was determined by EWURA, or set at a premium to the biomass tariff for a 0.5 MW plant. The said FIT was set for 15 to 25 years and would not change even following the arrival of the national grid. Moreover, the tariff was pegged to the US$, thereby maintaining the financial situation of the developer (EWURA, 2020). However, TANESCO would continue to face exchange-rate financial fluctuation risk. The extent of foreign investment that the SPPs attracted in the country could not be assessed. Similarly, the long-term exchange-rate fluctuation of the Tanzanian shilling against the US$ impact on TANESCO's financial performance could not be evaluated. However, over the years, there was less interest for the utility to sign new SPPAs owing to the exchange-rate risks and diseconomies of scale the mini-grids introduce to the national grid.

12.1.3.3 Third-Generation SPP Framework

The third-generation SPP framework was introduced in 2017 with an aim to improve on the mini-grids enabling environment, inclusivity, and governance. The framework allows mini-grids at multiple locations to acquire a single license (above 1 MW) and registration for mini-grids using the same technology (below 1 MW); defines eligible customers who

need their tariffs to be reviewed by EWURA; allows grid-connected mini-grids to operate in islanded mode when the main grid power supply is not available; and provides additional credibility on the clarity on the calculation of compensation for distribution assets when the main grid is connected to previous isolated mini-grids.

Note that the SPP framework engulfs regulations and rules for all renewable-energy and small-power-generation infrastructure of up to 10 MW, including mini-grids and embedded plants that generate and export power to the national grid or decentralized grid operated by TANESCO, as well as those that directly supply on their distribution networks. As such, the SPP framework is also relevant to SPPs and VSPPs mini-grids as generators and DNO. It appears therefore that there is no specific regulation for mini-grids.

Consumer tariffs for SPPs with own distribution network with a capacity of more than 0.1 MW are computed and approved by the regulator. VSPPs below 0.1 MW with own distribution network are unregulated, and, hence, they set their tariffs. However, at the beginning of August 2022, three cross-boundary companies owning more than 12 VPPs mini-grids came under regulation. These companies are PowerGen, PowerCorner, and JUMEME.

Tanzania's energy policy does not promote consumer energy subsidies. Instead, the policy allows cross-subsidies within energy consumer categories for the national grid and SPPs with more than 1 MW and their own distribution network. SPP regulatory framework is innovative with smart subsidies as capital grants in the form of matching grants of US$100,000 for undertaking feasibility studies, ESIA, and business plans, and performance-based grants of US$500 for each electricity consumer connection.

Developers are encouraged to register at TIC to benefit from tax- and subsidy-related aspects. Solar PV and wind equipment are exempted from import duties (EWURA, 2020 Rules; NEP, 2015). As regards asset recovery, SPPs and VSPPs are supposed to obtain a letter of support from the government to qualify for compensation due to grid arrival.

12.2 Methodology

The research aimed to investigate the regulatory framework and tariff aspects of electricity mini-grids in Tanzania, focusing on four key research questions. The study covered 17 villages across 9 regions—Ruvuma, Iringa, Kilimanjaro, Morogoro, Dodoma, Njombe, Kigoma, Pwani, and

Table 12.2: List of Mini-Grids Visited, Locations, Types, Capacities, Connection Status, and Operating Status

Mini-grid Type	*Village*	*Region*	*Capacity kW*	*Connection Status*	*Operating Status*
Tulila Hydro	*Mpepai*	*Ruvuma*	*5,000*	*Grid*	*Operational*
Chipole Hydro	*Magagura*	*Ruvuma*	*400*	*Grid*	*Nonoperational*
Mwenga Hydro	*Itipi*	*Iringa*	*4,000*	*Integrated mini-grid and main grid*	*Operational*
Mwenga Wind Power	*Usokami*	*Iringa*	*2,400*		
Kikuletwa Hydro	*Chemka*	*Kilimanjaro*	*1,650*	*Grid*	*Nonoperational*
TANWAT Biomass	*Kibena Njombe*	*Njombe*	*2,500*	*Grid*	*Operational*
TPC Biomass	*Langasani*	*Kilimanjaro*	*17,500*	*Grid*	*Operational*
Kibindu Solar PV–Biomass Gasification hybrid	*Kibindu*	*Coast*	*30 + 20*	*Mini-grid*	*Operational*
TANESCO Diesel	*Kigoma*	*Kigoma*	*6,250*	*Integrated mini-grid*	*Operational*
NextGen Solar PV	*Kigoma*	*Kigoma*	*5,000*		
Leganga Solar PV	*Leganga*	*Dodoma*	*15*	*Mini-grid*	*Operational*
Ngutoto Solar PV	*Ngutoto*	*Dodoma*	*15*	*Mini-grid*	*Operational*
Songambele/ Kitaita Solar PV	*Songambele/ Kitaita*	*Morogoro*	*6 + 10 kVA*	*Mini-grid*	*Operational*

(*Continued*)

Mini-grid Type	*Village*	*Region*	*Capacity kW*	*Connection Status*	*Operating Status*
Leshata Solar PV	*Leshata*	*Morogoro*	*6 + 10 kVA*	*Mini-grid*	*Operational*
Mji Mwema MFP Biodiesel/diesel	*Mji Mwema*	*Kilimanjaro*	*8.8*	*Mini-grid*	*Nonoperational*
Mpale Solar and Diesel hybrid	*Mpale*	*Tanga*	*50*	*Mini-grid*	*Operational*
Mvuha Solar PV	*Mvuha*	*Morogoro*	*20*	*Mini-grid*	*Nonoperational*
Biro Biomass	*Biro*	*Morogoro*	*30*	*Mini-grid*	*Nonoperational*
Total capacity			**44,900.8kW**		

Source: Authors' compilation.

Tanga—where 18 operational and nonoperational mini-grids were visited and provided diverse experiences (Table 12.2). To align our methodology with the research questions, a purposive sampling technique was employed to select key stakeholders, including representatives from the Ministry of Energy, EWURA, TANESCO, REA, EU delegation, Swedish Embassy, SPPs, and electricity end-users. The selection aimed to capture a spectrum of perspectives on the regulatory framework. Primary data collection involved in-depth interviews and focus group discussions during site visits to mini-grid operators, households, and small-and-medium-sized enterprises (SMEs). These methods were chosen for their effectiveness in gathering qualitative insights, as emphasized by Mpeta (2015). The interviews with mini-grid developers sought to uncover their perceptions of the existing regulatory rules and tariff arrangement, challenges faced, and suggestions for improvement.

Additionally, focus group discussions with developers were conducted to explore the viability of their businesses and gather insights into how they envision the evolution of the regulatory framework and policies. Engaging electricity end-users through interviews and focus group discussions aimed to understand their perspectives on inclusive and affordable services, along with their preferences for service delivery. The overarching goal was to identify common ground among diverse stakeholders, creating a sustainable and inclusive mini-grid business supportive of local economic development.

In addition, the study used a thematic analysis method to analyze collected data. This method was used to generate new concepts and insights derived from data. Furthermore, the method provides a comprehensive and rigorous approach to analyze the qualitative data (Sekaran & Bougie, 2016). The researchers listened to the recorded interviews and read the written data numerous times to understand and translate the content. Afterwards, the researchers extracted and combined text about mini-grids sustainability, inclusiveness, and governance to identify themes that were analyzed by using ATLAS.ti data analysis software. The ATLAS.ti software was employed to condense and abstract the themes into codes, which were then categorized and applied to the entire set of collected data. The data were reviewed to ensure that the script's original meaning is maintained. This comprehensive analytical approach enhances the robustness of the study's findings and ensures a detailed understanding of the regulatory framework aspects of electricity mini-grids in Tanzania.

12.3 Overview Concept on Mini-Grid Regulatory Framework Rules and Tariff Aspect

Tanzania in 2022 had a total installed power capacity of 1,740.77 MW, mainly sourced from hydro, gas, and oil (EWURA, 2023). The country imports all its petroleum fuels, making it vulnerable to global market prices. The Energy and Water Utilities Regulatory Authority (EWURA) monitors fuel prices monthly, incorporating operating costs, tariffs, and marginal profits into world market fuel prices (Ebert et al., 2019; International Energy Agency [IEA], 2022; UNDP, 2022; World Bank, 2021). Over the past 20 years, oil prices in Tanzania have been unstable but generally increasing, reaching US$1.56/l in 2023. If Tanzania heavily relied on diesel for rural electricity, the generation costs would be relatively high compared to photovoltaic (PV) and hydro sources.

In 1992, the first National Energy Policy was established that encouraged private sector participation in the energy sector. This policy marked the beginning of private generators being permitted to contribute to the national grid and utility supply, breaking the monopoly previously held by the utility in power generation (Marandu, 2012). In 1999, IPTL 100 MW diesel-fired IPP followed by Songas 40 MW natural gas–fired IPP in 2004 were commissioned to supply the national grid. Subsequently, there has been a shift in focus toward renewable energy sources as indicated in the national policy of 2015 (EWURA, 2016) and the power system master plan 2020 update (MoE, 2020).

Tanzania is actively engaged in exploring the potential advantages of the Clean Development Mechanism (CDM) as outlined in the Kyoto Protocol by the Intergovernmental Panel on Climate Change (IPCC) (Eberhard, 2010). In 2005, the CDM Executive Board clarified that national policies implemented after 2001 would not be factored into baseline calculations (CDM Executive Board, 2005). This means that combining the Clean Development Mechanism with feed-in tariffs is feasible without compromising eligibility for participation in the CDM.

This literature review aims to survey the existing body of knowledge concerning the regulatory framework and tariff structures associated with electricity mini-grids in Tanzania. The review sheds light on the evolving policy landscape and the key considerations in ensuring the sustainable growth of this sector.

12.3.1 The Regulatory Framework

Tanzania has been recognized as one of the leading countries globally in establishing sustainable business models for renewable energy–based mini-grids. To expedite electricity access and encourage the growth of small power projects by both local and foreign private investors, the Tanzanian government enacted the Rural Energy Act in 2005. This legislation led to the creation of the Rural Energy Agency and Rural Energy Fund (REA/REF) tasked with supervising the execution of rural electrification projects (REA, 2015).

EWURA, the Tanzanian energy utility regulatory authority, plays a crucial role in regulating energy pricing and overseeing tariff issues and policies (EWURA, 2016; Gratwick et al., 2006). Originally, when the Rural Energy Board was established, TANESCO held a legal monopoly in electricity generation and supply. However, private sector involvement, as envisioned by the Rural Energy Act, only became possible after the industry was liberalized through the Electricity Act of 2008. Even though TANESCO remained vertically integrated after 2013, the act allowed other industry players licensed by the EWURA to participate in the generation and distribution segments (United States Agency for International Development [USAID], 2014).

In 2009, Tanzania introduced the Standardized Power Purchase Agreement (SPPA) and, in 2010, adopted a standard tariff methodology (EWURA, 2009, 2016). The SPPA forms the legal basis for connecting renewable energy generators to both the national grid and isolated mini-grids, enabling the export of excess power (up to 10 MW) to the national grid and decentralized grids (EWURA, 2011; Rickerson et al., 2013; Tenenbaum et al. 2014). In 2013, there were 21 isolated TANESCO-owned mini-grids and five Zanzibar Electricity Corporation (ZECO)–owned mini-grids, relying on existing diesel generation that SPPs had the potential to replace, either entirely or partially (Bhattacharyya, 2013). The SPP framework also allows independent SPPs to construct new isolated mini-grids to provide electricity to communities without access and directly sell to new customers (EWURA, 2010; Tenenbaum et al. 2014). In cases of connection to isolated mini-grids, the Tanzanian SPP framework offers a high FIT for SPPs selling electricity to TANESCO's existing mini-grids (Moner-Girona et al., 2016).

The duties of the regulatory authority, EWURA, encompass setting the tariff for SPPs, overseeing power purchase and service agreements, issu-

ing licenses, and ensuring the maintenance of floor prices for a duration of 15 years. Up to 2022, EWURA had granted approval for SPPAs of a total capacity of 40.1 MW, involving biomass (15.6 MW), solar (2 MW), and hydropower plants (22.5 MW). These are contributing 25.4 MW of power to the main grid.

Among the 10 approved SPPAs, 6 are designated for isolated mini-grids, involving one solar project (2 MW), 3 biomass plants (5.1 MW), and 2 hydropower projects (totaling 8.5 MW). Additionally, three more projects are in progress, consisting of two hydropower projects (4.1 MW) and one solar project (1 MW). Furthermore, there are 32 other SPP projects in various stages of development and preparation.

Furthermore, the Electricity Act of 2008, which replaced the Electricity Ordnance of 1932 last amendment of 1957, is the basis of the comprehensive SPP regulatory framework of Tanzania of 2008 that was developed with the assistance of the World Bank via the Tanzania Energy Development and Access Expansion Project (TEDAP) (Odarno et al., 2017). Under this act, any activity from generation, transmission, distribution, supply, cross-border trade, financial and physical trading, and electrical installations requires a license. The exemption under Section 18, from 2008 under first-generation SPP regulatory framework, allowed rural generation activities below 1 MW and off-grid distribution and supply activities below 1 MW to operate without a license. Under the second-generation SPP framework established in 2015, the threshold for unregulated installed capacity was lowered from 1 to 0.1 MW so that many rural generating facilities were inclusive, could qualify to use FIT, and be able to sell power to the decentralized grids or national grid popularly referred to as anchor customers.

Essentially, the main elements of the SPP regulatory framework consist of (a) institutional framework and market structure of the Tanzanian electricity sector; (b) national policies that affect mini-grid development; (c) acts, regulations, and rules relevant to mini-grids; (d) international and national strategies that support mini-grid development; and (e) plans, programs, and projects that support, promote, and finance renewable energy mini-grids. Elements (a) to (c) are presented below.

12.3.1.1 Institutional Arrangements of the Sector

The institutional framework involves a number of key stakeholders that promote, regulate, develop, operate, and benefit from mini-grids in Tan-

zania. These key stakeholders include the Ministry of Energy (MoE), EWURA, Tanzania Electric Supply Company (TANESCO), Rural Energy Agency (REA), Independent Power Producers (IPPs), SPPs, VSPPs, developers, financiers, development partners, NGOs, CBOs, and end-use customers (see Box 12.1).

Box 12.1: SPP Framework Stakeholders

The Ministry of Energy (MoE) formulates and articulates policies and strategies conducive for stakeholders to promote renewable energy.

The EWURA has mandates for technical and economic regulation of electricity, petroleum, natural gas, and water sector utilities. It is a licensing authority that is mandated to establish as well as monitor standards for goods, services, and supply conditions. The authority is also responsible for the preparation of rules and guidelines for small power producers (SPPs) and distributors on their activities, tariff and fee determinations, accounting, reporting customer services, and safety measures. The authority is also responsible for the establishment, regulation, approval of tariff rates to be used by service providers, as well as monitoring and reviewing their performance and tariffs over time. Furthermore, the regulator is responsible for conflict resolution among the trading partners. As such, the authority is responsible for monitoring the performance of the minigrids, their operating efficiency, and the quality of supply services to the customers.

Tanzania Electric Supply Company (TANESCO) is a vertically integrated power utility responsible for generation, transmission, distribution, and sales to end-use customers on Tanzania Mainland and bulk power sales to Zanzibar and Pemba islands. It is also a power off-taker for independent power producers (IPPs) and SPPs as well as imports from neighboring countries. IPPs and SPPs supply the TANESCO-operated national grid, and some of the SPPs also supply electricity through their own isolated grids and through those operated by the utility TANESCO.

Rural Energy Agency (REA) is an autonomous body under MoE responsible for the promotion, stimulation, facilitation, and improvement of modern energy access in the rural Tanzanian Mainland, as well as facilitation and promotion of efficient production and energy end-uses; preparation and reviewing of application procedures, guidelines, selection criteria, and terms and conditions for the allocation of grants; financing of approved projects by the Rural Electrification Fund; capacity-building and technical assistance to project developers and rural community recipients; and undertaking preparation of bid documents for rural energy projects.

IPPs are private large power plants of more than 10 MW that bulk-supply power to the national grid. In turn, SPPs are private companies, cooperatives, or communities that independently generate 100 kW to 10 MW and can sell power to the national grid or decentralized grid owned by TANESCO or via their distribution networks. Very Small Power Producers (VSPPs) are those that generate 15 to 100 kW and distribute to their distribution networks. DNOs are public, private, cooperatives, and communities licensed to distribute and sell power to end-use customers.

NGOs and CBOs also support and promote electrification in the country, some of which have developed their own renewable propelled mini-grids that distribute power to end-use customers. Some of these organizations are only involved in the advocacy of clean energy provision, efficient energy usage, and support in electrification.

Development partners, financiers, and the government fund renewable mini-grid projects, to assist in the provision of smart subsidies for the rural population to afford electrification connection and end-use energy tariffs.

End-use customers or retail electricity customers are the direct beneficiaries of the electricity supplied by the national grid and mini-grids.

12.3.2 Acts, Regulations, and Rules Relevant to Mini-Grids

The Electricity Act of 2008 established the framework to guide the MoE and various key stakeholders like EWURA, REA, TANESCO, IPPs, SPPs, VSPPs, and end-use customers. The Act includes elements that form the SPP framework and Small Power Projects Tariffs. The Act also gives EWURA regulatory responsibilities for licensing, development of rules and regulations, tariff-setting and approval processes, monitoring, enforcement of standards/regulations, and so on.

The Energy and Water Utilities Regulatory Authority Act of 2001 established the Energy and Water Utilities Regulatory Authority with responsibilities for technical and economic regulation of the energy and water sectors. In September 2008, EWURA approved the Standardized Small Power Purchase Agreements (SPPAs); in June 2009, it approved the standardized tariff calculation methodology for the national grid; and, in September 2009, it approved a Standardized Tariff Methodology and applicable tariff for sale of electricity to mini-grids, as well as the Development of Small Power Project Rules of 2020.

The national utility, IPPs, and SPPs are subjected to and must abide by a set of well-defined procedures, rules, and standards involving registration, construction, operation, and power supply delivery services as set out by laws passed by the country's lawmaking body and oversight bodies or regulators.

As such, since 2015, the national utility along with IPPs and SPPs of capacity more than 100 kW are subjected to heavy-handed regulation, whereas VSPPs below 100 kW are subjected to light-handed regulation, for example, registration, no licensing, and no retail tariff approval by the regulator. However, retail tariff computation by the regulator can occur if more than 30 end-use customers complain of unfair rates being charged by VSPPs. This is not mandatory for VSPPs with registered capacity below 15 kW.

The Rural Energy Act of 2005 established the Rural Energy Fund (REF) and Rural Energy Agency (REA) and its board with the responsibility to promote modern energy access in rural areas, finance rural energy projects, and provide matching and performance grants to rural energy developers including mini-grids as well as private sector promotion. The REF has greatly contributed to the accelerated deployment of renewable mini-grids in Tanzania since 2008. The REF receives financial support from

the government budget, development partners' contributions, and various services' levies in the country and funds the rural electrification plans on a competitive approach whereby selected projects for implementation are ranked based on the poverty of resources.

Tanzania Investment Act of 1997 established the Tanzanian Investment Centre to coordinate and promote investments including renewable mini-grids.

The Occupation Health and Safety Act of 2003 enforces the health, safety, and welfare of workers including mini-grid operators and end-use customers.

The Environment Management Act of 2004 established the Environment Management Council that enforces the undertaking and approval of environmental and social impact assessments for all energy projects as well as energy producers to operate their infrastructure efficiently with minimum environmental impacts to society.

The Public Private Partnership Act of 2010 introduced the responsibilities and obligations of the parties, financial management and control, penalties, remedies, and dispute resolution. The law established the PPP Coordination Units at TIC and the Ministry of Finance that assist investors including mini-grid investors.

