LASTING IMPACT

SUSTAINABLE OFF-GRID SOLAR DELIVERY MODELS TO POWER HEALTH AND EDUCATION

UNITED NATIONS FOUNDATION

SUSTAINABLE ENERGY FOR ALL

UKaid from the British people

CATALYST OFF GRID ADVISORS

United Nations Foundation (Washington, DC Office)
1750 Pennsylvania Ave. NW Suite 300
Washington DC 20006 USA
www.unfoundation.org

Andromeda Tower 15th Floor
Donau City Strasse 6
1220, Vienna, Austria
www.SEforALL.org

This document has been produced with the financial assistance of the U.K. Department for International Development. The views expressed herein can in no way be taken to reflect the official opinion of the U.K. Department for International Development.

CONTENTS

ACKNOWLEDGEMENTS

This report was made possible through the contributions, guidance, and support of several stakeholders.

This report was commissioned by the UN Foundation, in collaboration with Sustainable Energy for All. The UN Foundation team, led by Jem Porcaro and Luc Severi, oversaw the development of the report and worked closely with SEforALL, led by Caroline McGregor.

We would like to thank the members of our Steering Group, who provided valuable feedback on the report's design and findings. This includes the United Nations Development Programme (Marcel Alers, Saleban Omar, Natalia Linou), the World Bank (Raihan Elahi, Rahul Srinivasan), the United States Agency for International Development (Katrina Pielli, Maria Hilda Rivera), the Department for International Development (Hannah Davis), Global Off-Grid Lighting Association (Koen Peters, Laura Sundblad), and Sustainable Energy for All (Caroline McGregor, Glenn Pearce-Oroz).

Catalyst Off-Grid Advisors assisted the UN Foundation and Sustainable Energy for All in preparing the report. The team included Dan Murphy, Christine Eibs Singer, Ian Muir, Lindsay Caldwell Umalla, Matt Hirsch, Rebecca Titcomb, Chris Connolly, and Rasheed Auguste.

The authors are also grateful to the case study interviewees, who are listed in Annex B of the report, for their contributions.

We acknowledge with gratitude the financial assistance of the U.K. Department for International Development.

We also thank: Natalie Lanham-Parker (designer), Justine Sullivan (editor), and Kimberly Farmer (support).

ACRONYMS

AC	Alternating Current
Ah	Amp hours
ARS	Arogya Raksha Samithis
CAPEX	Capital Expenditures
CEDP	Community Energy Development Programme
CEM	Community Energy Malawi
CBO	Community-Based Organizations
CRED	Community Rural Electrification and Development Project
CREDA	Chhattisgarh State Renewable Energy Development Agency
DC	Direct Current
DO	Development Officer
DPW	Department of Public Works
ECOWAS	Economic Community of West African States
ERT	Energy for Rural Transformation
ESCO	Energy Service Companies
GOP	Government of the Philippines
GoU	Government of Uganda
GSM	Global System for Mobile communications
HC	Health Center
HQ	Headquarters
HR	Human Resources
IA	Innovation Africa
ICT	Information and Communications Technology
IEC	International Technical Commission
INR	Indian Rupees
KT	Karuna Trust
KOSAP	Kenya Off-Grid Solar Access Project
kWh	Kilowatt hour
kWp	Kilowatt peak
LED	Light emitting diode
M&E	Monitoring and Evaluation
MERA	Malawian Energy Regulatory Authority

ACRONYMS

MIGA	Multilateral Investment Guarantee Agency
MoES	Ministry of Education and Sports
MoH	Ministry of Health
MREAP	Malawi Renewable Energy Acceleration Programme
NGO	Non-Governmental Organization
NHM	Chhattisgarh National Health Mission
NHM	National Health Ministry
OPEX	Operating Expenditures
OPEX	Operating Expenditures
O&M	Operations and Maintenance
PHC	Primary Health Care Centers
PV	Photovoltaic
PRIs	Panchayat Raj Institutions
PSPs	Private Service Providers
PTA	Parent Teacher Association
ROGEP	Regional Off-Grid Electrification Project
RKS	Rogi Kalyan Samithi
SLA	Sealed Lead Acid
SLI	starting, lighting, and ignition (battery)
SEP	Solar Energy Package
SMS	Short message service (text messaging)
S4H	Solar for Health
SSMP	Sustainable Solar Market Package
UN	United Nations
UNDESA	United Nations Department of Economic and Social Affairs
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNDP	United Nations Development Programme
UOS	University of Strathclyde (UOS)
USD	United States Dollars
V	Volts
VRLA	valve-regulated lead-acid (battery)
Wp	Watt Peak

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

INTRODUCTION AND BACKGROUND

Access to reliable, affordable, and modern electricity services is critical to achieving the universally adopted Sustainable Development Goals (SDGs). Energy access is particularly essential in driving progress across SDG 3, Good Health and Well-Being, and SDG 4, Quality Education, both of which are social services that depend on access to electricity in schools and health facilities. Electricity access enhances access to quality essential health care services while making health systems more resilient. In the education sphere, access to electricity enables lighting and extended studying hours; facilitation of information, communication and technology (ICT); enhanced staff retention and teacher training; among other benefits.

Despite the importance of energy access, however, power is unavailable or unreliable in the majority of schools and health facilities across Sub-Saharan Africa and South Asia. A recent survey [1] of 78 countries found that only 41% of low- and middle-income country health care facilities have reliable electricity. Education facilities experience even lower access rates: According to UNESCO estimates in 2017, only 35.1% of sub-Saharan African primary schools and 50.7% of those in Southern Asia had access to electricity. [2]

Many of these unelectrified public institutions are located in remote areas and characterized by poor surrounding infrastructure and low energy demand, making them unattractive to traditional energy service providers. Thus, off-grid solar photovoltaic (PV) power systems present a key opportunity to provide clean, reliable, and cost-effective electricity to schools and health facilities that would otherwise not have access to reliable electricity. The dramatic cost reductions and technological improvement of solar technology in the past decade has made solar an economically and technically viable solution that can be deployed in a fraction of the time it would take the centralized grid to arrive.

Nonetheless, ensuring that these off-grid solutions can provide access to electricity on a long-term, sustainable basis does not come without its challenges. Despite the growing number of standalone solar systems being installed in health and education facilities in low- and middle-income countries, many of these systems prematurely fail or underperform, leading to the perception that renewable technologies are too new and unreliable to continuously serve the needs of communities. According to the Photovoltaics for Community Service Facilities study conducted by the World Bank (2010), many PV systems become inoperative after 3–5 years if proper maintenance and repair services are not provided.

This report uses case studies to shed light on what kind of off-grid solar delivery models contribute to—and, likewise, hinder—sustainability. The purpose of the report is to help decisionmakers in the public and private sector design sound off-grid electrification projects for rural schools and health centers by helping them evaluate the most effective and appropriate delivery model for their specific country context.

[1] *Cronk, R., & Bartram, J. (2018). Environmental conditions in health care facilities in low-and middle-income countries: coverage and inequalities. International Journal of Hygiene and Environmental Health, 221(3), 409-422.*

[2] *UNESCO. (2018). UIS.Stat. Retrieved December 2018, from UNESCO Institute of Statistics: http://data.uis.unesco.org/#*

ANALYTIC FRAMEWORK & METHODOLOGY

The central question this report seeks to answer is: What kind of delivery models contribute to the sustainability of solar PV systems in off-grid, public health, and education facilities? The report addresses this question by evaluating several past, ongoing, and emerging efforts to deliver off-grid solar PV power to schools and health facilities in emerging economies using an analytic Framework for Sustainability built around:

- Three pillars of sustainability:

  1. **Organizational sustainability**—project stakeholder arrangements to preserve system functionality, including division of responsibilities, ownership and accountability, alignment of incentives, and capacity to carry out responsibilities.