The guiding policies that work in tandem with the above-mentioned acts and regulations and their main purpose are given in Table 12.3.

The mentioned selected national policies support or hinder investments in mini-grids are briefly outlined below. The National Energy Policy of 2015 promotes renewable energy investments via waiver of duties on solar- and wind-based investments. The National Environment Policy of 2015 enforces mini-grid projects to undertake ESIA and obtain clearance before project financing and construction for sustainable energy development. The Water Policy of 2002 provides for optimal mini-hydro-grids' water rights to be granted by the government for sustainable and equitable allocation of water resources among competing end-uses of various economic sectors.

The National Forest Policy of 1998 provides for the protection of rivers' catchment forests and water sources for sustainable water resources availability during various seasons of the year and over the years as well as curbing soil erosion that causes silting of mini-hydro-plants' intakes and reservoirs.

The National Investment Promotion Policy of 1996 facilitated the enactment of a law establishing the Tanzania Investment Centre that pro-

Table 12.3: National Policies

National Policy	*Main Purpose*
The National Energy Policy of 2015	Provides conducive business environment for private investments and local participation in the sector and supports global initiatives on the provision of sustainable energy for all, promoting energy conservation and efficiency and increasing energy access to modern energy and share of renewables in the electricity generation energy mix (NEP, 2015).
The National Environment Policy of 2015	Articulates provision of an environmental framework law and environmental standards as well as promotion of environmentally friendly technologies and diversified energy sources by harnessing renewable energy sources.
The Water Policy of 2002	Articulates putting in place fair procedures for accessing and allocation of water resources to benefit the social and economic activities of the nation.
The National Land Policy of 1997	Promotion, ensuring the land tenure system and optimal land resources allocation without sacrificing the ecological balance of the environment.
The National Forest Policy of 1998	Aims at enhancing forest sector's conservation and management of natural resources to contribute to sustainable development of the country.
The National Investment Promotion Policy of 1996	Promotion of investments in the development of commercial and alternative sources of energy.
The National Gender Policy of 2002	Focuses on establishing poverty eradication strategies with gender equality aspects.

vides a single roof support to mini-grid investors for various services like business registration, land and water applications, and tax aspects.

The National Gender Policy of 2002 provides for poverty eradication among households and addresses gender balance issues in mini-grids investments and operation and maintenance.

12.3.3 Tariff Structures for Mini-Grids in Tanzania

Many countries employ traditional feed-in tariffs typically based on their approach to the electricity generation costs. This involves determining the incentive level considering the anticipated electricity generation amount and the estimated lifespan of the power plant. Given that the costs of electricity generation differ based on the renewable energy technology, most feed-in tariffs establish specific rate levels for each technology (Klein et al., 2008). The underlying idea is that distinct technologies necessitate varying levels of support to become financially viable for investment. Conversely, a flat rate is often seen as a mechanism promoting the adoption and expansion of the most competitive, or lowest-cost, renewable energy technology.

In Tanzania, the current SPP framework is employed to establish a fixed rate for selling electricity to the national utility TANESCO's grid, set at an annual average value of US$0.10/kWh. Additionally, a higher rate of US$0.25/kWh is allocated for selling electricity to isolated mini-grids. It is crucial to note that these off-FIT levels are below the cost of diesel for generator sets (EWURA, 2020).

Two distinct approaches are considered for determining off-FIT values. First, under specific circumstances, setting an off-FIT based on the avoided electricity cost may be sufficient to support new renewable energy projects in off-grid areas. Second, in cases where the utility's avoided cost is insufficient, the incentives are calculated based on the electricity generation costs.

Tariff structures for mini-grids in Tanzania are designed with a multifaceted approach. They aim to balance affordability for consumers, cost recovery for operators, and sustainability for the system. The tiered pricing structure, including cross-subsidized lifeline tariff , for example, Mwenga integrated system customers, has been introduced to ensure that low-income households have access to electricity at affordable rates. Furthermore, innovative models, such as pay-as-you-go and community-based tariffs, have been explored to cater for diverse consumer needs.

The pricing of electricity from mini-grids in Tanzania is a critical aspect of their sustainability and the affordability of electricity services for end-use consumers. A key concern is how to establish tariff structures that strike a balance between attracting private sector investments and ensuring that electricity remains affordable for low-income households. The current tariff structure relies on a cost-reflective-based approach, which considers the capital and operational costs of mini-grid systems. Ensuring affordable tariffs while covering the costs of system development and operation remains a central challenge in this context.

In turn, electricity tariffs for VSPPs mini-grids in Tanzania appear to be a controversial issue that has drawn the interest of various stakeholders—development partners, development banks, commercial banks, investors, mini-grid operators, the government, the regulator, REA, the national utility, renewable energy suppliers, politicians, and so on. The main issues include tariff affordability, fairness, equity, and social aspects related to tariffs as they affect the rural population. Therefore, tariff categories, levels, and their impact to the various stakeholders need to be cost-reflective to mini-grid operations; must be prepared transparently and be inclusive to all key stakeholders; be fair to the energy suppliers and end-users; and be affordable, stable, and predictable to end-users so as to allow smooth energy sector governance.

From 2015 to 2022, pan-territorial or uniform tariffs were prepared by the regulator employed by the national utility and were requested by some of the government leaders to be employed by the SPPs and VSPPs customers in their distribution networks. This surfaced to be the most controversial issue in the sector as regards commercial sustainability of the diverse size and locations of mini-grids and their operations, and inclusiveness among all stakeholders and in the energy sector's governance.

12.3.4 Tariff-Setting

EWURA employs the Standardized Tariff Methodology to calculate the electricity prices for grid-connected generators and isolated mini-grids operated by the national utility as stipulated in the Small Power Projects Rules of 2020. The methodology is based on the concept of avoided costs, determining a tariff comparable to the cost of alternative options available to the buyer (EWURA, 2009, 2019). This involves averaging the short-run and long-run marginal costs as determined in the power system master plan.

TANESCO operates several isolated grids powered by fuel oil plants in various locations across Tanzania. The long-run marginal cost of Tanzania's grid power (adjusted for losses) serves as the foundation for calculating the avoided costs in the long term, with the anticipation that all mini-grids will eventually integrate with the main grid. EWURA has initiated a revision of tariffs based on a cost-of-service study report from 2013. The outcome indicates that tariffs for mini-grids are considerably higher than those for main grid generation (EWURA, 2016; Rickerson et al., 2013). There are several efforts the government employed so as to decrease tariff of mini-grids. Among these, the government through EWURA established second-generation SPP framework in 2015 that calculates tariffs based on technology (hydro, biomass, wind, and solar energy projects) and capacity of the mini-grids (0.1–10 MW) to decrease tariff of mini-grids. Despite these efforts made by the government, tariffs for mini-grids continue to be higher than those for main grid generation (Odarno et al., 2017).

Less discussed is the aspect of whether SPP FIT is cost-reflective to the provision of the services. It appears that FIT computed by the regulator and sold by SPPs to the national grid and decentralized grids operated by TANESCO, which is an anchor customer, tends to be financially sustainable if mini-grids are efficiently operated and maintained. Moner-Girona et al., 2016 also discusses this matter with regard to Tanzania. Pueyo et al. (2022) also discuss the aspect of productive energy usage in improving the financial viability of mini-grids. However, regulated and unregulated VSPPs mini-grid tariffs are very high and prevail in areas where affordability is a major concern, making financial sustainability highly questionable. Mottram (2022) reveals that communities experience electricity price injustice when mini-grids treat electricity as economic goods. Whether tariffs for mini-grids can be financially sustainable is further discussed by Zigah et al. (2016). Thus, there is a need to further study tariff aspects in Tanzania and provide recommendations that shall contribute to lowering mini-grid tariffs.

12.3.5 Gaps in the Existing Literature

While the regulatory framework and tariff structures for mini-grids in Tanzania have evolved positively, the literature highlights several challenges. Inconsistent application of regulations, bureaucratic hurdles in obtaining licenses, and limited involvement of local communities in tar-

iff design remains a persistent challenge. Additionally, there is a paucity of literature that adequately addresses the practical aspects of regulatory framework and tariff implementation, specifically in the aspects of sustainability, inclusiveness, and governance of mini-grids in Tanzania. Therefore, this study provides an insight into the current state of mini-grid regulation and tariff design in the Tanzanian context.

12.3.6 Comparative Analysis

Drawing comparisons with international experiences, it is evident that Tanzania's regulatory framework and tariff structures align with global best practices. However, case studies from countries like Kenya, which have implemented community-based tariff models effectively, offer valuable lessons for some of Tanzania's community mini-grids that failed due to low revenue collection to sustain operations. Emulating these successes could address some of the existing challenges and promote community engagement in tariff design and decision-making.

This literature review provides an overview of the regulatory framework and tariff aspects of electricity mini-grids in Tanzania. While the existing literature reveals substantial progress and alignment with international best practices, persistent challenges and gaps necessitate further research. By learning from comparative experiences and addressing practical issues, Tanzania can continue to enhance its mini-grid sector, ensuring that it effectively contributes to electrification and community development. The development of electricity mini-grids in Tanzania is a promising approach to address energy access challenges in off-grid and remote areas. The regulatory framework for mini-grids in Tanzania has evolved significantly, with notable achievements in creating a conducive environment for private sector involvement.

12.4 Evidence from Field Findings

The aim of this study was to investigate the regulatory framework and tariff aspects of Tanzania. This was achieved through visits to mini-grids as well as stakeholder interviews with managers of EWURA, TANESCO, REA, as well as SPPs' and VSPPs' developers and operators. The collected information was analyzed by using ATLAS.ti software, and the results are presented as follows.

12.4.1 Regulatory Framework–Related Aspects

This objective aimed to assess the regulatory framework of electricity in Tanzania. Apart from the rules, regulations, standards, and other directions documented on the regulator's website, this objective was achieved through conducting interviews with managers of EWURA, TANESCO, REA, and SPPs developers. The major finding of the study was that the main impetus of mini-grid regulation has been to set a conducive, transparent, and fair environment for various stakeholders involved in the sector to be able to play their roles so that the national objective of enhanced electrification access by renewable mini-grids is achieved for the benefit of the country. As such, Tanzania's regulatory framework has been revised over time to pave the way for investors and developers to accelerate the deployment of mini-grids in the country by addressing key aspects, including approval processes of projects, grid compatibility of the proposed technologies versus existing technologies, grid interconnection requirements, and compliance to prevailing national standards for service provision. Table 12.4 provides codes for the thematic analysis of the regulatory framework.

Table 12.4: Codes for the Thematic Analysis of Regulatory Framework–Related Aspects

Theme	*Regulatory Framework*
Codes	*Approval process* *Grid compatibility* *Grid interconnection* *Technical standards*

12.4.1.1 Approval Processes

The study found that planning, development, and commissioning to operation and maintenance of a mini-grid involves many steps and clearances by a number of different institutions in the country. The developer must identify a site to develop, the technology to be used, and undertake the following steps for various clearances to project realization (see Table 12.5).

Also, the study revealed that, from project planning to project realization, developers have to work closely and inclusively with various stake-

Table 12.5: Steps for Mini-Grid Development Clearances

Step	*Institution*	*Clearances*
1	*Tanzania Investment Centre (TIC)*	Investment facilitation: project registration, tax registration, land lease aspects, business licensing registration, immigration issues (for foreigners), and labor issues
2	*TIC, MoE, REA, TANESCO, and EWURA*	Project identification and promotion; submission of concept note
3	*Village/Local government*	Land lease or right of occupancy
	Water Basin Office	Water right (hydro projects)
4	*TANESCO/MoE*	Letter of intent (for SPPs to sell power to TANESCO)/Letter of support for VSPP to qualify for compensation when the grid arrives
5	*REA*	Feasibility studies, ESIA, business plan, and financing facilitation
6	*NEMC/Ministry of Environment*	Environmental clearance
	EWURA	Provisional license
7	*District/Municipal Council*	Building permit
8	*Distribution network operator*	SPPA signed
9	*Investor/developer*	Plant construction
10	*EWURA*	Plant commission and final license

Source: Authors' compilations.

holders at village and district up to the national level so as to successfully develop and commission the projects. Investors and developers complained of project delays due to the many steps to be taken as required by the numerous institutions with which they had to work, resulting into persistent delays at various stages of the project implementation phase. Often delays occur in institutions which are, in fact, outside the energy sector; for example, it takes more than 90 days to submit and obtain environmental clearance. The TIC is supposed to be a one-stop-center for investors by facilitating them in obtaining various project clearances. Owing to a lack of coordination among various institutions, delays in project development or the selection of the wrong technology have occurred in renewable mini-grids projects (Odarno et al., 2017). Furthermore, there is a clear lack of coordination among donors and government institutions, in particular access to central databases, and fewer projects have been funded or limited funding has been committed by donors. Following obtaining a letter of intent from TANESCO, a developer is granted a provisional license for three years for project studies, clearances, financing, construction, and to plant commission before securing a final license. The project duration has sometimes been surpassed, causing the regulator to cancel the projects or advise the signed parties to opt for alternatives and seek mediation to deal with existing regulations.

Based on the insights discussed, it was revealed that.

> *In project development, collaboration with stakeholders from local to national levels is vital. Bureaucratic hurdles and inter-institutional complexities often lead to delays, especially in obtaining environmental clearances. The TIC aims to simplify processes, yet in renewable mini-grids, disjointed efforts cause hiccups. Discord among donors and government institutions limits funding. The three-year provisional license can tighten, leading to regulatory cancellations or alternative mediation.*
>
> Interview with EWURA Manager, 2022

12.4.1.2 Grid Compatibility

Furthermore, the study has observed that small power projects that sell power to the grid/isolated grids owned by TANESCO must be compatible with existing and operating grid system to be connected to it as per SPP

rules of 2020 (EWURA, 2020). In the case of a VSPP establishing its own distribution network, or a developer wanting to undertake services as a DNO, the infrastructure needs to be commissioned as grid-compatible. In the case of a VSPP, they must obtain a letter of support from the MoE so as to qualify for infrastructure compensation when the grid extends to their network.

Several regulatory tools have been put in place: The Electricity (Grid and Distribution Codes) Rules, 2017, GN 451; The Electricity (Generation, Transmission, and Distribution) Activities Rules, 2019 GN 462; The Electricity (Standardized Small Power Projects Tariff Order) Order 2019, GN 464; The Electric (Supply Service) Rules 2019.

Observations about visited sites indicate operational problems in integrated mini-grid switching due to wrong (Current Transformer ratio) settings at the initial days of interconnection. This happens due to lack of experience by the operators in running such systems. Also, there were problems of synchronization and associated costs to SPPs when the national grid is not stable, as they have to purchase expensive power from the national grid many times.

Also, the following challenge is revealed by TANESCO manager:

> *In setting up small power projects, it's crucial to match them with the existing grid system, as per the 2020 SPP rules. If a project creates its own distribution network, it needs to make sure it works well with the grid. There are rules and tools, like the 2017 Electricity (Grid and Distribution Codes) Rules, to guide this. Mistakes in the initial setup, like wrong CT ratio settings, can cause issues, especially for mini-grids. So, getting it right from the start is important.*
>
> Interview with TANESCO Manager, 2022

12.4.1.3 Grid Interconnection

Moreover, mini-grid visits revealed that SPPs being developed for sale to the national grid, or isolated grids owned by the national utility along SPPA, strive to select the right technology, size, and undertake component matching to allow interconnection with the grid or synchronization for optimum levels of power exchange and quality of supply services. As such, the interconnection point, equipment requirements, and expected operating conditions are agreed upon by both parties and signed as part of

the SPPA with detailed drawings and appropriate specifications appended to the SPPA. This is according to the SPPA Electricity (Development of Small Power Projects) Rules 2020 GN 491. Observations during the visits of all of the visited operating SPP mini-grids connected to the grid and isolated mini-grids operated by TANESCO show that they comply with connectivity conditions as set out in the grid code rules.

Furthermore, it was found that

> *In creating small power projects for the national grid or local grids, it's crucial to choose the right technology and match components for smooth interconnection. The Standardized Power Purchase Agreement 2020 and Electricity (Development of Small Power Projects) Rules 2020 (GN 491) stress the importance of clear agreements on equipment, operating conditions, and detailed specifications.*
>
> Interview with TANESCO Manager, 2022

In addition, mini-grids visits revealed that, mini-grids connected to the grid and isolated mini-grids operated by TANESCO seem to be operating smoothly. The TANWAT mini-grid efficiently supplied TANESCO's Njombe, Makambako, and Uwemba mini-grids during 2006 to 2008 and then the national grid from 2010 to 2019; afterwards, however, the plant failed, and services resumed only in 2022 following the refurbishment of the plant. TPC mini-grid in Kilimanjaro region has been efficiently supplying the national grid since September 2010 to date. Tulila supplied the Songea, Mbinga, and Tunduru mini-grid from 2015 to 2018 and the national grid since 2018. Mwenga hydro-based and later Mwenga hydro- and wind-integrated mini-grid system has been efficiently supplying the national grid since 2012.

> *This is evidenced by one of the respondents who indicated that*
>
> *Most observed SPP mini-grids, both connected to the grid and isolated ones by TANESCO, operate smoothly. Notably, TANWAT served TANESCO's grids efficiently from 2006 to 2019, resuming in 2022 after refurbishment. TPC has been supplying the national grid since 2010, Tulila since 2015, and Mwenga hydro and wind since 2012.*
>
> Interview with TANESCO Manager, 2022

12.4.1.4 Technical Standards

The study also found that, apart from listed rules and regulations mentioned in Section 4.1.3, relevant standards include TZS 1373:2011 (Power Quality—Quality of Supply); TZS 1374: 2011 (Power Quality—Quality of service and reliability); and TZS 1375:2011 Electromagnetic compatibility (EMC—limits for voltage change, voltage fluctuations and flickers in low-voltage supply system for equipment with rated current of <16A per phase and not subject to conditional connection and other standards governing limits for harmonic current emission).

Also, visits to mini-grids showed that a number of VSPPs that are nonregistered and nonregulated adopt the lowest approved standards (e.g., use of 25 mm2 wire) in their distribution infrastructure, and, when the grid is extended into their premises, they must construct new infrastructure with a higher standard (e.g 50 mm2 or even higher wire size). As an example, a mini-grid in the coastal area used nonstandard wooden poles in terms of pole diameter for its distribution network.

Such non-regulated and non-standard mini-grids cannot receive subsidies or government funding to support their businesses.

12.4.2 Tariff-Related Aspects

Economic regulation involves tariff derivation, setting standards for quality of supply, and entry and exit conditions for providing services (Tenenbaum et al., 2014). Tariff-related aspects are separately dealt with in this section. Apart from documents available on the EWURA and other energy institutions in Tanzania websites, the objective to assess tariff-related aspects of electricity in Tanzania was achieved through conducting interviews with EWURA managers, TANESCO managers, REA managers, and SPPs developers. The major finding of the study was that electricity tariff–related aspects appear a sensitive or rather controversial issue in Tanzania, as there are diverse viewpoints that are challenging to reconcile. To understand the problem, one needs to review the tariff-setting methodology being applied in the computation of tariffs; prevailing tariff types and levels being used by different business models (see Table 12.6); and comparison of the mini-grid and national grid tariffs, to determine whether cost recovery is achieved from the said various tariffs to guarantee electricity sector governance and whether tariff levels being applied match with quality of power supply services requirements of various types of customers.