  2. **Technical sustainability**—assurance that systems meet electricity needs of host facility and operate as designed.

  3. **Economic sustainability**—availability of financing and incentives to ensure satisfactory system installation, operation, and maintenance.

- Four project lifecycle phases:

  1. **Inception**: Define project goals and approach, including target outcomes and expected mandates and responsibilities of implementation partners.

  2. **Design**: Select facilities and assess needs, including system sizing. Draft procurement documents and other project development materials for contract bidding.

  3. **Build**: Procure hardware, execute installation contracts, deploy PV assets.

  4. **Operation and Maintenance (O&M)**: Conduct or contract out routine and ad hoc maintenance. Replace components, including batteries, as necessary. Continue until asset has completed 10- to 15-year lifetime. At this point, assets are either considered obsolete, and would either be extensively refurbished or replaced entirely (more typical). This would then signal the return to the lifecycle inception phase.

FIGURE 1. MODEL SUSTAINABILITY FRAMEWORK

Sustainability Framework Pillars	Organizational	Technical	Economic
Three "pillars" of sustainability—Organizational, Technical, and Economic	Arrange project stakeholders to preserve systems' long-term functionality	Make certain installed systems are robust and fit for purpose	Ensure financing and incentives are structured for the long haul

MODEL SUSTAINABILITY FRAMEWORK

Each pillar contains four project lifecycle phases—Inception, Design, Build, and Operation and Maintenance (O&M)	Define core goals and approach	Finalize facility siting, expected needs, and system sizing	Undertake procurement and execute installation contracts	Ensure system performance for its expected life
Project Lifecycle Phases	I. Inception	II. Design	III. Build	IV. O&M

This framework was applied to seven case studies to generate practical and actionable "Key Insights", representing critical learnings that can impact sustainability. By examining decisions and outcomes through a sustainability lens, the report aims to help decisionmakers design public facility electrification projects with maximum long-term impact. The cases are based on in-depth interviews with stakeholders who have led off-grid solar programs in Malawi, Tanzania, Uganda, Kenya, India, Philippines, and West Africa (and which are detailed in Annex A). The report covers a variety of geographic localities, sizes of electrification programs, and approaches to achieving the same goal. Some of the programs have concluded, while others are still in the early stages of implementation. They offer insights into challenges for off-grid solar installations across the four lifecycle phases, and the three pillars of sustainability. Most importantly, each illustrates a distinct approach to combining public, philanthropic, and private actors and their associated models. With these insights, the report then looks at two emerging cases currently under design in Africa and two hypothetical cases that were developed for this report, intended to stretch the current thinking around delivery models for electricity in off-grid public facilities.

ORGANIZATIONAL SUSTAINABILITY INSIGHTS

The organizational aspects of public facility electrification projects are critical to sustainability since the finance provider, the system installer, and system owner are almost always different actors, and incumbent stakeholders are often expected to play new roles. As such, incentives are not necessarily aligned and responsibilities may be placed on institutions with no capability or desire to fulfill them. Careful planning, stakeholder engagement, and sensitization are therefore often required to achieve organizational sustainability at a given site. The report's key insights regarding organizational sustainability are:

- **Key Insight #1: Project "Champions" should mitigate the risk of a responsibility vacuum or budgetary hole when exiting during O&M phase**. In the majority of case studies included in this report, project Champions ultimately devolved responsibility for O&M to the local level as part of an effort to secure greater engagement and buy-in for the project, though varying degrees of long-term "backup support" from central entities were observed.

- **Key Insight #2: Passing the Champion role to local actors can be effective, but only if they have sufficient human and financial resources.** The cases in this report underscore the necessity of resources accompanying responsibility. In addition to securing the required financing for the long-term O&M costs of installations, these cases demonstrated the need for capacity development to be made available to local actors.