Table 12.6: Codes for the Thematic Analysis of Tariff-Related Aspects

Theme	*Tariff*
Codes	*Tariff-setting* *Tariff levels* *Mini-grid and national grid tariff comparison* *Cost recovery*

12.4.2.1 Tariff-Setting

The study found that tariff-setting methodology is guided by the "Electricity Development of Small Power Projects Rules 2020" (EWURA, 2020). A small power project operator supplying power to the grid or isolated grid operated by the national utility shall charge a tariff approved by the regulator and computed based on avoided-cost principles for SPPA signed before August 1, 2015, the tariffs of which shall be revised annually or technology-specific principles for SPPA signed after August 1, 2015. The latter approach requires that the tariff is calculated to be cost-reflective with a margin for profit. It should be noted that before August 1, 2015, the tariffs were technology neutral and were different during dry and wet seasons. Furthermore, avoided costs for the main grid were lower than those in isolated mini-grids (see Tables 12.7 and 12.8).

Moreover, the study revealed that tariffs for the second generation were technology and size based—hydro, biomass, solar, and wind—and cover the following: (a) operating costs; (b) depreciation on capital, whether supplied by the Small Power Producer or Small Power Distributor or oth-

Table 12.7: Tariffs for Main Grid Connection Under the First-Generation SPP Framework (Avoided Cost)

Description		*Approved Tariff w.e.f. May 1, 2019 (TSh/kWh)*
Standardized Small Power Purchase Tariff		*203.11*
Seasonally Adjusted Standardized SPPT Payable in	*Dry Season*	*243.73*
	Wet Season	*182.80*

Source: EWURA.

Table 12.8: Tariffs for Mini-Grid Before and After Grid Connection Under First-Generation SPP Framework (Avoided Cost)

	Before Year 2018 Grid Connection (TSh/kWh)	*After Year 2018 Grid Connection (TSh/kWh)*
Standardized Small Power Purchase Tariff	*480*	*180*

Source: TaTEDO-SESO Field Data.

ers; (c) interest expenses; (d) reserves to deal with emergency repairs and replacements; and (e) taxes and a reasonable return on equity that reflects the risks faced by the Small Power Producer or Small Power Distributor (Table 12.9).

This is evidenced by one of the respondents who revealed that

> *The tariff for small power projects connecting to the grid or a national utility's isolated grid is determined by the 'Electricity Development of Small Power Projects Rules 2020' (EWURA 2020). Projects signed before August 1, 2015, follow avoided-cost principles with annual revisions, while those [signed later] use technology-specific principles, ensuring cost-reflectivity with a profit margin. Notably, tariffs were technology-neutral before August 1, 2015 and varied*

Table 12.9: Tariffs for SPPs Selling Electricity to the Grid Based on Specific Technology Under Second Generation (w.e.f. June 21, 2019)

Capacity (MW)	*Mini hydro*	*Wind*	*Solar*	*Biomass*	*Bagasse*
	USc/kWh	*USc/kWh*	*USc/kWh*	*USc/kWh*	*USc/kWh*
0.1–0.5	*10.65*	*10.82*	*10.54*	*10.15*	*10.71*
0.51–1.00	*9.9*	*9.95*	*9.84*	*9.34*	*9.09*
1.01–5.00	*8.95*	*9.42*	*9.24*	*8.64*	*8.56*
5.01–10.00	*7.83*	*8.88*	*8.34*	*7.60*	*7.55*

Source: EWURA.

> *between dry and wet seasons. Additionally, avoided costs for the main grid were lower than those for isolated mini-grids.*
>
> Interview with EWURA Manager, 2022

In addition, the results showed that previously VSPPs were unregulated, and, as such, they set their own tariffs without the approval of the regulator. Tariffs were most often set to cover their costs of providing services, which included a margin for profit. Normally, the tariff was presented to the consumers prior to the beginning of business operations so that the consumers were aware and could voice their concerns. An extension of the problem is that the services provided by most of the VSPPs does not last 24 hours/7 days a week, making it rather cumbersome in establishing tariffs for customers billed who are using load-limited meters. Energy services are purchased using cellular phones, card tokens, etc., but these systems are not well understood by some of the customers. This concern was raised by many household consumers interviewed during the VSPP mini-grid visits. In part, the cost of regulating the multitude of VSPPs located in distant and remote locations serving a few customers, whose major load is lighting, is a major challenge expressed by the regulator.

Furthermore, some VSPPs have complex billing systems, for example, flat-rate billing per day using load-limiters, which applies and requires to be paid regardless whether power has been consumed or not. Such billing systems do not encourage energy efficiency and demand-side management of the energy services by the customer. Energy services are purchased using cellular phones, card tokens, and so on, but these systems are not well understood by some of the customers.

Also, we were informed that from 2015 to 2022 all VSPPs were directed by the government to charge the same subsidized pan-territorial retail tariff charged by TANESCO of TSh 100 per unit. Many VSPP investors stopped providing their services and suspended the development of new projects, as the pan-territorial retail tariff was not financially sustainable for their businesses. The pan-territorial retail tariff was waived in 2022, and now VSPP can set their own tariffs, if they serve less than 30 customers and there are no customer complaints registered with the regulator.

On August 1, 2022, the regulator instituted via Government Notice a VSPP tariff of TSh 1,600 per unit for the following solar-based mini-grid service providers: PowerCorner, PowerGen, and JUMEME. Tariff derivation for other renewable energy VSPP is ongoing. Many VSPP investors

request that the government subsidize the services so that VSPP investors can make a profit by selling at the pan-territorial tariffs that apply to the national utility. PowerCorner owns 12 mini-grids with a total installed capacity of 310.1 kW; PowerGen 20 mini-grids, 438.9 kW; and JUMEME 21 mini-grids, 1,141kW. Retail tariff derivation for other renewable energy VSPP is ongoing. Despite solar and wind equipment being exempted from various duties, many solar-based VSPP investors request that the government subsidize their services so that they can make a profit by selling at the pan-territorial retail tariffs that apply to the national utility. So far, subsidies in the form of matching grants are provided by REF to SPP developers who have received a letter of intent from TANESCO to undertake feasibility studies, ESIA, and business plans. Also, SPPs obtain performance grants for each customer they connect. It appears, however, that VSPPs developers do not benefit from both types of subsidies enjoyed by SPPs that could make tariff-setting mechanism inclusive to VSPPs as well.

Additionally, this is evidenced by another respondent:

> *Very Small Power Projects (VSPPs) set their own tariffs without regulatory approval, often covering costs and adding profit margins. Some used flat-rate billing, hindering energy efficiency. From 2015 to 2022, all VSPPs were mandated to charge a subsidized tariff, leading to service disruptions. In 2022, VSPPs can set tariffs, but challenges remain, with calls for government subsidies and concerns about regulatory complexities for small, remote projects. Unlike Small Power Projects (SPPs), VSPPs currently lack certain subsidies, impacting their ability to compete in tariff setting.*
>
> Interview with Ministry of Energy Manager 2022

12.4.2.2 Tariff Levels Within and Across Mini-Grid Locations

The results show that Tanzania has two types of tariffs—connection charges and energy charges. Infrastructure connection charges depend on the distance of the customer from the point of connection; the type of connection whether single-phase or three-phase power supply; and the power or voltage level of connection—low voltage 230 to 400V, medium voltage 11 to 33 kV, or high voltage 132 to 400 kV. Connection charges differ among service providers, and incentives provided by energy service providers also contribute to differences.

Energy charges are costs associated with energy consumption services provision following connection to the service provider infrastructure. Energy charges include (a) uniform block tariff whereby the tariff is the same for each unit consumed despite consumption level, (b) ascending block tariff whereby it is cheaper for small consumption levels, but tariff increases with consumption, and (c) descending block tariffs whereby the tariff reduces with consumption.

Tariff types and levels differ with the business model employed: community, private, faith-based, and public. Also, tariff levels depend on whether the project is subsidized or whether some of the infrastructure components are exempted from duty or taxes or a combination of these. Examples are given below.

This is evidenced by one of the respondents who indicated that

> *In Tanzania, we have two types of tariffs: connection charges and power service tariffs. Connection charges vary based on customer distance, connection type (single or three phase), and power or voltage level (low, medium, or high). Differences among service providers and incentives contribute to variations. Power tariffs, associated with energy consumption, come in three types: uniform block, ascending block (cheaper for small consumption), and descending block (reduces with consumption). Tariff levels vary with business models (community, private, faith-based, public) and subsidies or tax exemptions for infrastructure components.*
>
> Interview with Ministry of Energy Manager, 2022

Also, the results indicated that SPPT are standardized based on generation technology and size of the SPP plant, since they all sell to the national utility. SPPs selling to own mini-grids differ depending on the business model being employed. Community-owned-and-operated mini-grids set their own tariffs that are approved during the annual meetings and are inclusive via customers' participation and endorsement. Private business model SPPs selling to customers in own mini-grids must submit a tariff application to the regulator who reviews it and may require the developer/operator to present their application for a public hearing whereby intended/connected customers offer their views and then the regulator authorizes the tariff that is cost-reflective to the services to be provided. In the case of the faith-based organizations (FBO) business model, the electrical infrastructure is sometimes donated, and power services are provided as a

charity service with a tariff that is often very low and not cost-reflective. In that regard, FBO-owned mini-grids tend to be financially unsustainable. In turn, public-owned SPPs like TANESCO business model, must submit a tariff application to the regulator for review and be subjected to a public hearing before approval via government gazette notice.

From 2008 to 2015, VSPP tariffs were unregulated whereby they set their own tariffs that they presented to their intended customers during project development. And it was required that tariffs be presented to those customers receiving connection and retail energy services, prior to connection. For VSPPs with more than 30 customers, retail tariff was reviewed by the regulator, if any customer filed a complaint to the regulator regarding tariff level as being unjust or about poor-quality power supply services, then the regulator could intervene to remedy the situation. As of August 2022, regulation of VSPPs tariffs started with mini-grids owned by PowerCorner, PowerGen, and JUMEME companies.

VSPP retail tariffs are also affected by the type of billing, metering, and bill payment model in practice. If billing is based on credit meters that are read once a month, then the bills are computed based on the unit energy cost and energy units consumed. However, such a practice is not preferred by project developers, as it creates debt with some of the rural customers who fail to repay and end up being disconnected. Instead, load-limiters or prepayment energy meters are preferred, as these technologies avoid this issue. However, load-limiters do not incentivize the consumer to undertake energy efficiency in consumption as a demand-side management. Also, some of the VSPP customers with load-limiters pay every day for their connection, whether the power supply provided is used or not. This type of metering practice should be avoided in rural areas as it contributes to making the tariffs to be high and many customers fail to comprehend. Prepayment energy metering seems most suitable to both developers and energy end-users. The payment arrangement/model most preferred by VSSPs is pay-as-you-go, whereby units are pre-purchased online, and customers are connected and disconnected online when the units are consumed, or payment days are over, whatever form of arrangement used. The pay-as-you-go payment arrangement at least guarantees enough revenue for the service provider and appears to pave the way for the financial sustainability of VSPPs if efficiently operated and maintained. What remains as a burning governance issue, however, are the high tariffs that are charged by VSPPs to rural customers, as most of them cannot afford such high tariffs. Notwithstanding the existence of robust and streamlined SPP framework and

tariff-setting mechanism in Tanzania, equity and fairness of high tariffs charged by VSPPs remain a challenge to the government and the regulator, and much work is needed to be done so that the rural poor with affordability and inclusivity problems are aligned to initiatives aimed at addressing the broader mini-grid sector governance aspects.

In addition, the study found that

> *The billing, metering, and payment model significantly impact Very Small Power Project (VSPP) tariffs. Credit meters, read monthly, risk bad debts from rural customers. Load-limiters, though avoiding bad debts, lack energy efficiency incentives. Pay-as-you-go, with pre-purchased units, is preferred for both developers and users, ensuring revenue and financial sustainability. However, the challenge remains in addressing high tariffs for rural customers, demanding a delicate balance between financial viability and affordability, requiring further governance considerations in the mini-grid sector.*
>
> Interview with EWURA Manager, 2022

12.4.2.3 Mini-Grid Versus National Grid Tariff Comparison

The results revealed that customer connection charge tariffs are supposed to fully cover the cost of extending electrical infrastructure to the new customer. In the case of the national grid and mini-grids supplied by TANESCO, approved connection tariffs differ between urban areas and rural areas (see Appendix A). SPPs that sell directly to the national grid and to own distribution networks have customer connection charges. In turn, all SPPs have own distribution networks and have different connection charges (see Appendix B). SPPs offer lowered connection fees as an incentive to connect as many customers as possible. Equally, several solar-based VSPPs visited charge TSh 50,000 to connect, including for house wiring (actual cost is much higher), which is subsidized by the service provider as an incentive to connect as many customers as possible to establish a threshold of customers for their network. TANESCO grid and mini-grid rural customers pay a connection charge of TSh 27,000 (being only VAT) as an incentive to connect, but costs exclude house wiring.

Energy charges are set to be cost-reflective to energy service providers. As such, energy charges tariff purely depend on economies of scale and

the efficiency of operating the energy system. Therefore, grid energy generation tariffs tend to be lower than mini-grid SPP generation tariffs, and SPP generation tariffs are lower than VSPP generation tariffs.

Also, the results show that main grid retail tariffs have three components: service charge in TSh/month, maximum demand charge in TSh/kVA, and energy charge in TSh/kWh. The service charge covers billing costs; the maximum demand charge is a fee on maximum demand registered in kVA each month or 75% of the average maximum demand in kVA in the last three months registered by the end-use customer, and energy charge reflects the cost of operation and maintenance of the energy services by the end-use customer.

Additionally, it was revealed that, SPPT tariffs are generation energy tariffs for kWh exported to the grid or decentralized grid. They do not include the maximum demand charge or capacity charges in kVA often charged by IPPs when they trade with TANESCO, since SPPs trade at medium and low voltage and their contracted capacities cannot be guaranteed at all times of their operations—that is, they are not dispatchable. Furthermore, SPPs with own distribution network have retail customer energy charges in kWh. In turn, VSPP retail energy charges tariffs are also in terms of energy for each kWh consumed. Owing to their small market, high capital costs, and low utilization factors of the infrastructure, they tend to be very high compared to national grid tariffs and feed-in tariffs charged by SPPs when they sell power to TANESCO.

Therefore, grid versus mini-grid tariff differences exit. Regulated VSPP end-use customer tariffs are to the tune of TSh 1,600/kWh, for unregulated VSPPs, about TSh 2,000 to 4,000/kWh. SPPs selling to TANESCO under SPPTs charge about TSh 180 to 480/kWh (for first-generation SPPs) and USc 7.55 to 10.82/kWh or TSh 189 to 270/kWh (for second-generation SPPs). Note that in the case of SPPT for SPPs registered under the first-generation framework based on avoided costs, the tariff plunged from TSh 480/kWh to TSh 180/kWh upon grid extension to the mini-grid. In turn, national grid retail energy tariffs range from TSh 100 to TSh 292/kWh, if monthly service charge and maximum demand charge for large customers are excluded. Note that D1 subsidized energy charge tariff sold to TANESCO end-use customers at 100 TSh/kWh is a lifeline tariff that is cross-subsidized by tariff T1 retail customers. In view of the above, huge tariff-level differences exist between subsidized D1 tariff for main grid customers in comparison to VSPP regulated and

unregulated tariffs in mini-grids. The tariff-level difference is rather modest between the national grid and SPP-supplied customers.

Moreover, it was evidenced by one of the respondents who revealed that

> *Connection charges cover electrical infrastructure costs, varying by location. Energy charges reflect efficiency, with grid tariffs lower than mini-grids, and SPP tariffs lower than VSPPs. Main grid tariffs include service, demand, and energy charges. VSPP tariffs are notably higher due to small markets and high capital costs. National grid tariffs range from [TSh 100 to TSh 292/kWh], differing significantly from VSPP tariffs.*
>
> Interview with EWURA Manager, 2022

End-use Customer Aspects

The results show that main grid customers expect to obtain 24 hours/7 days a week energy services. Small and large residential customers are connected by single-phase two-wire and three-phase four-wire low-voltage connections, respectively. Productive energy consumers—workshops, grain mills, oil press mills, carpentry workshops, and SMEs connect depending on their power needs. Mini-grids operated by SPPs also tend to comply with such services. Moreover, main grid and SPP-served customers have customer service charters with service providers that is approved and monitored by the regulator regarding power supply quality service standards. VSPPs service operators do not have such customer service provision charters with their customers, which rather makes it a shortcoming in their services to customers.

Furthermore, it was found that most of the solar VSPPs are small in installed capacity and, as such, cannot provide three-phase power supply to relatively large customers involved in productive energy uses—carpentry works, grain milling, oil press mills, and so on. Some VSPPs tend to limit such large customers to undertake their services during low and peak periods of the day and disconnect from the services during the peak periods. Another challenge expressed was that there are not readily available large capacity–rated single-phase motors that they can use in some of the villages that provide only single-phase power supply. As such, some of them were forced to revert to the use of diesel- and petrol-fueled prime movers. During the study, we visited three VSPP mini-grids that had been

encroached by the national grid. Productive-use customers immediately switched from prime movers to electricity-driven motors for their services due to lower operating costs and better service provision. However, owing to the long distances of the medium-voltage supply lines to some of the villages connected to the grid, 1 to 2 days in a week power supply service was not provided due to preventive and nonpreventive maintenance being done during such days. As such, the large productive-use customers had to switch back to prime movers during those days or stop their services.

Moreover, the results indicated that in the case of SMEs, for example, barber shops, salons, shops, and food and drinks kiosks, service providers connected to the national grid when providing services and reverted to the mini-grids when the national grid was out. What happened was that the national grid and mini-grid services coexisted. In the case of most of the lighting customers, they remained only connected to the national grid and, hence, used other sources like candles, wick lamps, or battery-charged lamps. These aspects are discussed to show the extent of impact beyond tariff-level comparison between the national grid and mini-grids. The third SPP generation framework has provisions following the national grid extension to the mini-grid, and this creates the possibility for mini-grid infrastructure to be compensated. Observations made about the three villages showed that in cases where national grid and mini-grid coexist, the mini-grids were not compensated since the mini-grids had no letter of support from MoE. One cross-boundary solar-based VSPP operator confirmed that 10 of his mini-grids had been encroached by the grid, but they have not been compensated while still coexisting with the national grid.

This is evidenced by one of the respondents who indicated that

> *Main grid customers enjoy 24/7 energy services, with residential customers connected via single or three-phase low-voltage. Productive consumers connect based on power needs. Main grid and SPP customers have service charters monitored by the regulator, but VSPPs lack such provisions, affecting customer satisfaction. Some solar VSPPs face challenges serving large customers with three-phase power, leading to limitations on usage during peak periods. In instances where national grid and mini-grid services coexist, SMEs switch between them based on availability. The compensation for mini-grid infrastructure is available in the SPP framework, but experience shows challenges in cases where coexistence with the national grid is not supported by the Ministry of Energy.*
>
> Interview with Energy User, 2022

12.4.2.4 Cost Recovery

The study found that cost recovery is key to the financial sustainability of mini-grids and contributes to electricity sector governance on the part of service developers and providers and energy service end-users. Cost recovery is achieved if revenues from sales of energy and various services rendered by the utility cover the costs of service, including generation, transmission, distribution, administration costs, depreciation, and costs of various utilities consumed. Cost recovery is augmented if there is a profit margin.

Also, the study indicated that, during the past years, the national utility has been complaining that the approved retail customer tariff is not cost-reflective. In the last two years, however, TANESCO has been collecting annual operating revenue more than annual operating costs, but, when considering the outstanding debt from previous years, it has not been making a profit. Moreover, the average SPPT or feed-in tariffs charged by SPPs selling to TANESCO is higher than the average selling price of TANESCO. This implies the tariff is not attractive to TANESCO. SPPs selling power to TANESCO grid or decentralized grid via FIT, whereby TANESCO is an anchor customer, or via other anchor customers like large productive users, tend to be financially viable, if such SPPs are efficiently operated and managed.