- **Key Insight #3: The design process should align perspectives of external and internal Champions**. The cases demonstrated the need for a clear understanding of the trade-offs involved in key decisions, across all parties at a negotiating table, given that this choice carries material consequences for whomever carries O&M responsibility down the line.

- **Key Insight #4: Centralized design and/or procurement may introduce delays but also long-term benefits**. The cases illustrated the component quality challenges that may arise with local-level procurement, while also noting that centralized approaches that use strict quality standards can enhance system robustness and longer-term sustainability prospects.

- **Key Insight #5: Project Champions should conduct O&M planning for a 10- to 15-year time horizon, in line with small, standalone PV system lifespans**. Given that many public facility electrification projects receive support from development partners over a finite time period, project Champions often have a strong tendency to plan on a time scale that falls well short of the 10-15-year lifespan of well-maintained PV systems.

- **Key Insight #6: Well-incentivized and resourced 'central' organizations competent in PV O&M can suc-**

cessfully manage significant asset portfolios. There is a common tendency for project Champions to cede O&M responsibilities to local actors at some point. These local actors often lack the human, technical, and/or financial capacity to successfully deliver on these critical responsibilities, and the hand-over itself is exceedingly risky. The value of decentralized O&M is being challenged as evidence emerges that well-resourced central organizations can effectively manage considerable asset portfolios.

TECHNICAL SUSTAINABILITY INSIGHTS

Technical sustainability addresses how installed systems are fit for purpose, i.e., that they not just operate as intended but that they also meet the key energy needs of the facility for which they were designed. This includes the efforts made to assess current and expected energy needs, the technical design of systems that will accommodate such needs (including quality standards for components), and the efforts made to facilitate system maintenance through both technical means (e.g., remote monitoring) and technical training. The report's key insights regarding technical sustainability are:

- **Key Insight #1: Ensure facility energy needs are understood and reflected in system design**. PV system design is about picking the right type and size of core components to ensure the system's ability to operate well and meet loads long term. Energy audits are invaluable in technical design and procurement planning.

- **Key Insight #2: Understand behavioral and usage-pattern changes that PV systems may cause**. In several case studies, estimates of anticipated load requirements struggled to consider how the PV system would affect user behavior. Project designers are beginning to build in a considerable buffer to address unanticipated load growth.

- **Key Insight #3: Consider trade-offs between custom and standard system packages**. Standard system designs can simplify design and procurement, but they increase the risk of mismatch with facility needs.

- **Key Insight #4: Deploy new technologies and flexible designs to counter early PV system failure**. The continued pervasive use of antiquated battery technologies in public facility PV installations is noteworthy. Remote monitoring technology can assist with O&M but is not a panacea. Energy efficient appliances and modular systems are readily available technologies that are underutilized.

- **Key Insight #5: Enforce strict design and component quality standards backed by a competent oversight authority**. Low-quality and mismatched components often drive early system failure. Currently available international standards are often difficult to interpret and not always relevant for small PV systems. Standards enforcement is critical, but the requisite skill building is required.

- **Key Insight #6: Use qualified technicians for installation and independent third parties for certification**. To guarantee system quality early in project lifecycle, installers can use certified technicians and qualified, independent third parties to verify that installations meet component and workmanship standards. Upfront costs may increase, but long-term O&M costs should go down.

- **Key Insight #7: Regular preventive maintenance protects system components and is good value for money**. Preventative maintenance is relatively low-cost measure that can have a high impact on sustainability by helping diagnose problems - such as component failure and system misuse - early, while keeping facility staff engaged in system health and maintenance. Although remote monitoring can complement routine maintenance, it is not a substitute.

- **Key Insight #8: Follow O&M protocols, supported by intensive and sustained capacity building**. In all cases, local capacity to deliver on O&M protocols was often lacking. All entities tasked with O&M should be assessed for capabilities and supported by skill-building. These capacity enhancements must then be properly costed out, with financing secured to ensure they are delivered.