In turn, when the VSPPs were required by the government during 2015-2020 period to sell their power using the subsidized pan-territorial tariff being used by TANESCO of TSh 100 per kWh, against the existing tariffs of TSh 2,000 to 4,000 per kWh, there was no cost recovery. As such, some of the VSPPs stopped provision of their services, and developers stopped developing new mini-grids. From 2022, the previous tariffs employed by VSPP were once more allowed. Furthermore, VSPPs sell power in rural areas where affordability is a challenge, as they operate under low power utilization situation and where the availability of anchor customers is rare. As such, VSPP business models and financial sustainability appears questionable.

High tariffs charged by VSPPs in rural areas do not meet the aspirations of the government on social and equity considerations. So, they are not considered as a long-term solution for electrification of those areas. As such, there is a need for subsidy provision to VSPPs so that they can sell power at affordable rates and as enjoyed by customers in the national grid.

This is evidenced by the response of one of the respondents who stated that

> *Cost recovery is crucial for mini-grid sustainability, involving revenue covering all service costs and ensuring a profit margin. TANESCO faces challenges with non–cost-reflective tariffs and accumulated debt. Higher SPPTs from SPPs are unattractive to TANESCO. VSPPs struggled with a subsidized tariff, impacting services. Subsidies are essential for VSPPs to offer affordable rates, aligning with electrification goals.*
>
> Interview with TANESCO Manager, 2022

12.5 Conclusions and Recommendations

12.5.1 Concluding Remarks

The study concluded that Tanzania is fortunate to have a comprehensive and innovative SPP framework that addresses most of the key players and actors of the mini-grid development and operation challenges that, if well-observed, can significantly contribute to accelerated deployment of mini-grids in the country and, hence, speed up electrification of the rural areas. Furthermore, the Tanzanian SPP framework has migrated from first-generation technology-neutral tariff to second-generation technology-specific and size-based tariffs pegged to the US$ to the third SPP generation framework whereby integrated mini-grid operation is allowed and compensation for infrastructure can be provided to the mini-grid following grid extension to the mini-grid, though compensation has not happened to date. Moreover, the framework is inclusive of most of the mini-grid players' interests and accommodates standards and regulations that can contribute to the technical, environmental, and financial sustainability of mini-grids, which, however, is a challenge for the regulator to monitor and observe standard service provision in a multitude of VSPPs widely dispersed in the rural areas of Tanzania. The framework has sound rules and regulations that aim at making mini-grids and the rest of the electricity sector governance possible.

Concerning tariff aspects, the study concluded that tariff aspects are indeed controversial owing to divergent interests, limited resources to monitor and regulate tariffs in rural areas where the cost of provision of energy services is high, overall high risks in the sector, and the high tariffs being charged by VSPPs because of this. Equity and social aspects from high tariffs charged by VSPPs, for example, is a major concern of the government and the regulator, as the main grid low-income retail customers are subjected to

subsidized tariffs and, in contrast, their counterparts in VSPPs mini-grids face very high tariffs. This kind of energy service injustice is a concern in the country's mini-grids and electricity sector governance. It be noted that Tanzania is among a few African countries that has enjoyed political and economic stability for a long time. From 2015 to 2020, there were government's interventions to impose subsidized lifeline tariff prevailing in the national grid to as well prevail in VSPP mini-grids. This resulted in many VSPPs halting service provision and developers stopping development of new projects as well as development partners to withhold financing of mini-grids. Since 2022, VSPPs have been allowed to charge cost-reflective tariffs, and the regulator has provided a tariff for three mini-grid operators with many VSPP mini-grids, though the tariff is 16 times the subsidized tariff in the main grid. Similar efforts are ongoing to establish tariffs for all the VSPPs providing service to more than 30 customers.

Some of the key responses to the main research questions in the study include the following:

The study concluded that business models that have succeeded in delivering technical and financial sustainability for mini-grids are SPPs with SPPAs, with TANESCO an anchor customer, with hydro- and biomass-based SPPs, and wind- and solar-based SPPs in integrated mini-grid systems. Owing to diseconomies of scale and end-use customer's affordability problems and metering challenges, VSPP models are not sustainable. Also, women and children have benefited from improved lighting, cooking, and saloon and drinks kiosk SMEs and improved schools and health services. Developers, technology suppliers, laborer's, and communities in general benefit from the mini-grid supply chain.

Furthermore, key mini-grid drivers include the right energy technologies, policies, regulatory framework, innovative financing arrangements, effective business models, and smart subsidies. Hinders of mini-grids are political interventions, high cost of regulation for VSPP below 100 kW, lack of knowledge by community leaders and end-use customers on tariffs and metering aspects, social equity issues involving well-to-do national grid customers who are highly subsidized against poor customers in rural areas whose retail prices are 16 to 40 times than the national grid consumers. Lastly, Tanzania's comprehensive SPPs regularity frameworks are key to accelerated deployment of mini-grids in the country and can be adapted in other Sub-Saharan African countries.

The study concluded that the following regulatory and tariff-based challenges can be addressed:

Starting with the government, the challenge is provision of coherent policy guidelines that ensure social equity as a component of electrification whose intervention can be ensured by improved existing regulations. Owing to multitude of SPPs in the country, it is expensive to monitor their performance and, in turn, maintain quality of supply services by the regulator; one good model of intervention is to monitor quality of supply, operational efficiency, and tariff matters. Prevailing pan-territorial tariffs of the national utility appear not cost-reflective, and the regulated SPPs investors face difficulties to enter into SPPA with the utility as FIT appears higher than their average selling price. This issue can be handled by the regulator by undertaking a cost-of-service study. Not a single VSPP mini-grid has been compensated following national grid encroachment, despite maintaining the national standards and steps in project development.

End-use customers have no approved customer care service charters for VSPPs in their locations. This issue can be addressed by the establishment of a standardized VSPP service charter. Metering, billing, and payment arrangements via web-based platforms are complex and could be replaced with simple models. VSPPs' retail tariffs are very high and controversial, which, for equity and social aspects, could be addressed by the adoption of pan-territorial uniform tariffs in the national grid via subsidization.

12.5.2 Recommendations for Further Research

Future research in this domain should focus on addressing the identified challenges and gaps. Studies that explore the practical implementation of tariff structures, assess their impact on community development, and provide actionable policy recommendations can contribute significantly to the field. Additionally, an in-depth analysis of the socioeconomic and environmental impacts of mini-grids, within the Tanzanian context, is essential for a holistic understanding of the sector.

However, the challenges of regulatory implementation and tariff structuring remain, and further research and policy development are needed to ensure the sustainability and scalability of mini-grid systems. The impact of electricity mini-grids on energy access in Tanzania is evident, but more comprehensive studies are required to assess their long-term socioeconomic and environmental implications, ultimately guiding the development of more effective and inclusive policies in this sector.

However, there is a need for more rigorous research to assess the long-term sustainability and scalability of these mini-grid systems, as well as their

impact on poverty alleviation, job creation, and social development in Tanzania.

References

Ahlborg, H. and Hammar, L. (2011) Drivers and Barriers to Rural Electrification in Tanzania and Mozambique-Grid Extension; Off-Grid and Renewable Energy Sources. Proceedings of World Renewable Energy Congressm, Sweden, 8-13 May 2011, 2493-2500.https://doi.org/10.3384/ecp110572493

Bhattacharyya, S, (ed.), 2013, Rural Electrification Through Decentralised Off-grid Systems in Developing Countries, Springer, London.

BOT (Bank of Tanzania). (2023). *Tanzania in Figures 2022*. Ministry of Finance and Planning, Government Printer.

CDM Executive Board. (2005). *Clarifications on the consideration of national and/or sectoral policies and circumstances in baseline scenarios (Version 02)*. EB 22 Report Annex 3: Technical Report. UNFCCC.

Eberhard, A. (2010). Tanzania: Learning the hard way. In J. Kapika & A. Eberhard (Eds.), *Power-sector reform and regulation in Africa, Lessons from Kenya, Tanzania, Uganda, Zambia, Namibia and Ghana*. HSRC Press.

Ebert, S., Metschies, D. G. P., Schmid, D., & Wagner, A. (2019). *International fuel prices 2009*. EWURA, Dar-es-Salam Technical Report. Federal Ministry for Economic Cooperation and Development (BMZ).

EWURA (Energy and Water Utilities Regulatory Authority). (2009). EWURA is the publisher. *Development of small power projects rules* (Order 10–12). EWURA, Dar-es-Salam Technical Report.

EWURA. (2010). *The Electricity Act (CAP 131): The electricity development of small power projects rules*. EWURA, Dar-es-Salam Technical Report. EWURA as the regulator is the publisher of this. This version has been superseded by a new rule in 2020, listed below. The electronic copy of the old rule is not available.

EWURA. (2011). *Guidelines for the development of small power projects*. EWURA, Dar-es-Salam Technical Report.

EWURA. (2016). *The Electricity (Development of Small Power Projects) Rules, 2016, The Electricity Act (CAP 131). Office of the Attorney General, The United Republic of Tanzania, https://www.*

dropbox.com/scl/fi/7nf3f0nuhgj745xivxorr/Sustainability-Inclusiveness-and-Governance-of-Mini-Grids-in-Africa-Analysis-and-Case-Studies.pdf?rlkey=goso3yrhdlrgaznxzxeqzu025&e=1&dl=0

EWURA. (2019). *The Electricity (Standardised Small Power Projects Tariff) Order 2019, GN. 464.* https://www.ewura.go.tz/uploads/documents/en-1744714982-ElectricityReport.pdf

EWURA. (2020). *The Electricity (Development of Small Power Projects) Rules. GN. 491. Published by EWURA as the regulatory agency. https://www.scribd.com/document/851063025/The-Electricity-Standardized-Small-Power-Projects-Tariff-Order-2019-GN-No-464*

EWURA. (2023). *Electricity Sub-Sector Regulatory Performance Report for the Financial Year 2021/22*. Ministry of Energy.

Gratwick, K., Ghanadan, R., & Eberhard, A. (2006). Generating power and controversy: Understanding Tanzania's independent power projects. *Journal of Energy in Southern Africa, 17, 39–56*.

IEA (International Energy Agency). (2022). *World Energy Outlook*. Technical Report. Organisation for Economic Co-operation and Development (OECD).

Klein, A., Held, A., Ragwitz, M., Resch, G., & Faber, T. (2008). *Evaluation of different feed-in tariff design options*. Best practice paper for the international feed-in cooperation. Energy Economics Group, Fraunhoffer Institute (https://www.seda.gov.my/pdfdownload/evaluation-of-different-fit-design-options-best-practice-for-the-international-feed-in-cooperation/)

Marandu, E. E. (2012). The prospects for local private investment in Tanzania's rural electrification. *Energy Policy, 30*, 977–985.

MoE (Ministry of Energy). (2020). *Power System Master Plan 2020 Update*. Ministry of Energy, The United Republic of Tanzania

Moner-Girona, M., Ghanadan, R., Solano-Peralta, M., Kougias, I., Bódis, K., Huld, T., & Szabó, S. (2016). Adaptation of Feed-in Tariff for remote mini-grids: Tanzania as an illustrative case. *Renewable and Sustainable Energy Reviews*, *53*, 306–318.

Mottram, H. (2022). Injustice in Rural Electrification: Exploring equity concerns in privately owned mini-grids in Tanzania. *Energy Research & Social Science*, *93*. 102829, pp1-9. https://doi.org/10.1016/j.erss.2022.102829

Mpeta, E. J. (2015). *Research methodology: Methods and techniques*. Mkuki na Nyota.

NEP, 2015, National Energy Policy, https://www.nishati.go.tz/uploads/documents/en-1622283004-National%20Energy%20Policy%20(NEP),%202015.pdf

Odarno, L., Sawe, E., Swai, M., Katyega, M. J. J., & Lee, A. (2017). *Accelerating mini-grid deployment in Sub-Saharan Africa: Lessons from Tanzania*. WRI.

Pueyo, A., Ngoo, G., Daulinge, E., & Fajardo, A. (2022). *Transforming energy access – Promoting inclusive productive uses of energy from solar mini-grids in Lake Victoria, Tanzania*. IDS Research Report. Institute of Development Studies.

REA, 2015, Annual Report for the Financial Year ended June 30th 2014, Rural Energy Agency, United Republic of Tanzania (https://rea.go.tz/Articles/rea-annual-report-for-the-financial-year-ended-june-30th-2014)

Rickerson, W., Hanley, C., Laurent, C., & Greacen, C. (2013). Implementing a global fund for feed-in tariffs in developing countries: A case study of Tanzania. *Renew Energy*, *49*, 29–32.

Sekaran, U., & Bougie, R. (2016). *Research methods for business: A skill-building approach* (7th ed.). Wiley and Sons.

Tenenbaum, B., Greacen, C., Siyambalapitiya, T., & Knuckles, J. (2014). *From the bottom up: How small power producers and mini-grids can deliver electrification and renewable energy in Africa*. World Bank Publications.

Tenenbaum, B., Greacen, C., Siyambalapitiya, T. and Knuckles, J. (2014) From the Bottom Up: How Small Power Producers and Mini-Grids Can Deliver Electrification and Renewable Energy in Africa; Directions in Development—Energy and Mining. World Bank: Washington, D.C., United States

UNDP. (2022). *Overcoming barriers: Human mobility and development*. Human Development Report, Technical Report. Oxford University Press.

URT, United Republic of Tanzania (2017). Energy Access Situation Report, 2016 Tanzania Mainland. Government report prepared by National Bureau of Statistics (NBS) and Rural Energy Agency (REA), https://www.nbs.go.tz/nbs/takwimu/rea/Energy_Access_Situation_Report_2016.pdf

URT, 2020, Energy Access and Use Situation Survey II in Tanzania Mainland 2019/20 Summary of Key Findings. The United Republic of Tanzania, https://rea.go.tz/Articles/energy-access-and-use-situation-survey-in-tanzania-mainland-april-2020

URT. (2022). *The 2022 Population and Housing Census: Administrative Units Population Distribution Report*. National Bureau of Statistics and Office of the Chief Government Statistician Zanzibar.

USAID (United States Agency for International Development). (2014). *Power Africa in Tanzania: What power Africa means for Tanzania. USAID, Washington DC (now defunct)*

World Bank. (2021). *World Development Report. Development and climate change*. Technical Report. The International Bank for Reconstruction and Development.

World Bank. (2021). *Tanzania Economic Performance Report*. The World Bank, Washington, DC

Zigah, E., Barry, M., & Creti, A. (2016). Are mini-grid projects in Tanzania financially viable? In S. Groh et al. (Eds.), *Electricity access, decarbonization, and Integration of Renewables*. Energy Policy and Climate Protection. https://doi.org/10.1007/978-3-658-38215-5_10

Appendices

Appendix 12.A: TANESCO End-Use Customer Tariff—April 1, 2016 to 2024

Customer Category	*Component*	*Unit*	*Approved Tariff*
D1	*Service charge*	*TSh/month*	*0*
	Energy charge (0–75 kWh)	*TSh/kWh*	*100*
	Energy charge (above 75 kWh)	*TSh/kWh*	*350*
T1	*Service charge*	*TSh/month*	*0*
	Energy charge	*TSh/kWh*	*292*
	Maximum demand charge	*TSh/kVA/month*	*0*
T2	*Service charge*	*TSh/month*	*14,233*
	Energy charge	*TSh/kWh*	*195*
	Maximum demand charge	*TSh/kVA/month*	*15,004*
T3-MV	*Service charge*	*TSh/month*	*16,769*
	Energy charge	*TSh/kWh*	*157*
	Maximum demand charge	*TSh/kVA/month*	*13,200*
T3-HV	*Service charge*	*TSh/month*	*0*
	Energy charge	*TSh/kWh*	*152*
	Maximum demand charge	*TSh/kVA/month*	*16,550*
Key:			
D1: *Low usage (lifeline tariff) for domestic customers who consume on average less than 75 kWh per month. Any unit exceeding 75 kWh is charged a high rate of TSh 350 per kWh. Under this category, power is supplied at a low-voltage single-phase (230V) connection.*			

Customer Category	*Component*	*Unit*	*Approved Tariff*
T1: *General usage tariff for customers including residential, small commercial and light industrial use, public lighting, and billboards. Power is supplied at low-voltage single-phase (230V) connection, as well as at three-phase (400V). Lifeline (D1) tariff is cross-subsidized by T1.*			
T2: *Applicable to general-use customers where power is metered at 400V, average consumption is more than 7,500 kWh per meter reading period, and demand does not exceed 500 kVA per meter reading period.*			
T3-MV: *Applicable to customers connected to medium voltage.*			
T3-HV: *Applicable to customers connected to high-voltage supply, including ZECO, Bulyanhulu Gold Mine, and Twiga Cement Factory.*			

NB: (a) Prepaid energy metering for D1, T1, and T2 tariff categories; credit energy metering for T2, T3-MV, and T3-HV with kVA maximum demand metering.

(b) T2, T3MV, and T3HV consumers who stop consumption or consume less power in kVA will be charged on average 75% of the previous three months' maximum kVA recorded. Energy charges in kWh will be charged as indicated. After 3 months, the demand charge will be according to the prevailing reading.

c) End-use customer connection charges, excludes VAT 18%, REA 3%, and EWURA 1%.

Single-Phase Charges

Service Line	*Approved Connection Charges (TSh)*	
	Urban Rate (VAT Exclusive)	*Rural Rate (VAT Exclusive)*
Within 30 meters	*272,000*	*27,000*
Within 70 meters (one pole)	*436,964*	*27,000*
Within 120 meters (two poles)	*590,398*	*27,000*

Source: TANESCO.

NB:

a) Beginning July 1, 2021, service-line-connections charge in the urban and rural areas is uniform and is TSh 27,000 as directed by the Minister of Energy.

b) Beginning January 5, 2022, connection charge of TSh 27,000 continues to apply only in all rural areas, and urban areas reverted to previously EWURA-approved connection charges.

Three-Phase Charges, Excludes VAT 18%

Service Line	*Meter Type*	*Approved Connection Charges (TSh)*	
		Urban Rate (VAT Exclusive)	*Rural Rate (VAT Exclusive)*
Underground wire connection		*Actual cost + 10%*	*Actual cost + 10%*
Within 30 meters (Cable 16 mm²)	*Prepaid*	*772,893*	*772,893*
Within 30 meters (Cable 16 mm²)	*AMR*		
Within 30 meters (Cable 35 mm²)	*Prepaid*		
Within 30 meters (Cable 35 mm²)	*AMR*		
Within 70 meters (one pole)	*Prepaid*	*1,058,801*	*1,058,801*
Within 70 meters (one pole)	*AMR*		
Within 120 meters (two poles)	*Prepaid*	*1,389,115*	*1,389,115*
Within 120 meters (two poles)	*AMR*		

Source: TANESCO.

Appendix 12.B: Trend of SPP Feed-in Tariff (2009–2020) Sold to TANESCO

a) Trend of Avoided-Cost SPP Feed-in Tariff 2009–2019 (main grid)				
Year	*Wet season December–July (TSh/kWh)*	*Dry season August–November (TSh/kWh)*	*Standardized Tariff (TSh/kWh)*	*Percentage Change (%)*
2009	*86.5*	*115.33*	*96.11*	*Base Year*
2010	*99.27*	*132.36*	*110.3*	*15*
2011	*109.02*	*145.36*	*121.13*	*10*

Year	*Wet season December–July (TSh/kWh)*	*Dry season August–November (TSh/kWh)*	*Standardized Tariff (TSh/kWh)*	*Percentage Change (%)*
2012	*137.29*	*183.05*	*152.54*	*26*
2013	*157.4*	*209.87*	*174.89*	*15*
2014	*177.58*	*236.78*	*197.31*	*12.82*
2015	*171.85*	*229.13*	*190.94*	*−3.23*
2016	*171.42*	*228.58*	*190.46*	*−0.25*
2017	*182.80*	*243.73*	*203.11*	*6.64*
2018	*182.80*	*243.73*	*203.11*	*0.00*
2019	*182.80*	*243.73*	*203.11*	*0.00*
2020	*182.80*	*243.73*	*203.11*	*0.00*

b) Trend of Avoided-Cost SPP Feed-in Tariff 2009−2019 (Isolated Mini-Grid)

Year	*Tariff (TSh/kWh)*	*Percentage Change (%)*	*Effective Date*
2009	*334.84*	*Base Year*	*January 1, 2009*
2010	*368.87*	*10.16*	*January 1, 2010*
2011	*380.22*	*3.07*	*May 1, 2011*
2012	*480.50*	*27.00*	*May 1, 2012*
2013	*490.50*	*2.08*	*September 1, 2013*
2014	*482.64*	*−1.60*	*July 1, 2014*
2015	*493.97*	*2.34*	*April 1, 2015*
2016	*477.16*	*−3.40*	*April 1, 2016*
2017	*499.25*	*4.84*	*April 1, 2017*
2018	*499.25*	*0.00*	*NA*
2019	*Nil*	*Nil*	*NA*

Source: EWURA.