- **Key Insight #9: Remote monitoring can enhance O&M, but its benefits are often limited by the capacity of those providing oversight**. Remote monitoring, even in its most basic form, can collect and assess critical information about system performance. This data can help identify issues before they cause downtime, troubleshoot with local staff, learn when batteries are nearing end of life, and broadly understand system usage. Protocols and skills must be in place to interpret and respond as monitoring systems flag issues.

ECONOMIC SUSTAINABILITY INSIGHTS

At its most basic level, economic sustainability centers on financing for installation, operation, and maintenance of installed systems to ensure these systems remain fully functional over the course of their planned lifetimes. The adequacy and reliability of O&M budgeting, especially regarding the replacement of failed components such as batteries, is critical to project sustainability. Moreover, the pillar concerns the economic incentives that, if well-crafted and well-aligned, will ensure key actors deliver on critical responsibilities pertaining to long-term system sustainability. The report's key insights regarding economic sustainability are:

- **Key Insight #1: Program budgets should be optimized for system sustainability, not number of systems deployed**. Funders and project Champions face inherent resource constraints in project development. Given finite budgets, they must evaluate the trade-offs between sustainability and scale. Design choices that improve the chance of completing a 10- to 15-year lifecycle but reduce the number of facilities reached should be considered.

- **Key Insight #2: Project Champions must account for, and consistently meet, financing needs over the expected lifespan of the deployed energy solution**. Funding required for lifetime system maintenance is rarely assessed or secured. O&M needs are often calculated (and sometimes secured) relative to the duration of the project that is financing the installations. This is often a 3- to 5-year period, far short of what should be a design life of three times that.

- **Key Insight #3: Incentives for supply and install contractors are critical**. Mechanisms must exist to prevent contractors from taking profits post-installation and abandoning follow-on responsibilities. Contracts must give installers a clear financial interest to fulfill obligations throughout the coverage period, until a third party assumes O&M.

- **Key Insight #4: PV system revenues are unlikely to cover ongoing O&M costs**. Health clinics and schools are generally poorly suited to generating income from any surplus energy. If they do succeed in operating such a side business, the profits it reaps are often insufficient to cover full O&M costs.

- **Key Insight #5: If O&M is decentralized, project Champions must secure funding**. System ownership and O&M in public facility electrification projects tend to flip to local organizations, such as community-based organizations or local governments. However, the handoff often is often unfunded. Local organizations, typically under-resourced, cannot divert scarce discretionary funds to maintain systems.

- **Key Insight #6: O&M outcomes must be directly tied to economic benefits or penalties**. In remote locations, private sector service providers are often the only parties capable of regular and ongoing O&M, and they deliver value principally when incentivized with compensation or penalized for failure.

EMERGING MODELS

The report evaluates emerging practices in the delivery of off-grid PV projects for public facilities based on the Kenya Off-Grid Solar Access Project (KOSAP) for Underserved Counties and the Regional Off-Grid Electrification Project (ROGEP) in West Africa. Both projects take innovative approaches to organizational, technical, and economic sustainability. Each project's critical design features and key sustainability considerations are highlighted below.

Under **KOSAP**, the key parties are private service providers (PSPs), Kenya Power (the Kenyan national power utility), and the local governments. PSPs will competitively bid for the right to supply, install, and maintain solar systems at community facilities in a given geographic service territory, signing back-to-back supply and installation agreements and 10- to 15-year O&M contracts. World Bank financing will cover supply and installation. Kenya Power will make O&M payments funded by a service tariff charged to local governments. While this model shifts risk and responsibility to the PSPs, the capacity of local governments and Kenya Power to hold PSPs accountable will be critical. PSPs' trust in Kenya Power to consistently make O&M payments will also impact long-term success. PSPs have an incentive to provide service because O&M payments will be performance-based, although it is not yet clear how performance will be measured, in part because remote monitoring does not appear to be a design feature.

PSP selection will be based on the lowest net present value of total supply, installation, and maintenance costs over the full 10- to 15-year contract period. This encourages competition on cost and promotes accountability. Contractors also must submit a performance security for supply and installation and maintenance contracts. This comprehensive approach should give PSPs incentives to install high-quality systems and maintain them. However, there is a substantial risk that Kenya Power revenues from the tariff for electricity service to public facilities may not cover O&M costs, and local governments may not pay Kenya Power for electricity service. To mitigate this risk, the project created a reserve fund covering six to 12 months of payments for PSPs in the event of payment delays or default. It remains to be seen whether this measure will give sufficient comfort to PSPs for them to participate in the forthcoming tender.

ROGEP will electrify public facilities, including health centers and schools, in 19 West African countries. The project attempts to overhaul stakeholder responsibilities. While the participating government ministries will select project sites, perform energy audits, and set electricity service levels, private energy service companies (ESCOs) will accept nearly all remaining responsibilities for an estimated five to seven years, or at least through one battery replacement, including raising capital, procurement, installation, and O&M. Payments to ESCOs are tied to system performance, including uptime. ESCOs will likely have flexibility over system design and specifications, encouraging innovation. However, the five- to seven-year contract period may discourage deployment of high-quality components, such as lithium-ion batteries. Adding minimum requirements for preventive O&M would further mitigate risk. The project's reliance on remote monitoring to determine performance-based payments to ESCOs may prove challenging, given the project's footprint across 19 countries and with facilities that will in some cases be far from core telecommunications infrastructure on which remote monitoring systems typically rely.

Line ministries in each of the 19 countries will be responsible for payments to ESCOs. Presumably at least a portion of this financing will come from the project itself, which will provide some security/guarantees to the ESCOs and their financial backers. To bolster this, the project envisages a guarantee from the Multilateral Investment Guarantee Agency (MIGA), which would cover at least a portion of line ministry obligations in the event of payment delay or default. It remains to be seen whether this innovative structure will be viable, particularly given that ESCOs will need to carry considerable risk over the contract period and presumably also raise outside financing (likely in the form of debt, and possibly in the form of equity) to cover the capital outlay that will only be recouped over the five- to seven-year contract period.

The report also examines two hypothetical cases that follow best practices in sustainability, one rooted in the public sector and another in the private sector. The hypotheticals are informed by existing practice and literature on organizational structure. Both hypothetical models aim to maximize sustainability by minimizing handoffs to third parties and securing financial and technical resources upfront to cover the full system lifetime.

The hypothetical Public Utility model centralizes responsibility for all aspects of off-grid electrification at public facilities within a single entity. As a government-owned entity, the public utility would work with line ministries but maintain asset ownership and responsibilities for design, supply and installation, and O&M, enlisting private contractors only to support system installation. Government-led working groups would set service levels by facility type. Utility technicians would take over system design and procurement with an emphasis on component quality and high standards, reflecting long-term asset ownership and the utility's assumption of risk. The public utility would secure total lifetime funding for projects before deployment with capital from public entities, including financing from development partners. The national budget would fund lifetime operations. Public facilities would not pay directly for energy, eliminating off-taker risk and the need for local revenue generation.

The **Private Concessions model** provides exclusive territorial rights for companies to deliver electricity for off-grid public facilities during 10- to 15-year terms. Providers receive guaranteed government payments for service delivery. The government manages the bidding process and oversees service quality. This model shares several features of the ROGEP example—including payment for service, bidders' need to bring outside financing, long-term contracts, and bundled sites for bidding and economies of scale—though importantly it diverges on some of the economic sustainability considerations. Concessionaires would be required to secure funds for all capital expenditures, though there would be a partial repayment after installation to buy down the cost of financing and preset incremental payments tied to service delivery. The government would secure all O&M phase funding upfront for the entire 10- to 15-year term, placing these funds in an escrow account. While this would lower repayment risk for bidders and their investors, the ability and willingness of private-sector operators to pre-finance large capital expenses and accept repayment over a long time is unknown.