NB: The last avoided-cost-tariff adjustment was done in 2017.

C) End-Use Customer Tariffs for SPP Hydro- and Wind-Integrated Mini-Grid Connected to National Grid

Table 1: End-Use Customer Energy Charge Tariff from 2012 to January 2022, and February 2022 to Date

Tariff Category	*Component*	*2012–January 2022*	*February 2022 to date*
		TSh/kWh	*TSh/kWh*
D1 < 50 kWh	*Domestic Low Usage*	*60.00*	*100.00*
D1 > 50 kWh	*Domestic High Usage*	*273.04*	*273.00*
T1-1 phase	*General Usage*	*234.04*	*292.00*
T1-3 phase	*General Usage*	*234.04*	*292.00*

NB: The tariff is exclusive of VAT 18%, REA 3%, and EWURA 1%.

Source: TaTEDO-SESO, Field Data.

Table 2: End-Use Customer Connection Charges 2012 to Date

Tariff Category	*October 2012–November 2018*		*December 2018–January 2022*		*After February 2022*	
	Application Fee TSh	*Connection Fee TSh*	*Application Fee TSh*	*Connection Fee TSh*	*Application Fee TSh*	*Connection Fee TSh*
D1	*5,000*	*150,000*	*5,000*	*150,000*	*0*	*27,000*
T1—single phase	*5,000*	*150,000*	*5,000*	*25,000*	*5,000*	*25,000*
T1—three phase	*5,000*	*380,000*	*5,000*	*380,000*	*5,000*	*150,000*

NB: The tariff is exclusive of VAT 18%; upon receiving connection, each customer is provided with 50 kWh. Prepaid kWh metering and PAYGO revenue collection system are used.

Source: TaTEDO-SESO, Field data.

CHAPTER 13

Household Agency in Sustainability Transitions: A Case Study of Mini-Grids in Kenya

Elsie Onsongo,[1†] Rosebella Nyumba,[1] Ann Njuguna,[1] Mourice Kausya[1] and Beryl Onjala [1]

[1] *Nuvoni Centre for Innovation Research, Nairobi, Kenya*
[†] *Corresponding author e-mail: eonsongo@nuvoniresearch.org*

Acronyms

IRENA	*International Renewable Energy Agency*
HH	*household*
MPESA	*mobile money used in Kenya*
EPRA	*Energy and Petroleum Regulatory Authority, Kenya*
KPLC	*Kenya Power and Light Company*
KES	*Kenyan Schilling*
USSD	*Unstructured Supplemental Service Data*

Abstract

Mini-grids are increasingly recognized as a pivotal element in the global energy transition toward more sustainable, reliable, and accessible energy systems. Their role in this transition is multifaceted, addressing not only the technical aspects of energy provision but also socioeconomic and environmental challenges. A complex socio-technical system around mini-grid development has emerged, with extant literature examining the network of actors involved, while often treating households as a homogenous unit within the network that benefits from the installed system. While holding household agency constant may sometimes be necessary to simplify the already-complex innovation system around mini-grid development, it makes for a largely inadequate analysis. The role of the household within the system is difficult to overlook since it informs the activities and the evolution of standard prac-

tice in mini-grid systems. Against this background, this chapter explores how household agency manifests in the transition to using the energy generated within renewable energy mini-grids. Keeping in mind the varying dynamics of mini-grids and the challenges and opportunities presented, the chapter examines the innovative ways in which households engage in transition to using mini-grid electricity in terms of modifications to their behavior, social practices, and technology adoption. To explore these issues, a case study of Kenya based on primary data collected from 14 mini-grids spread across southern, western, northern, and central regions of Kenya is analyzed. The findings highlight the nuances around household agency and innovation around the use of energy from mini-grids.

Keywords: mini-grids, innovation, household agency, socio-technical system

13.1 Introduction

Energy poverty, sustained by low electricity access, remains a persistent challenge across the Global South, reflecting the long-standing underdevelopment of national electricity grid infrastructure (Ukoba et al., 2024). Efforts to extend the main grid to underserved areas are constrained by widespread income challenges among marginalized households (Muchunku et al., 2018) and prohibitive costs associated with extending the grid (Samarakoon, 2019). In response to high expenses involved in extending the main grid to areas with low population density and minimal energy needs (Zebra et al., 2021), mini-grids have been introduced as an alternative. Similarly, in addressing the broader challenge of energy poverty, decentralized renewable energy systems, which have been touted as the next-best option to transition to low-carbon electrification (Zalengera et al., 2020), have been introduced. This decentralization is crucial for integrating renewable energy sources, such as solar, wind, and hydro, into the energy mix. Furthermore, they are instrumental in bridging the energy access gap in rural and remote areas, given their effectiveness in reaching the last mile where extending the main grid is not feasible. Additionally, the development of renewable mini-grids presents a key pathway for advancing energy access, low-carbon transitions, and system resilience in geographically isolated and marginalized regions. Governments and the private sector have taken the opportunity to set up mini-grids within regions that are geographically distant or difficult to connect to the grid, as seen in (Sesan et al., 2024).

Socio-technical systems have impacts on people, infrastructure, technology, processes, culture, and goals (Sony & Naik, 2020) and highlights the dynamics between technology and society and how they are mutually influencing and shaping each other (Lukovics et al., 2017, see also Otte & Vik, 2017 and Sony & Naik, 2020) et al. (2017; see also Otte & Vik, 2017; Sony & Naik, 2020).

The energy poverty challenge perpetuated by low electricity access is one with which the Global South continues to contend, with a historical focus on underdeveloped national electricity grid infrastructure. Factors that limit grid connectivity by vulnerable households in underserved regions include low-capacity demands within these regions, prohibitive costs associated with extending the grid, and, coupled with it, the low household income among marginalized households (Zebra et al., 2021). To combat this challenge, decentralized renewable energy systems have been touted as the next-best option to transition to low-carbon electrification (Moner-Girona et al., 2018; Zalengera et al., 2020). For the private sector and government alike, this has presented an opportunity to set up mini-grids within regions that are geographically distant or difficult to connect to the grid.

Mini-grids are increasingly recognized as a pivotal element in the global energy transition toward more sustainable, reliable, and accessible energy systems. Their role in this transition is multifaceted, addressing not only the technical aspects of energy provision but also socioeconomic, environmental, and resilience challenges. In the context of energy transitions, mini-grids offer a pathway to integrate renewable energy sources at a local level, thereby contributing significantly to the decarbonization of energy systems. Mini-grids facilitate the decentralization of energy systems by allowing local generation and consumption of electricity, reducing the dependence on centralized power plants and transmission networks. This decentralization is crucial for integrating renewable energy sources, such as solar, wind, and hydro, into the energy mix (IRENA, 2019). Furthermore, they are instrumental in bridging the energy access gap in rural and remote areas, given their effectiveness in reaching the last mile where extending the main grid is not feasible (World Bank, 2020). The provision of reliable and affordable energy through mini-grids supports various aspects of socioeconomic development, including education, healthcare, and local industries (Bhattacharyya, 2012).

In turn, a complex socio-technical system around mini-grid development has emerged, encompassing a network of actors drawn from the private sector, governments, development partner organizations and nonprofits, and communities and households, among others. The heterogeneous nature of actors forming the socio-technical system has been examined in

the literature. Research has compared the various systems put in place by the private sector, for instance, and further considered some of the characteristics of their operations that either bolster or undermine their performance (Jahangir et al., 2020; López-González et al., 2020; Nsengimana et al., 2020). However, households, which are the primary target of such projects, are primarily considered a homogenous unit within the network that benefits from the installed electricity generation projects.

While holding household agency constant may sometimes be necessary to simplify the already-complex innovation system around mini-grid development, it makes for a largely inadequate analysis. The role of the household within the system is difficult to overlook, because it informs the activities and the evolution of standard practice by developers. The decision made by households to participate or abstain from the transition is important and is determined by various prevailing household dynamics. These factors align with the agency exercised by households to determine the extent to which a household will participate in mini-grid projects as part of an energy transition.

Predicated on this background, our study will set out to answer the following research questions. First, how does household agency manifest in the transition to using the energy generated within renewable energy mini-grids? Second, keeping in mind the varying dynamics of mini-grids, including the challenges and opportunities presented, what are the innovative ways in which households engage in transition to using mini-grid electricity in terms of modifications to their behavior, social practices, and technology adoption? Last, how do energy use and household agency differ across the various systems in place?

To explore these issues, we analyze a case study of Kenya based on primary data collected in between January 2022 and September 2023 from 14 mini-grids spread across southern, western, northern, and central regions of Kenya. The mini-grids are set up by various developers and have an expansive geographical scope and, therefore, have different characteristics. In-depth interviews were conducted with mini-grid developers, financiers, and regulators. At the local level, further interviews were done with connected and unconnected households, productive users, along with community leaders and local governments. These data are analyzed for household demographic characteristics, the various uses of energy by members of the household, and the patterns of use.

The findings illuminate the role of households in the development of the mini-grid energy sector in developing contexts. In parts of the literature and in practice, it is often taken for granted that households in

marginalized areas automatically want access to electricity and will accept any form of power delivered to them and may have little capacity to effectively participate in the processes that deliver that power to the community. There is also little nuance about how households then utilize mini-grid energy once connected and whether their practices subsequently influence the developments in mini-grid technologies and business models and, on a broader scale, the policy environment.

In this regard, our findings highlight the nuances around household agency and innovation around the use of energy from mini-grids. For the different characteristics that mini-grids have, households have adapted their decisions around the use of energy to challenges such as the high cost of energy, and unreliable energy supply, among others. This manifests through measures such as fuel stacking and opting for particular electric appliances over others. The study recommendations are around measures to consider household practices of cost-cutting and supplementing energy consumption in the operations and business models of operators in underserved regions to improve sustainability measures for the various actors in the socio-technical innovation system.

The remainder of the chapter is organized as follows. In Section 13.2, literature on household agency and the role of households in sustainability transitions is reviewed, followed by research methodology and a detailed description of the data (Section 13.3) and its analysis (Section 13.4). Next, the results are discussed (Section 13.5), and the chapter is concluded.

13.2 Literature Review

13.2.1 Mini-Grids and Energy Transitions

Mini-grids are localized grids that can operate independently or in conjunction with the main power grid. Mini-grids are a midway solution for rural electrification between the extension of the main grid—which is costly, and solar home systems—which generally have lower capacity (Chattopadhyay et al., 2015; Pedersen, 2016). Thus, mini-grids are recognized as a crucial element in global energy transitions toward more sustainable reliable and accessible energy systems. Their role in the energy transition is multidimensional: They bridge the energy access gap in rural and remote areas (Nuru et al., 2021). They address the technical challenges of energy provision in areas that are difficult to access via the grid. Furthermore, they integrate renewable energy sources such as solar, wind,

and hydro at the local level, thus addressing environmental challenges in energy provision (Brent & Rogers, 2010; Katre & Tozzi, 2018). They also support the decentralization of energy systems to enable local generation and consumption of electricity (IRENA, 2019). The provision of reliable and affordable energy through mini-grids supports various aspects of socioeconomic development, including education, healthcare, and local industries (Bahaj et al., 2019; Bhattacharyya, 2018; Ngowi et al., 2019; Pueyo & DeMartino, 2018; Terrapon-Pfaff et al., 2018).

However, the sustainability of mini-grids, particularly in the context of providing reliable, renewable, and affordable energy access, is a subject of considerable debate and analysis within the academic and policymaking communities (Bhattacharyya & Palit, 2016; Winther et al., 2020). Their sustainability is contingent upon navigating complex economic, environmental, social, and technical challenges. Household participation, access, adoption, and impacts of mini-grid energy are key to understanding the dynamics of mini-grid sustainability, especially in the Global South, where most mini-grids serve marginalized and vulnerable communities (Gollwitzer et al., 2018; Liu & Bah, 2021).

13.2.1.1 Household Agency

In extant literature, households are defined differently depending on the rationale and disciplinary focus of the study. In the context of energy systems such as mini-grids, and taking a techno-economic view, a house can be described as a single structure whereby information on sources of energy and device upgrades can be gathered (Ellsworth-Krebs et al. 2015; Raven et al., 2021). Studies geared toward social and situational energy consumption perceive a home as a social unit and a central base of dominant social contexts and dynamics. In this chapter, we borrow from Raven et al. (2021) and define a household as a social unit or entity often (but not always) made up of several individuals who are related. With the development of mini-grids in underserved areas, households not only play a key role in the adoption of energy but also determine how and when electricity is used. Therefore, studying household agency in the context of mini-grids is crucial because it offers insights into how individual and family choices impact the adoption, efficiency, and overall success of these decentralized energy systems. Household agency here is defined as the ability of households to make autonomous decisions regarding their

energy use, including the selection of energy sources, management of consumption, and investment in energy-efficient appliances.

To better understand the role played by households in sustainability transitions, we look at household behavior as one of the key contributory factors. Two antagonistic discourses around households in sustainability transitions exist. On one hand, households are viewed as a homogeneous unit, or a "closed box" (Moglia et al., 2011; Seebauer et al., 2019), while another strand highlights the dynamic and heterogeneous nature of households, seen as an "open box" (Bergman & Eyre, 2011; Lazowski et al., 2018; Naus et al., 2014; Strengers, 2011). In the open box view, households are presented as heterogeneous units existing in numerous scales interacting with other units in a social system. Households individuals differ in character, values, and beliefs and play distinct crucial roles in sustainability transitions. Furthermore, households play a significant role in determining the path taken by social innovations, the use of resources, and have been earmarked as targets of environmental guidelines and regulations (Raven et al., 2021).

Studies aligned with the "open box" view show that, while there may be similarities in households from a demographic standpoint, there are huge differences in domestic use of energy that are behavioral in nature, for instance, frequency in showering, or leaving lights on in unoccupied rooms (Guerin et al., 2000; Hyysalo et al., 2013; Ornetzeder, M., & Rohracher, H. (2006)). Nevertheless, we should not overlook the importance of technology, as households also model their behavior around technologies that they adapt (Hyysalo et al., 2013).

More often than not, households have contributed to the design and adoption of an innovation explicitly or implicitly. Innovative behavior at the household level is often analyzed under the notion of user innovation—a growing and vibrant stream of literature on sustainability transitions that explores the implications of designers and users coming together through a myriad of activities and linkages (Ornetzedera et al., 2006). Some of the roles played by users of innovation are reinvention and improvement of technology; altering norms, behaviors, and social-technical practices through socialization (Naus et al., 2015; Raven et al., 2021). Communities have played a role in raising awareness and distribution of innovations. However, only less than 1% of the total energy user population engages in innovations and with limited influence in the design and planning processes (Hyysalo et al., 2013). This limited engagement prompts the need to look at barriers and enablers of household engage-

ment or participation in energy systems and transitions, especially in contexts where they as users adapt technologies to local needs.

Household behavioral change in energy transitions often involve modifying technologies to better suit their daily practices, such as retrofitting home energy systems and integrating renewable sources into existing setups (Hyysalo et al., 2013). For solar home systems, users have been observed to experiment with configurations, share modifications, and influence market designs by providing feedback to manufacturers (Schot et al., 2016). These behaviors not only enhance technology adoption and fluid transitions but also contribute to broader systemic changes such as shifting societal norms toward energy decentralization (Raven et al., 2021). In developing contexts where energy access is fragmented and uneven, household agency manifests in adaptive strategies that bridge gaps in formal systems, emphasizing coevolution of user practices and technologies (Schot et al., 2016).

In the context of mini-grids, household behavior shows a mix of adaptation—(partial) adoption and innovation. For example in rural Zambia, households connected to solar mini-grids exhibit slow and partial shifts from traditional fuels like kerosene and candles to electricity, but they often revert to former sources due to unreliable service and high costs (Muhoza & Johnson, 2018). This shows agency through selective and hybrid energy use rather than full transitions. Also, unmet expectations can either cause retrogressive abandonment of mini-grid or progressive-timing consumption to match supply availability or combining mini-grid power with backup coping mechanisms (Muhoza & Johnson, 2018). Similarly across several African mini-grid projects, households exercise agency and behavioral change by participating in innovating payment and finance mechanisms such as pay-as-you-go models, adopting productive uses such as irrigation pumps or small business appliances, providing feedback to adjust tariffs, extending evening work hours, and fuel switches or reduced reliance on traditional fuels such as diesel (Eales, 2024; Muhoza & Johnson, 2018; Raven et al., 2021). These adaptations and behavioral changes also encompass gender dimensions. Gendered roles affect the creation and adoption of technologies. In some contexts, women often tale primary responsibility for managing energy consumption due to traditional domestic roles, which shape the design and uptake of energy-saving solutions (Tjørring, 2016). Similarly, women leverage technologies for household tasks and income-generating activities despite limited decision-making power, which influence adoption of renewable off-grid sources such as solar home systems (Standal et al., 2020).

In Kenya, evidence from community-based solar mini-grids show households alter their daily routines to leverage electrification for productive use (Kirubi et al., 2009). However, while rural electrification provides an avenue for a transition from traditional energy sources, overall consumption remains low, which often confines behaviors to basic lighting rather than transformative productive uses (Pueyo & DeMartino, 2018). Household agency in mini-grid transitions is therefore nuanced, often shaped by affordability, reliability, and inclusivity.

13.2.2 Energy Justice and Household Agency in Mini-Grids

The discourse around energy justice brings households and communities center stage in energy transitions by exploring recognition, procedural, or distributional justice in energy systems.

Historically, foreign companies have dominated the design and operation of mini-grids, creating a system that prioritizes selling electricity as a commercial good to individual households, fostering a capitalist system (Strengers 2013). Recently, governments, particularly in Sub-Saharan Africa, have begun regulating the sector to create a more equitable distribution of benefits. This move represents a shift toward protecting vulnerable customers and fostering a more fair and just mini-grid electricity system.

The dominant narrative is that mini-grid developers, many of whom are foreign companies, initially set the rules of the game in the mini-grid electricity regime. The consequence was that the trajectory of development went toward a development of highly commodified services, that is, electricity, to be sold to individual household consumers. In this case, neoliberal capitalist accumulation endures (Strengers, 2013). It is only recently that governments, particularly in Sub-Saharan Africa, are stepping in to set new regulations for the sector in an attempt to level the playing field or protect vulnerable customers.

It is not very clear in the literature to what extent communities in mini-grids coordinate deliberations, facilitate social learning, build alignments, and mobilize power for transformation (Brisbois, 2020). It is not clear whether mini-grids have responsive consumers and to what extend they are capable of being "prosumers."

It is within this context that questions of social justice become important. There is a growing body of energy research that has identified critical

injustices in energy transitions in society. The resolution of these injustices must be part of just transition agendas (Calver & Simcock, 2021; Milchram et al., 2018; Sovacool et al., 2017; Wangand Lo, 2021).

Household agency is at the core of this discourse, for example, through

- the difficulties they face in attaining assets, capabilities that would enable their effective participation in mini-grid systems;
- the difficulties they face in navigating systems preset by developers whenever they are using mini-grid systems;
- the protection of consumer and citizen rights under data extraction; and
- the unfairness in the relative distribution, between system-level operators and households, of the benefits and risks in mini-grid systems (Smit et al., 2023).

To promote just transitions, there is a need to document and understand these dynamics between households and the energy systems they use. However, the risk remains that households are treated as fixed, uniform entities that simply require "inclusion" or "empowerment" to be done to them, rather than being recognised as diverse subjects with different positions toward energy transitions.

At its core, the concept of energy justice emphasizes that sustainability transitions should consider not only the technical and economic viability of energy systems but also their moral and social implications in order to holistically address injustices in access, distribution, and participation (Sovacool & Dworkin, 2015; Sovacool et al., 2017). This framework is structured around three primary tenets—distributional justice, which is concerned with fair allocation of energy benefits and burdens; procedural justice, which ensures that there is transparent, inclusive, and equitable decision-making processes; recognition justice, which identifies and acknowledges those affected by injustices; and rectification of historical vulnerabilities of marginalized groups (Sovacool et al., 2017).

The discourse around energy justice positions households and communities at the forefront of energy transitions by exploring the dynamics of recognition, procedural, or distributional justice within energy systems. Historically, foreign companies have dominated the design and operation of mini-grids in regions like Sub-Saharan Africa, often prioritizing electricity as a commercial commodity sold to individual households, thereby reinforcing capitalist structures that may marginalize vulnerable populations (Angel, 2021; Strengers, 2014). Recently, governments in

Sub-Saharan Africa have begun regulating the sector to create a more equitable distribution of benefits, protect vulnerable households, and foster a more fair and just mini-grid electricity system. This shift enhances household agency in mini-grids by recognizing and supporting their behavioral modifications and social practices as critical components of just and sustainable mini-grid transitions.

Household agency is therefore at the center of energy justice discourse, as it manifests in how households navigate (and reshape) mini-grid systems despite structural constraints and vulnerabilities. In this context, this chapter therefore positions energy justice, through its tripartite framework, as a lens to critically analyze how these systems are structured and the possibilities and limitations of household agency within sustainability transitions. Distributional justice directs attention to allocation of both benefits and burdens of mini-grid systems. In Kenyan mini-grid context, mini-grids have often been designed and operated predominantly by private or foreign developers, who are the ones that define pricing models, service packages, technologies, among others. This has often resulted in the commodification of electricity as a market good rather than a social right (Angel, 2021; Strengers, 2014). Households then become consumers or price-takers in these systems rather than co-producers, while developers get most of the economic value generated through energy service provision. This reinforces inequalities in affordability, reliability, and access, eventually determining who can participate in and who remains marginal to the energy transition. Addressing distributional injustices would therefore require incorporating "redistributive mechanisms," such as community ownership models, and redistribution of benefits through subsidies or financial incentives that protect vulnerable users (Calver & Simcock, 2021).

Procedural justice highlights the limited role of communities in coordinating deliberations or facilitating social learning within mini-grid governance, with unclear evidence on whether households act as responsive consumers or "prosumers" who actively produce or manage energy (Brisbois, 2020) In most cases, the design, implementation, and operation of mini-grids remain developer-centric, with households having limited opportunities to influence how technologies are deployed or how services are managed. Even when participatory mechanisms exist, they are often tokenistic, driven by donor or regulatory requirements rather than genuine coproduction.

For households, this procedural exclusion constrains their exercise of agency and, in turn, necessitates adaptation to pre-established rules rather than negotiate them. Embedding procedural justice means recognizing households as co-designers and decision-makers, capable of contributing local knowledge, priorities, and innovations to energy planning. This may involve creating participatory governance structures, local energy committees, or cooperative management systems that institutionalize household participation beyond consultation (Jenkins et al., 2018).

13.3 Research Methodology

We undertook qualitative content analysis to critically interpret household agency through available textual data obtained from interview transcripts. The interviews were structured one-on-one and were conducted on three primary groups:

Interviews and focus group discussions with households, both connected and unconnected to the mini-grids visited, and respective community leaders.
Mini-grid developers and their representatives in operations and maintenance.
Policy actors, in this case, are the Ministry of Energy and the regulator.

13.3.1 Coding Scheme

The data collected were analyzed using Atlas.ti software, and the analysis process was operationalized according to the coding scheme (Table 13.1):

13.3.2 Analysis Using Atlas.ti

The interviews were recorded and transcribed verbatim, after which the transcripts were imported into the Atlas.ti software. Coding was done deductively using the above scheme, which evolved and was reconstructed as new dimensions and variables emerged. Researchers engaged in a rigorously iterative coding process that entailed deliberations among researchers on the codes assigned to different excerpts of the transcript. Several cycles of coding were done. The first cycle involved naming the excerpts

Table 13.1: Assessment of Parameters

Variable	*Sub-Variable*	*Indicators*
Household (HH) **Agency**	*Agency before connection*	*Types of energy used before connection* *Actions of unconnected* *Decision to connect* *Pre-project activities and campaigns* *Community mobilization and sensitization*
	Agency after connection	*Payments and obligations* *Upgrading power tiers and electricity meters* *Post-installation meetings and education* *Collaborating with providers* *Queries and complaints channels* *Opting out of electricity connection*
	Adoption of technology	*Types of technology* *Purchase and use of electric devices* *Boosters and barriers to adoption*
	Behavior modification	*Social practices* *Behavior change* *New habits (energy-stacking, leaving lights on)* *Change in attitudes* *Prospective behavior modification*

(Continued)

Variable	*Sub-Variable*	*Indicators*
HH **Innovation**	*Any new activity or new way of doing things never done before by community*	*Remodeling existing innovations* *New business ventures* *Generating new products* *Innovative way of honoring payments* *Acquiring new skills related to electricity* *Leveraging social networks for unconnected users*
	Adoption of technology	*Using new devices* *New innovations* *Learning to use MPESA*
Challenges	*HH challenges*	*Challenges pre-connection* *Challenges post-connection*
HH **Opinion**	*Before connection*	*Cost of installation* *Cost of power—electricity charges/tariffs* *Method of entry of providers into community*
	After connection	*Cost of power/electricity charges* *Management of mini-grid*

of data, while in the second cycle past theories were revisited, and initial frequent and significant codes were synthesized into more refined codes (Charmaz, 2014; Tracy, 2019). The researchers also conducted a third cycle of coding to make the codes more focused. For example, in the first level of coding, we had household agency as the first code assigned to an excerpt, and this was later split to modification of behavior, which in the end was narrowed down further to generate the code "*energy stacking.*"

The study employed random sampling, whereby every household connected or unconnected had a chance of being included in the study. Out of the 150 household interviews, 23 were purposefully selected for this study due to the agency and diversity in energy use they employed and their unique pathways in energy adoption. Households unconnected to

Table 13.2: Household Demographics

Age	*Gender*	
	Male	*Female*
21–25	*0*	*4*
26–30	*4*	*1*
31–35	*0*	*0*
36–40	*2*	*1*
41–45	*0*	*1*
46–50	*2*	*0*
51–55	*0*	*3*
56–60	*1*	*0*
61–65	*2*	*0*
66–70	*1*	*1*
Total	*12*	*11*

the grid also played a substantive role in exercising agency, which often translated to said households not participating in the move toward the use of clean renewable energy.

The definition of the agency has varied across disciplines, defining the agency as the ability to pursue goals that one values and has reason to value (Anderson, 2012). Anderson (2012) further measured household agency using the following variables: elderly dependency ration, child dependency ratio, trust in one's local network/community, Subsistence Time deprivation, and associational activity. The five variables are instrumental in the transition of households from poverty. Of the five household agency proxies, two are capability measures (elderly dependency and subsistence time deprivation), which impedes households' ability to take advantage of opportunities at their disposal and bring about change.

Table 13.2 above shows the distribution of respondents by age and gender. Majority of respondents interviewed were between the ages of 26 and 30. The total amount of respondents interviewed was 23, with 12 of them male and remainder 11 female.

Table 13.3 above indicates nonhousehold interviews, conducted with key informants and mini-grid operators and financiers.

13.4 Analysis of Results

Table 13.3: Interviews Conducted

Type of Interview	*Persons Interviewed*
Focus Group Discussions	*13 households connected to mini-grid M*
Focus Group Discussion	*13 households connected to mini-grid L*
Focus Group Discussion	*12 households connected to mini-grid B*
Key Informant Interview	*6 board members of mini-grid P*
Key Informant Interview	*Customer relationship manager, mini-grid Y*
Key Informant Interview	*1 mini-grid financier*
Key Informant Interview	*5 mini-grid operators*

This study primarily highlights the nuance of household agency and decision-making around the use of energy generated from mini-grids. Households adapt their energy decisions to challenges such as the high cost of energy and unreliable energy supply, among others. This manifests through measures such as energy- stacking and opting for particular electrical appliances over others.

The results of the study show that household agency may occur in all or either of two phases:

Before connection to mini-grid.
After connection to the mini-grid.

The concept of household agency undergoes a transformative process during the connection to mini-grid, characterized by the actions and steps taken by households to adapt to the new technology in a way that suits their needs. In contrast, post-connection household agency emerges as a manifestation of behaviors adopted to adapt the new technology to their unique needs. As households familiarize themselves with the introduced technology, they exhibit ingenious and innovative traits facilitating their seamless adjustment.

The study also looks at household agency and innovation in the lens of a community made up of different households coming together to make decisions that would later have a general effect on individual households. These collective decisions have far-reaching implications, influencing the individual households within the community and contributing to the overall mini-grid development process. This perspective challenges the

misconception that households are passive recipients, emphasizing their active role in shaping and influencing the technology they adopt.

13.4.1 Household Agency Toward Connection to the Mini-Grid

The study traces mini-grid electricity adoption pathways of 23 unique households located in the western, northern, and central parts of Kenya. To get connected to the mini-grids, households have to play an active role that begins by showing interest in the mini-grid electricity. The households under study are located in the underserved areas that are neither connected to the main grid or any off-grid system. Accordingly, introduction of mini-grids is a game-changer in the energy market of these areas.

In preparation to setting up a mini-grid, the developers engage the households in discussions around mini-grids and their intent to establish one in the area. The developers work with community leaders, starting with the chief who spreads word about a meeting with the mini-grid developers. The people charged with this responsibility normally visit households to inform them of the news. Household representatives in turn exercise their agency by diarizing the date and venue of the meeting and showing up for the meeting.

> *Masiga was going around telling people about the pending meeting and the expected guests, my husband is the one who attended.*
>
> *B4 narrates*

This represents an active agency decision where the household chose who to attend the meeting given the household circumstances.

Household agency in the connection to the mini-grids extends beyond mere attendance at meetings. Households actively contribute and influence the mini-grid development process by expressing their views in these meetings. Representatives from these households participate in discussions focused on crucial aspects such as tariff negotiations, influencing the mini-grid's location and advocating for the employment of community members at the mini-grid. Some households also conversely exercised agency by not attending sensitization meetings as they calculated that other priorities exceeded the value of participating in the meetings. These different types of responses show that attending the meetings is not automatic but reflects household decisions regarding the opportunity costs.

Again, such choices emphasize recognition justice as households weigh the value of participation against immediate needs.

> *At the time they called for a meeting, I was busy, and this prevented me from going.*
>
> D20 reports

Beyond the decision to attend, the quality of participation varied significantly, and this exposes gaps in procedural justice. Some household representatives came with specific concerns and questions while others remained silent. Some communities had already established institutions such as savings groups (chamas) and organized community leadership that enabled coordination of the meetings and community position prior to the meetings. These communities could arrive with unified proposals and negotiating positions. Some communities lacked such institutional infrastructure, meaning households attended meetings as individuals rather than representatives of coordinated groups. These variations had direct consequences for negotiated power, as communities with these established coordinated mechanisms could organize collective responses to the developer proposals, whereas those without such coordinated mechanisms faced barriers for collective action even where households' concerns were similar. One respondent described the formal process:

> *How was PMC chosen? B2: We were chosen by the community…. We had a chairperson, his vice, secretary, his assistant, treasurer and organizer. We totaled six, and I was the organizer at PMC. We were chosen by the community to be in charge of these areas and oversee the visits and how work was going on.*
>
> *(B2)*

This formalized community committee structure enabled systematic representation and coordination. Where such structures existed prior to mini-grid development, or were rapidly established during community mobilization, communities possessed institutional vehicles for exercising collective agency.

Notably, at some sites, multiple meetings convened by developers reached an impasse as community members did not agree with the pro-

posed tariffs. In response, developers exhibited flexibility, scheduling additional meetings to address concerns and proposing new tariff structures that resonated with the community members. This iterative process underscores the collaborative nature of decision-making and the importance of aligning with the perspectives of the households. It is, however, important to note that there is a limit to which mini-grid developers can negotiate tariffs with the community. The final figure is subject to approval by the national regulator, which is EPRA.

In some sites, households assert agency through discussions and negotiations on the tariffs, site selection, and employment opportunities for the locals.

> *Even if you've decided yourselves, you can't agree on a price much higher than the one set by those people. You also can't decide on a price so low that it would seem the ones collecting the money are stealing from you. They have rates too. It shouldn't be higher than theirs and it shouldn't be lower than theirs.*
>
> *(B2)*

When unresolved, the community escalated the issue.

> *It wasn't even a demonstration. We just threatened. After we made calls and those people failed to come. We then decided the only solution was to shut it down so that it doesn't work, and they see that nothing is happening, that things have stopped, so that they can come and listen to our complaints. That was the protesting we meant. When we were doing that, they were not responding. They were just communicating on the phone because of the caretakers that watch the premises. Eventually they came and we talked with them and found a solution. We decided to just continue with the electricity but one day they will come.*

These tactics embody procedural justice as the community compelled the developer to adapt a tariff within bounds set by the regulator.

Advocating for job opportunities of the local communities advances distributive justice. The designated representatives play a crucial role, negotiating for job opportunities in the mini-grid construction, operation, and maintenance on behalf of the community. The negotiation process involves constructive dialogue between community representatives and developers, where views are exchanged to reach mutually beneficial agree-

ments. Developers, recognizing the importance of community support, accommodated these requests, creating a sense of ownership and participation within the community, which is key for the project survival.

Beyond negotiations, households contribute labor toward setting up the mini-grids further manifesting agency. The configuration of mini-grid technology and setting up of the distinct equipment that are linked to establish a mini-grid are often done by technicians from the mini-grid developer company; however, they cannot do all the work that involves setting up a mini-grid. Accordingly, households chime in to engage in the array of tasks involved. In one site, households made contributions by volunteering to offload equipment from a ferry to the mini-grid site.

> *We accepted. And then now where the community fairly participated and that was felt by everybody was the removal of the materials from the ferry—off loading—which took us like almost 20 days because those who went today, you'll not see them there tomorrow. [laughs] I think you know the weight of a transformer. It was just being lifted by hands. No…machine to carry it out until later on…now they came to the crane.*
>
> *(Respondent M3)*

Contrarily, households served by mini-grids demanded pay for the labor they offered. They were engaged in digging holes that would be used to install poles. This active involvement of households not only shapes the direction of the mini-grid development process but also establishes a model of inclusive decision-making in sustainable energy transitions.

In Kenya, land has remained a contentious issue, this is even further aggravated by the fact that in some places land ownership is communal. In these areas, community leadership plays a vital role in deciding the mini-grid's location. The negotiation process for way leaves, an essential part of the installation, involves direct engagement with households. The decisions made by households in these negotiations directly impact the course of this process. In cases where the land is privately owned, households wield significant influence over decisions concerning the mini-grid's location and granting way leaves. This is a win-win situation for both the households and the developers who often get a chance to do business while the households are paid for leasing the land. This agreement is however not arrived at easily. Development

partners and mini-grid financiers have often played an intermediary role between the households and mini-grid developers where they step in to explain to households why they have to pay for electricity even in cases where land has been given freely by the community. Additionally, mini-grid financiers engage households at community level by acting as mediators between the community and the private mini-grid developers. They step in whenever households are not satisfied by the private developers to answer questions like, why are the developers charging such a high tariff yet they have been given land for free, why are their charges higher than that of Kenya Power and Light Company (KPLC), what are they getting in exchange for allowing the private company to establish their business here? Why charge for the electricity yet solar energy is supposed to be free? Beyond mediating between the community and the mini-grid developer, the financiers also play a similar role like that of mini-grid developer of educating remote communities of what mini-grid electricity is and how it works. Household agency can be traced in their inquisitiveness in the questions they ask the mediator and not just relenting to the operation framework set for them. More so, their willingness to create time and avail themselves for such trainings is indicative of their agency.

Before establishing a base in an area, mini-grid developers, especially those championing clean cooking and engaged in sale and distribution of household electric devises, do market surveys to gauge household incomes and get an idea of what use the households would want to put the electricity to and number of people in households. Households' participating in the surveys is a form of agency as they give delicate important information that may promote or impede the establishment of mini-grids in the area. Developer O representative notes that

> *A team of customer acquisition sign-up agents is sent to the ground and everybody showing a willingness is signed up and the next step which is now doing a more detailed survey takes place, so we determine the amount of land an individual owns, the kind of shelter an individual owns, permanent, semi- permanent, temporary, the income, sizes of these households, number of children, livestock, the particular crops grown all this is captured. We come back and do our analysis and identify those that will make more sense to us.*

To get connected to electricity, households must allow technicians from the mini-grid company into compounds to do the wiring, set up ready boards, and undertake any other activity pertaining to installation. Addi-

tionally, these households must pay installation fees to facilitate power installation. Study findings show that in as much as most households pay the installation due to looming business opportunities, better education performance improved security and other benefits of electricity, even though not all households are able to afford the installation fee. *"I don't have power because it is expensive, installation is expensive [and] the daily premiums are also high, its KES 66per unit which is very high"*—L1 laments. In the same breath, there are households who pay installation fees just to have their homes connected to power; this is done in installments where a down payment is made, after which monthly deductions are made from subscription/premium fees. Though a majority of the households are excited at the prospect of being connected to mini-grid energy, there are a few exceptions who saw it best to hold on to their current source of energy since they thought it was optimum for their needs, which included mainly lighting, powering electronic devices such as radio and TV, and charging phones: "*My husband thought that since we have a big solar panel and battery there is no need for us to install the mini-grid electricity yet we have solar, we do not pay, my husband bought it on a one off payment and there are no premiums attached"—Respondent R reported.*

13.4.2 Household Agency After Connection to the Mini-Grid

In this section, household agency after connection to mini-grids is discussed; agency after connection manifests in three ways; household engagement in activities that aid in coping with challenges after connection, adoption of technology, and modification of behavior.

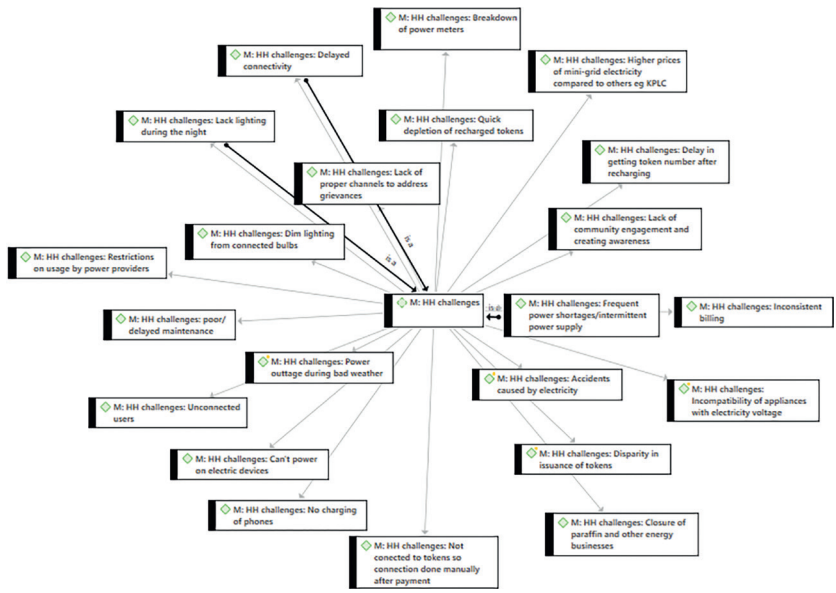
13.4.2.1 Challenges Faced by Households

Connection to the mini-grid is not an end to itself, after connection to the mini-grid, households face astronomical challenges that trigger their agency in a quest to solve or cope with the challenges at hand. The challenges emanate from technical and system failures that are further intensified by poor operation and maintenance in some of the mini-grids. Households play a

key role in ensuring the continuity of their power supply; this has been an uphill task since mini-grids are faced with problems that the developers are also grappling with. Mini-grid energy use is not a linear process in that once installation is done the household benefits from a continuous access of electricity. Households have to exercise their agency by continuously paying the subscription fees, joining a constant learning curve where they always have to learn how to surmount every energy-related challenge and optimize how they use electricity, adopt to the new technology, modify their behavior, and innovate their way around when using mini-grids. Therefore, households exercise their agency to respond to the numerous challenges they face upon connection to the mini-grid (Figure 13.1).

After installations, households have to pay for electricity, and all mini-grid developers interviewed, with an exception of one, have adopted Mpesa, a mobile phone-based money transfer service as the only mode of payment. Mpesa float is not always available in remote surroundings:

Figure 13.1: Network Presentation of Household Challenges on Atlas.ti 22



> *Here the services of Mpesa are a great problem. At some point, there is no float in the whole of Longech and this forces us to proceed up to Talgon to pay and get all that we may want sometimes getting float from someone depends on trust if not you can never get any stock.*
>
> *L2 laments*

Accordingly, households must learn how to make payments to their assigned account numbers. There are instances when even after payments the power does not come on automatically, if it is a token system, the person who made the payment ought to key in the unique number on the meter box. The mere decision of choosing to pay for the electricity also shows agency since without payment there is no electricity. System failure prevents electricity auto-reconnection, and there are instances where household representatives have to call mini-grid operators for them to have their power restored after payment "*The only thing we experienced initially is that there [were] no tokens, we would pay but they had to come and adjust*"—C4 notes. Contrarily, D1 boasts: "*If I pay even now, they send me the token without delay. I wonder when others complain. I don't know where the problem is but for me, I don't have any challenge.*" Again, a segment of households show their agency by choosing to navigate the challenge of high electricity tariffs through devising inventive coping mechanisms. This involves a deliberate calculation of how long a given amount of purchased electricity should last, which in turn informs their planning strategies. By gauging the relationship between payment amounts and expected usage duration, these households can make judicious decisions about which appliances to use and when.

> *I'm okay. I know how long 100 takes so I know how much I should pay. If I get money and pay 500, I know it'll get to which day. Before it reaches, I've organized myself so children won't cry wanting to watch TV.*
>
> *Respondent N2* explains*

After connection to the mini-grid, households remain in constant communication with mini-grid operators who have been employed to manage mini-grid affairs at the grassroots level; they constantly call and engage mini-grid operators in discussions around power outages, fast token depletion, system failure, delay in reconnection after payment, and, in

some instances, an upgrade of the power tier they are using to a higher one that accommodates high-voltage electronic devices.

Meetings on energy use remain an important part of household agency even after connection to the mini-grid; the meetings are called by either households or mini-grid developers who remain in constant communication. Study findings show that households have continued to push mini-grid developers to lower tariffs, fulfill their promise of establishing other development projects in the locality, changing payment system from a flat-rate system to a metered rate, and installation of a token system whereby households can monitor their energy consumption. For instance, mini-grid L users in northern Kenya had demanded that mini-grid developers build a school and construct a borehole for the community as soon as the mini-grid started operating; this has however not been done, hence warranting a lot of negotiation meetings between the two groups. In another clear case of household agency, a section of households using mini-grid electricity pressured the mini-grid developer to switch from a flat-rate billing system to metered electricity. They were frustrated with community committee members going door-to-door demanding payments, especially when some households are using the electricity without paying. The situation is aggravated by the fact that some households only use electricity for basic lighting, while others use it for heavier appliances like televisions and irons, yet they are all charged the same. This pressure leads the developer to make the switch to metered connections, installing meters in every household.

*"Yes. It was a flat rate. But people refused the flat rate saying, 'We won't do the flat rate because some people have TV, some use ironbox, and we're paying the same amount with those only using electricity for lighting. We should pay according to your power consumption'"—explained respondent B2**. This highlights a distributional justice issue where the flat-rate billing created unfair burden distribution. Household using electricity for basic lighting paid the same amounts to households with higher consumptions despite their different electricity use and economic capacity, and this violated the community's sense of fair distribution. Again, the community mini-grids being a new technology in the energy-poor areas, households have had to adapt to the new technology and all that comes with it. Households have learned how to use and incorporate the use of electronic appliances such as electric pressure cookers, electric token meters, incubators, and posho mill machines. Households have also learned how to pay via Mpesa using their unique account numbers, how to use the Unstructured

Supplementary Service Data (USSD) code to check on the consumption of electricity, and how to use payment apps.

> *Now when it comes to making a payment, using that unique identifying meter number a customer is able to purchase tokens via their phone—it's called a jaza system which will come and ask you a question, which language will you like to use, you place it, Kiswahili, you want to pay for electricity, fill in the account number like 1 English…there are those who don't know English but knows Kiswahili then it goes back and takes you to load the number, you finish with that, it tells you [to] put account number then put your meter number, put the account and finally place the pin [and then] you are done .It goes automatically on, the system is connected to our meters.*
>
> Respondent L narrates

13.4.2.2 Adoption to Technology

During the initial planning stages, households inquire how they will be using the electricity from the mini-grid. This is to enable them understand the spectrum of appliances they will be able to use. Such discussions help the mini-grid developers with the mini-grid sizing, depending on households' preferences. After being connected, households have been ingenious in identifying what works best for them in terms of adopting to the new energy technology. In the advent of introduction of mini-grids to remote areas, electric appliances have been introduced to households whereby they have been encouraged to purchase these items. More so for electric appliances; for example, when electric cookers were first introduced, households were encouraged to purchase them. Those who did so have realized the study recommendations are around measures to consider household practices of cost-cutting and supplementing energy consumption in the operations and business models of operators in underserved regions to improve sustainability measures for the various actors in the socio-technical innovation system.

13.4.2.3 Behavior Modification

The inception of mini-grid energy use was welcomed by excitement as it marked a new dawn for connected households; however, along the

way they realized that they have to modify their behavior in relation to mini-grid power use in order to continue using the energy. High cost of electricity, unstable power connections, power outages, power rationing, payment system failure, and the need for a backup energy system triggered the modification of behavior. One, households now realized that they had to pay a huge cost for connection, and they started engaging in energy-stacking, which meant that they could no longer use the mini-grid energy exclusively; hence, they started incorporating their old sources of energy for both lighting and cooking to save on the overall expenditure toward energy. For instance, those using electric pressure cookers either stopped or regulated the use of the pressure cookers after establishing that they consume a lot of energy. D4 narrates that he only uses the electric pressure cooker to make tea, and the rest of the foods are cooked using firewood—this is because you can make tea faster in electric cooker. Phone torches, dry cell torches, and solar and paraffin lamps among others were used as backups in case of blackouts, system delay in auto-reconnection, and any power failure due to the unreliable nature of mini-grids.

> *We use this mini-grid electricity but when it doesn't work at night we use a torch that uses batteries.*
>
> T2 narrates

Other households have resorted to regulating the use of electric/electronic appliances like iron box, television, and electric pressure cookers in order to minimize the consumption of electricity, which in turn lowers the amount of money spent on electricity. D20 notes:

> *The TV uses electricity but I wondered how I would be able to use it…if I put tokens it consumes a lot…when one has a TV, the amount of token loaded cannot last more than 3 days. [I]t consumes a lot [;] therefore I only use TV to watch news [and] when I am done I switch it off.*

13.4.2.4 Household Innovation

While adopting to the new technology, households have been innovative in the use of mini-grids electricity. Their innovation manifests in the fol-

lowing ways; on one hand, some believe it is better to make little payments than higher payments as higher payments are deemed to deplete faster; for instance, there is the notion that if one pays KES 20 it will last longer than a payment of KES 50. On the other hand, some have resorted to making payments of 100 bob installments in order to bypass the Mpesa charges, since transactions of KES 100 and below are not charged. Unconnected households have also learned to leverage on social networks they have with connected households through charging their electronic devices in connected households, instead of traveling to shopping centers to charge their phones. Household innovation has also been depicted in the type of unique businesses started by households that have not existed in the locality before. These businesses include cyber cafes, egg hatching, barbershops, posho mills, and chaff-cutting businesses. Though households appear innovative, in most cases it is the mini-grid developers who advise them to set up such businesses in their quest to establish an anchor customer.

13.5 Discussion

Studying household agency in the context of mini-grids is crucial because it offers insights into how individual and family choices impact the adoption, efficiency, and overall success of these decentralized energy systems. Household agency—defined as the ability of households to make autonomous decisions regarding their energy use, including the selection of energy sources, management of consumption, and investment in energy-efficient appliances—plays a pivotal role in the operational dynamics of mini-grids. This focus is vital for several reasons:

First, understanding household agency helps in designing and implementing mini-grid systems that are more aligned with the actual needs, preferences, and behaviors of the end-users. By acknowledging the heterogeneity within communities, energy solutions can be tailored to enhance user satisfaction, thereby increasing the uptake and sustainable use of mini-grids. Second, studying household agency sheds light on the patterns of energy consumption and can lead to the identification of barriers to energy access and efficiency. Knowledge of these patterns allows for the development of targeted interventions aimed at promoting energy-saving behaviors and supporting investments in renewable energy technologies, contributing to the overall sustainability of mini-grids. Moreover, empowering households with the agency to manage their energy needs fosters a

sense of ownership and responsibility toward the mini-grid, potentially leading to more responsible energy consumption and a willingness to invest in the maintenance and sustainability of the energy system. Finally, insights gained from studying household agency can inform policy and regulatory frameworks, ensuring they support not just the technological and economic aspects of mini-grids but also the social dynamics that influence energy access and usage. This holistic approach is essential for the success of mini-grids in providing reliable, affordable, and sustainable energy, especially in remote and underserved areas.

In essence, studying household agency within the mini-grid context is essential for creating energy systems that are not only technologically and economically viable but are also socially inclusive and responsive to the needs of the communities they serve.

References

Anderson, B. (2012). Converting asset holdings into livelihood: An empirical study on the role of household agency in South Africa. *World Development*, *40*(7), 1394–1406.

Aran Eales (2024) Power to the People: Do With or Do For? Exploring Community Agency in African Mini-grids. CESET

Bahaj, A., Blunden, L., Kanani, C., James, P., Kiva, I., Matthews, Z., Price, H., Essendi, H., Falkingham, J., & George, G. (2019). The impact of an electrical mini grid on the development of a rural community in Kenya. Energies, 12(5), 778. https://doi.org/10.3390/en12050778

Brent, Alan Colin & Rogers, David E., 2010. "Renewable rural electrification: Sustainability assessment of mini-hybrid off-grid technological systems in the African context," Renewable Energy, Elsevier, vol. 35(1), pages 257-265

Bergman, N., Eyre, N. (2011). What role for microgeneration in a shift to a low carbon domestic energy sector in the UK? Energy Efficiency, 1-19.

Benjamin K. Sovacool, Michael H. Dworkin, Energy justice: Conceptual insights and practical applications, Applied Energy, Volume 142, 2015, Pages 435-444, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2015.01.002.

Bhattacharyya, S. C. (2018). Minigrids for the base of the pyramid market: A critical review. Energies, 11, 813. http://doi.org/10.3390/en11040813

Charles Kirubi, Arne Jacobson, Daniel M. Kammen, Andrew Mills, Community-Based Electric Micro-Grids Can Contribute to Rural Development: Evidence from Kenya, World Development, Volume 37, Issue 7, 2009, Pages 1208-1221, ISSN 0305-750X, https://doi.org/10.1016/j.worlddev.2008.11.005.

Charmaz, K. (2014). Grounded Theory in Global Perspective: Reviews by International Researchers: Reviews by International Researchers. *Qualitative Inquiry*, 20(9), 1074-1084.

Chattopadhyay, D., Bazilian, M., & Lilienthal, P. (2015). More power, less cost: Transitioning up the solar energy ladder from home systems to mini-grids. *Electricity Journal*, *28*(3), 41–50. https://doi.org/10.1016/j.tej.2015.03.009

Gollwitzer, L., Ockwell, D., Muok, B., Ely, A., & Ahlborg, H. (2018). Rethinking the sustainability and institutional governance of electricity access and mini-grids: Electricity as a common pool resource. *Energy Research & Social Science*, *39*, 152–161. https://doi.org/10.1016/j.erss.2017.10.033

Guerin, D. A., Yust, B. L., & Coopet, J. G. (2000). Occupant predictors of household energy behavior and consumption change as found in energy studies since 1975. *Family and Consumer Sciences Research Journal*, *29*(1), 48–80.

Hyysalo, S., Juntunen, J. K., & Freeman, S. (2013). User innovation in sustainable home energy technologies. *Energy Policy*, *55*, 490–500.

Herrejón, P.V., Lennon, B., & Dunphy, N.P. (Eds.). (2023). Living with Energy Poverty: Perspectives from the Global North and South (1st ed.). Routledge. https://doi.org/10.4324/9781003408536

However, the risk remains that households are treated as fixed, uniform entities that simply require "inclusion" or "empowerment" to be done to them, rather than being recognised as diverse subjects with different positions toward energy transitions.

Islam, T. (2014). Household level innovation diffusion model of photo-voltaic (PV) solar cells from stated preference data. *Energy Policy*, *65*, 340–350.

Joeri Naus, Gert Spaargaren, Bas J.M. van Vliet, Hilje M. van der Horst, Smart grids, information flows and emerging domestic energy practices, Energy Policy, Volume 68, 2014, Pages 436-446, ISSN 0301-4215, https://doi.org/10.1016/j.enpol.2014.01.038.

Jahangir, M. H., Shahsavari, A., & Vaziri Rad, M. A. (2020). Feasibility study of a zero emission PV/Wind turbine/Wave energy converter hybrid system for stand-alone power supply: A case study. *Journal of Cleaner Production*, *262*. https://doi.org/10.1016/j.jclepro.2020.121250

Joseph M. Ngowi, Lennart Bångens, Erik O. Ahlgren, Benefits and challenges to productive use of off-grid rural electrification: The case of mini-hydropower in Bulongwa-Tanzania, Energy for Sustainable Development, Volume 53, 2019, Pages 97-103, ISSN 0973-0826, https://doi.org/10.1016/j.esd.2019.10.001.

Jenkins, K., McCauley, D. and Forman, A., 2017. Energy justice: a policy perspective. *Energy Policy*, 105, pp.631-634.

Julia Terrapon-Pfaff, Marie-Christine Gröne, Carmen Dienst, Willington Ortiz, Impact pathways of small-scale energy projects in the global south – Findings from a systematic evaluation, Renewable and Sustainable Energy Reviews, Volume 95, 2018, Pages 84-94, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2018.06.045.

Kirsten Jenkins, Benjamin K. Sovacool, Darren McCauley, Humanizing sociotechnical transitions through energy justice: An ethical framework for global transformative change, Energy Policy, Volume 117, 2018, Pages 66-74, ISSN 0301-4215, https://doi.org/10.1016/j.enpol.2018.02.036.

Katre, A., & Tozzi, A. (2018). Assessing the Sustainability of Decentralized Renewable Energy Systems: A Comprehensive Framework with Analytical Methods. *Sustainability*, 10(*4*), 1058. https://doi.org/10.3390/su10041058

Katherine Ellsworth-Krebs, Louise Reid, Colin J. Hunter, Home -ing in on domestic energy research: "House," "home," and the importance of ontology, Energy Research & Social Science, Volume 6, 2015, Pages 100-108, ISSN 2214-6296, https://doi.org/10.1016/j.erss.2014.12.003.

Kingsley Ukoba, Kelvin O. Yoro, Orevaoghene Eterigho-Ikelegbe, Chinedu Ibegbulam, Tien-Chien Jen, Adaptation of solar energy in the Global South: Prospects, challenges and opportunities, Heliyon, Volume 10, Issue 7, 2024, e28009, https://doi.org/10.1016/j.heliyon.2024.e28009.

Lazowski B, Parker P, Rowlands IH (2018) Towards a smart and sustainable residential energy culture: assessing participant feedback from a long-term smart grid pilot project. Energy Sustain Soc 8(1):1–21

Liu, Y., & Bah, Z. (2021). Enabling development impact of solar mini-grids through the community engagement: Evidence from rural Sierra Leone. *Energy Policy*, *154*, 112294. https://doi.org/10.1016/j.enpol.2021.112294

Lise Tjørring, We forgot half of the population! The significance of gender in Danish energy renovation projects, Energy Research & Social Science, Volume 22, 2016, Pages 115-124, ISSN 2214-6296, https://doi.org/10.1016/j.erss.2016.08.008.

Lutzenhiser, L., 1993. Social and behavioral aspects of energy use. *Annual review of Energy and the Environment*, 18(1), pp.247-289.

López-González, A., Ranaboldo, M., Domenech, B., & Ferrer-Martí, L. (2020). Evaluation of small wind turbines for rural electrification: Case studies from extreme climatic conditions in Venezuela. *Energy*, *209*. https://doi.org/10.1016/j.energy.2020.118450

Marie Claire Brisbois, Decentralised energy, decentralised accountability? Lessons on how to govern decentralised electricity transitions from multi-level natural resource governance, Global Transitions, Volume 2, 2020, Pages 16-25, ISSN 2589-7918, https://doi.org/10.1016/j.glt.2020.01.001.

Magnus Moglia, Ashok Sharma, Kim Alexander, Aditi Mankad; Perceived performance of decentralised water systems: a survey approach. Water Supply 1 December 2011; 11 (5): 516–526. doi: https://doi.org/10.2166/ws.2011.081

Michael Sony, Subhash Naik, Industry 4.0 integration with socio-technical systems theory: A systematic review and proposed theoretical model, Technology in Society, Volume 61, 2020, 101248, https://doi.org/10.1016/j.techsoc.2020.101248.

Moner-Girona, M., Solano-Peralta, M., Lazopoulou, M., Ackom, E. K., Vallve, X., & Szabó, S. (2018). Electrification of Sub-Saharan Africa through PV/hybrid mini-grids: Reducing the gap between current business models and on-site experience. *Renewable and Sustainable Energy Reviews*, *91*, 1148–1161.

Muchunku, C., et al., 2018. Diffusion of solar PV in East Africa: what can be learned from private sector delivery models? WIREs energy and environment, 7, 282.

Naus, J., van Vliet, B.J. and Hendriksen, A., 2015. Households as change agents in a Dutch smart energy transition: On power, privacy and participation. *Energy Research & Social Science*, 9, pp.125-136.

Nsengimana, C., Han, X. T., & Li, L.-L. (2020). Comparative analysis of reliable, feasible, and low-cost photovoltaic microgrid for a residential load in Rwanda. *International Journal of Photoenergy*, *2020*(1). https://doi.org/10.1155/2020/8855477

Nuru, J. T., Rhoades, J. L., & Gruber, J. S. (2021). The socio-technical barriers and strategies for overcoming the barriers to deploying solar mini-grids in rural islands: Evidence from Ghana. *Technology in Society*, *65*, 101586. https://doi.org/10.1016/j.techsoc.2021.101586

Ornetzeder, M., & Rohracher, H. (2006). User-led innovations and participation processes: lessons from sustainable energy technologies. *Energy Policy*, 34(2), 138-150.

Pueyo, A., & DeMartino, S. (2018). The impact of solar mini-grids on Kenya's rural enterprises. *Energy for Sustainable Development*, *45*, 28–37.

Pedersen, M. B. (2016). Deconstructing the concept of renewable energy-based mini-grids for rural electrification in East Africa. *Wiley Interdisciplinary Reviews: Energy and Environment*, *5*(5), 570–587. https://doi.org/10.1002/wene.205

Philippa Calver, Neil Simcock, Demand response and energy justice: A critical overview of ethical risks and opportunities within digital, decentralised, and decarbonised futures, Energy Policy, Volume 151, 2021, 112198, ISSN 0301-4215, https://doi.org/10.1016/j.enpol.2021.112198.

Pia Piroschka Otte, Jostein Vik, Biochar systems: Developing a socio-technical system framework for biochar production in Norway, Technology in Society, Volume 51, 2017, Pages 34-45, https://doi.org/10.1016/j.techsoc.2017.07.004.

Rob Raven, David Reynolds, Ruth Lane, Jo Lindsay, Annica Kronsell, Dharma Arunachalam, Households in sustainability transitions: a systematic review and new research avenues, Environmental Innovation and Societal Transitions, Volume 40, 2021, Pages 87-107, ISSN 2210-4224, https://doi.org/10.1016/j.eist.2021.06.005.

Schot, J., Kanger, L. and Verbong, G., 2016. The roles of users in shaping transitions to new energy systems. *Nature energy*, 1(5), p.16054.

Seebauer, S. et al. (2019) 'Bottom-up citizen initiatives as emergent actors in flood risk 66 management: Mapping roles, relations and limitations', Journal of Flood Risk Management, 12(3), pp. 1–17. Available at: https://doi.org/10.1111/jfr3.12468.

Strengers, Y., 2011. Beyond demand management: co-managing energy and water practices with Australian households. *Policy studies*, 32(*1*), pp.35-58.

Standal, K., Talevi, M. and Westskog, H., 2020. Engaging men and women in energy production in Norway and the United Kingdom: The significance of social practices and gender relations. *Energy Research & Social Science*, 60, p.101338.

Subhes C. Bhattacharyya, Energy access programmes and sustainable development: A critical review and analysis, Energy for Sustainable Development, Volume 16, Issue 3, 2012, Pages 260-271, https://doi.org/10.1016/j.esd.2012.05.002.

Subhes C. Bhattacharyya, Debajit Palit, Mini-grid based off-grid electrification to enhance electricity access in developing countries: What policies may be required?, Energy Policy, Volume 94, 2016, Pages 166-178, ISSN 0301-4215, https://doi.org/10.1016/j.enpol.2016.04.010.

Shanil Samarakoon, A justice and wellbeing centered framework for analysing energy poverty in the Global South, Ecological Economics, Volume 165, 2019, 106385, https://doi.org/10.1016/j.ecolecon.2019.106385.

Smit, A., Swart, J. and Broersma, M., 2023. Digital inclusion of low-literate adults: challenging the sequential underpinnings of the digital divide. In Weizenbaum Conference" *Practicing Sovereignty: Interventions for Open Digital Futures*" (pp. 72-84). DEU.

Tanja Winther, Kirsten Ulsrud, Margaret Matinga, Mini Govindan, Bigsna Gill, Anjali Saini, Deborshi Brahmachari, Debajit Palit, Rashmi Murali, In the light of what we cannot see: Exploring the interconnections between gender and electricity access, Energy Research & Social Science, Volume 60, 2020, 101334, ISSN 2214-6296, https://doi.org/10.1016/j.erss.2019.101334.

Temilade Sesan, Adriana Fajardo, Lucy Baker, Unico Uduka, Mourice Kausya, Daniel Kerr, Elsie Onsongo, Okechukwu Ugwu, Ewah Eleri, Subhes Bhattacharyya, Strengthening commercial viability through greater inclusiveness in rural mini-grid deployment: Insights from Nigeria and Kenya, Energy for Sustainable Development, Volume 83, 2024, 101584, https://doi.org/10.1016/j.esd.2024.101584.

Tracy, S. J. (2019). Qualitative Research Methods: Collecting Evidence, Crafting Analysis, Communicating Impact (2nd ed.). Wiley.

Zalengera, C., To, L. S., Sieff, R., Mohr, A., Eales, A., Cloke, J., Buckland, H., Brown, E., Blanchard, R., & Batchelor, S. (2020). Decentralization: The key to accelerating access to distributed energy services in sub-Saharan Africa? *Journal of Environmental Studies and Sciences*, *10*(3), 270–289. https://doi.org/10.1007/s13412-020-00608-7

Zebra, E. I. C., van der Windt, H. J., Nhumaio, G., & Faaij, A. P. (2021). A review of hybrid renewable energy systems in mini-grids for off-grid electrification in developing countries. *Renewable and Sustainable Energy Reviews*, *144*, 111036.

CHAPTER 14

Concluding Remarks

Daniel Kerr,[1] Lucy Baker,[2] Temilade Sesan,[3] Elsie Onsongo,[4] Andrew Barnett [5] and Subhes C. Bhattacharyya [1†]

[1]Institute for Sustainable Futures, De Montfort University, Leicester, UK
[2]Geography and Environment Studies, Milton Keynes The Open University, UK
[3]Center for Petroleum, Energy Economics and Law, University of Ibadan, Ibadan, Nigeria
[4]Nuvoni Centre for Innovation Research, Nairobi, Kenya
[5]The Policy Practice, Brighton, UK
[†]Corresponding author e-mail: Subhes.bhattacharyya@dmu.ac.uk

14.1 Introduction

The research presented in this book began on March 2, 2020, when the SIGMA project was launched at De Montfort University, Leicester (UK). During the project lifetime, several UK colleagues changed their jobs, which resulted in an expansion and adjustments to the UK teams collaborating in the project. The difficult journey of the project through the COVID-19 pandemic and funding cuts required significant adjustments to the work plan and work arrangements, including two no-cost extensions that ultimately pushed the completion date to its third anniversary. The project officially ended on March 2, 2024, and a final dissemination event was held in Surrey to share the main findings and to explore the possible next steps for further research.

This chapter provides final reflections organized in three sections—evidence base (Section 14.2), lessons from country cases (Section 14.3), and areas for further work (Section 14.4).

14.2 Evidence Base

Different chapters of the book have presented new evidence leading to a coherent story about mini-grids in Africa, injecting a sense of realism into what is in practice a very tough business. This is in contrast to the overly

optimistic impression given by the otherwise excellent Energy Sector Management Assistance Program (ESMAP) review of mini-grids (ESMAP, 2022).

This evidence helps in framing a new narrative about mini-grids by **clarifying the objectives**. One objective aims at increasing relatively poor people's access to modern energy services offered by electricity, particularly in off-grid and remote locations. The second objective is to promote small-scale renewable energy in financially sustainable enterprises. Such a narrative need not shy away from the global experience that providing modern electrical services to poor people almost always will require some sort of subsidy (as was the case in much of Europe and the US). The key here is to try to make the subsidies "smarter" than is often the case—smart subsidies that help make markets, rather than destroy them. In this context, it is important to recognize how many grid systems in Africa are not profitable, providing substantial, if unintended, subsidies to the relatively rich people they currently supply. The World Bank recognizes that two or more decades of power sector reform to achieve financial viability in central grids, using the so-called standard model, have not been successful.[1]

Anecdotally, it would appear that the pursuit of the second objective, to produce financially viable small-scale (often PV) systems, is having some success when electricity supply is carefully matched to financially viable loads. This appears to be particularly the case with water pumping for fish farms, cold storage, and crop processing. These systems may well also provide employment and modern energy services to poorer people, but the main objective is a financially viable investment often away from the electricity grid. The problem arises when aid donors in particular confuse the two objectives and promote what one participant labeled "fictional models of profitability" in the area of "energy access."

The evidence indicates that private sector investment is flowing to the PV sector in Africa, but the investment did not flow to the sector as initially anticipated. What is also less clear is where it is going. Some private investment is blended with grant funds or aid-backed guarantees, but other investments are going to the more profitable end of the market and clients who have a reliable ability to produce an adequate return on the investment.

[1] Rethinking Power Sector Reform in the Developing World, Foster and Rana (2020). The study is based on over 30 background studies and reviews that are being published on a rolling basis in the World Bank's Policy Research Working Paper series and can be accessed on the project World Bank, Washington, DC, http://www.esmap.org/rethinking_power_sector_reform.

The nature of "failure" is also particularly important. Our team has found a proportion of mini-grids that were no longer working, and this gives the sense of realism to the studies. Our case studies have noted that the technology has "limited sustainability," "limited business viability," many mini-grids "were no longer working," and systems were often "underused" while others were overloaded.

The idea of success and failure is closely linked to the idea of "accountability." Monitoring and Evaluation rarely identify individuals and institutions who should have taken responsibility for technology choice and operations and maintenance. Again, it is in the nature of power relations that researchers and project managers will be reluctant to hold to account those who promote unrealistic expectations of financially viable "energy access" and those who promote their own programs without coordinating with others, both aid agencies and utilities and their grid extensions.

Certainly, one can believe that there are many actors in the mini-grid sector that are incentivized to emphasize (and often only report) "success." The SIGMA experience did not shy away from the realities of the mini-grid sector and reported on the wide range of results that have been experienced. This has produced rich evidence of what seems to work and what does not, and this offers a learning experience for others.

14.3 Lessons from Country Cases

The SIGMA work in Nigeria focused on the dimensions of sustainability of mini-grids in the country, evidence on productive uses of energy, and the success of these programs, as well as situating mini-grids in the wider rural electrification context of Nigeria. The agriculture-energy nexus in particular has been touted as a route to greater productive use and demand stimulation, but current evidence shows interventions earlier in the agricultural value chain are needed to enhance profitability.

Our country study has showed how an elaborate regulatory and financing framework for mini-grid development in Nigeria has largely failed to meet the needs of the poorest households and productive enterprises in rural areas. In fact, there is a fundamental disconnect between the realities of local communities and the decision-making processes through which national and global-level actors and institutions allocate resources to them. This raises questions of how just the proposed energy transition will be for historically marginalized communities in the context.

Sustainability and inclusiveness need to be promoted in concert. The main recommendations are (1) for harmonization of the regulatory environment to match the capabilities of small and medium developers alongside the larger electricity distribution companies, (2) review regulatory provisions to unlock latent rural electrification subsidies for mini-grids, (3) situate the role of mini-grids within broader rural electrification policy, and (4) learn from the promising approaches currently in use by private sector developers in Nigeria.

In the Senegal context, mini-grids are set to play a small role in the national operational plan for universal electricity access by 2025; there is a greater focus on electricity grid expansion and solar home systems. The universal access target is unlikely to be met. The future of mini-grids is likely tied to how projects are defined under the successor to L'Electrification Rurale d'Initiative Locale (ERIL), the Decentralized Rural Electrification, or d'Electrification Rurale Décentralisée (ERD) framework. Challenges remain, including with accountability related to the significant influence of development finance institutions; contradictions between the Return on Investment (ROI) expectations of private investors and the unprofitability of reaching low-income, often dispersed, electricity consumers; and the ambiguity of some parts of the government toward mini-grid development.

In the Tanzanian context, the work produced a number of conclusions. Tanzania's comprehensive small power project regulatory framework has been key to the accelerated deployment of mini-grids in the country; however, political factors, high tariffs, along with limited knowledge and access to financing still hinder mini-grid development reaching its full potential. Effective business models, such as mini-grids anchored by commercial customers, are key to financial sustainability, whereas very small power producer (VSPP) models do not appear to be sustainable. Their recommendations are that regulators should undertake monitoring and evaluation of the supply quality and tariff rates of VSPPs, consider direct subsidies of electricity services from VSPPs to make services more socially equitable (as women and children benefit most from access), and ensure metering systems are convenient to both suppliers and customers (e.g., via smart metering).

The Kenyan National Electrification Strategy is prioritizing mini-grids and solar home systems through the Kenya Off-Grid Solar Access Project (KOSAP): 34,000 connections are projected through 121 new solar mini-grids in the country. The Kenyan SIGMA team has conducted extensive fieldwork in eight separate counties in Kenya, visiting 15 current mini-

grid projects. SIGMA team research in Kenya has identified a number of challenges with current models of provision: regulatory transparency, the policy-level exclusion of remote communities, and coordination issues between national and local governments hinder mini-grid growth at a policy level. Economically, the sector is still reliant on external financing, and developers often focus on anchor consumers to break even on domestic supply. Underutilization of electricity keeps costs high for consumers in Kenyan mini-grids. Innovative financing models and patient capital are required to keep tariffs affordable for poorer, rural consumers. Socially, inclusiveness is often a challenge, and the benefits of electricity access are often realized more by men than women. Men and wealthier community members have higher levels of participation in mini-grid projects, and inclusive co-development of projects is costly for government and developers, without a clear value proposition for these organizations. Continuous stakeholder engagement is needed to understand regulations and, where possible, find a solution for ongoing challenges.

Our research has identified the barriers to achieving equitable energy access, including challenges relating to affordability and governance as well as a gendered understanding of how this access may or may not be determined. Our work has also highlighted the complex interactions taking place at different levels (local, national, or beyond) between technological solutions, local communities, and various stakeholders involved in the transition process (e.g., those involved in national policies and governance, supply and use ecosystem, and the international community). We find a much-nuanced evidence of mini-grid experience as a sustainable, inclusive, and well-governed solution for energy access in sub-Saharan Africa.

14.4 Areas for Future Work

Based on our research and interactions with various stakeholders, we have identified the following areas for future work.

14.4.1 Theme 1: Productive Uses of Energy for Mini-Grids and Enhancing the Mini-Grid Value Chain

The first thematic area focuses on productive uses of energy in mini-grids and how the value chain of mini-grids can be enhanced by including productive uses. The opportunity extends to enhancement of domestic demand to

improve revenue recovery through electric cooking or household entrepreneurship (e.g., micro-enterprises), as well as the challenges that integrating high-intensity loads from energy-intensive activities, such as cooking, can have on peak loads for mini-grids, and the high cost of energy storage to manage such peak loads. Demand-shifting as an alternative is important to consider, should loads be available in the system that are suited to this kind of demand-side management, such as electric water pumping or charging electric vehicles. However, locally relevant value chains (such as the Nigerian case of milling machines and agricultural value chain enhancement), as well as the challenges of developers focusing on affluent user groups to enhance their cost recovery, leading to issues, need specific attention.

14.4.2 Theme 2: Inclusivity and Leaving No One Behind: Approaches for the Bottom-of-the-Pyramid Users

The challenge of inclusive development and leaving no one behind is another area requiring attention. Streams of academic literature are divided on solutions to inclusive development: Many articles vilify development aid interventions and top-down approaches, while the market-based approach is criticized for focusing on profit over services. Bottom-of-pyramid (people in extreme poverty) users are very heterogeneous, and there are diverse inclusivity challenges facing developers who are interested in coproducing interventions. In Kenya, for example, inclusive development can take the form of feasibility studies and community consultations, but processes may not be inclusive: The example of women in groups being less likely to speak in front of elderly men was cited, and external parties often do not know how to overcome these entrenched power relations/cultural dynamics. Political will and accountability are fundamental for enabling citizens to escape the "poverty trap." The challenges of the donor-funded provision model, including the lack of community "buy-in" to donor-funded equipment distribution, need attention. Digitization may offer a route forward in this case, through creating equitable digital platforms for consultation, but needs to be implemented in an accessible and equitable manner.

14.4.3 Theme 3: Beyond Mini-Grids: Micro-scale Systems or Regional Integration

Our third theme for future developments aims to address challenges with mini-grid development. Recent developments in India and Bangladesh

have shown mini-grids being usurped by the main grid due to government policy on grid extension, which presents challenges to developers, particularly in the private sector where stranded assets are an issue. Standardized procurement processes and equipment installations are a potential route to reducing mini-grid installation costs. Mini-grids offer an alternative to unreliable grid provisions in some contexts, and, in some SIGMA cases where mini-grids and the main grid exist in tandem, mini-grid provision is preferred as the more reliable option. Many national grids, with Kenya cited as an example, are grappling with low consumption as an issue to cost recovery, in a similar manner to mini-grids. Options exist for investigating the economies of scale of larger, distribution-scale renewable energy installations and distribution networks, providing services where the main grid has not reached, but able to be interconnected to the main grid or operate as an island in periods of main grid unreliability.

14.4.4 Theme 4: Resilient, Equitable, and Affordable Energy Systems for All

In view of urgent, ambitious global actions for the transition to a secure, livable, and sustainable future for all, the focus has shifted to resilient systems. A sustainable future now requires mitigating economic and climate crises while building community resilience. Given that UN Sustainable Development Goals' (SDGs) SDG 7 on energy access is unlikely to be reached by 2030 and considering the implications of the widening gap between "haves" and "have-nots," renewed efforts targeting marginalized communities are essential. Instead of imposing solutions, future research could aim to facilitate local communities to envision affordable, sustainable, and resilient solutions to energy access that in turn help to solve some of the broader developmental challenges they face. Such a study could adopt a complex system-thinking lens and aim to explore local ways of knowing and doing, support conceptualization, and co-creation of appropriate solutions and map opportunities and options for building the ecosystem for a resilient livable future for all. The work could consider challenges in four dimensions, namely (1) governance, (2) affordability, (3) energy for all (equality), and (4) resilient and secure energy systems.

We believe the evidence, analysis, and reflections provided in this book will assist researchers in identifying pathways for affordable, sustainable,

and resilient energy access solutions for all and help unlock an equitable, resilient, livable future for all.

References

ESMAP (Energy Sector Management Assistance Program). (2022). *2022 mini grids for half a billion people: Market outlook and handbook for decision makers*. World Bank. http://hdl.handle.net/10986/38082

Foster, V., & Rana, A. (2020). *Sustainable infrastructure series*. World Bank. https://doi.org/10.1596/978-1-4648-1442-6

Access to clean and reliable electricity is widely recognised as foundational to sustainable development, yet millions of people—particularly in sub-Saharan Africa—remain without power. Mini-grids have become a prominent strategy for expanding electricity access in rural and peri-urban settings, but their long-term performance is frequently undermined by technical constraints, economic and financial risks, socio-political dynamics, and governance failures.

This book reports the findings of a collaborative research programme that evaluates mini-grids as an electricity-access pathway capable of supporting sustainable development in rural communities across sub-Saharan Africa. It asks whether mini-grids deliver reliable and secure supply for current and future needs; whether electricity is affordable and access is inclusive; whether projects are financially viable and attractive to investors; and whether mini-grids contribute meaningfully to local development priorities. The analysis synthesises extensive academic and practice-oriented literature and combines secondary evidence with primary data gathered through fieldwork. Using integrated quantitative and qualitative methods, the book develops evidence-based insights and recommendations for strengthening the mini-grid ecosystem and planning for large-scale deployment in support of SDG 7.

The editors of this volume, **Lucy Baker**, **Subhes Bhattacharyya**, **Daniel Kerr**, **Temilade Sesan**, and **Elsie Onsongo**, were directly involved in the research project that provided the foundation for the book. They bring a broad range of multidisciplinary expertise in energy access and rural electrification systems, encompassing energy politics and political economy, social science perspectives on energy transitions, energy governance, innovation systems, economics, and finance. Their combined expertise provides a strong interdisciplinary foundation for the analysis and perspectives presented in this volume.

On Sustainability