CONCLUSIONS AND AREAS FOR FURTHER INVESTIGATION

This report examined a variety of delivery models, yielding a variety of insights for policymakers, financiers, project designers, and service providers. Importantly, the report's sustainability framework should be valuable to practitioners as they design, implement, and evaluate off-grid public facility electrification initiatives. On balance, the report demonstrates that there is no one-size-fits-all solution, and that each context demands a distinct approach to ensuring long-term sustainability and scale.

The report surfaces the following common elements, which are fundamental to sustainable off-grid energy service delivery to public facilities:

- **Sustainability requires an all-encompassing definition of success**. Though well-maintained PV systems can operate for 15 or more years, project designs are setting five- to seven-year O&M plans, at best, with no plans or incentives for further service.

- **Sustainability demands integrated knowledge and sector-specific expertise**. Capacity-building that integrates social service knowledge with electricity planning and technology is critical for sustainability and scale, especially for long-term O&M.

- **Sustainability requires alignment of public and private sector incentives**. Private contractor responsibilities must include incentives for long-term engagement and oversight. Risks and stakeholder capacity need to be assessed and factored into incentives that are created during project design.

- **Philanthropic models and actors can contribute to sustainability.** Philanthropists can bring a purpose and financial and human resources that can bolster sustainability, though they typically do this on a more limited scale via pilot initiatives. It is important to leverage learnings from these pilots and think about how to structure the underlying model so that it can scale up.

- **Sustainability is enhanced when energy is a core element in facility planning.** Public facility construction and retrofit projects should further integrate energy planning. Health and education service organizations can partner with energy specialists to facilitate sustainable electricity solutions.

- **Sustainability requires both the ability and willingness to pay for electricity**. Dependency on revenue from electricity sales can threaten the sustainability of public facility off-grid PV projects. Ringfencing funding from government budgets may prove reliable, though budget holders must not divert those resources away from electricity service-related expenditures.

The report recommends areas for further research to improve site-level data collection and demand auditing and to develop a policy and regulatory toolkit, key performance indicators, cost calculators, and an environmental sustainability toolkit. Finally, it calls for the development of a comprehensive guide based on the sustainability framework covering process and approach to designing for organizational, technical, and economic sustainability.

The various delivery models and the sustainability framework that are showcased in the report reflect a solid foundation on which practitioners can build. The hope of the report authors is that years from now, when researchers conduct case studies on the latest approaches to off-grid PV project development, they will likely reveal a notable evolution in sustainability and scale, with credit due to all the project Champions and line ministries, O&M providers, and other stakeholders whose work gave cause to produce this report.

1. INTRODUCTION

OBJECTIVE AND SCOPE

This report evaluates different delivery models for deploying solar photovoltaic (PV) systems in public health and education facilities in resource-constrained settings from the perspective of how the models contribute to – and, likewise, hinder – sustainability. The report examines three aspects of sustainability: (i) organizational sustainability, addressing the stakeholders responsible for operations and maintenance (O&M) throughout a system's lifetime; (ii) technical sustainability, addressing how a project meets the key energy needs of the host facility; and (iii) economic sustainability, addressing financing and incentives to support long-term O&M. The analysis is intended to help planners of all types, including those from governments, their development partners, and philanthropic entities, to design and sustainably implement robust off-grid public-facility electrification projects. It should do so by helping these planners make informed decisions across the lifecycle of a project, facilitating the adoption of effective and appropriate delivery models for their specific country context. Moreover, the authors of this report hope to encourage innovation in the way off-grid PV solutions are designed for and delivered to public facilities.

The scope of this report focuses on public health and education facilities such as schools, hospitals, and clinics because of the direct, principal effects of health and education on social welfare.[3] Despite recent advances in solar home system adoption for electrifying private homes, PV projects for public facilities have not received the same attention or market adoption.[4] The geographies prioritized in this report are sub-Saharan Africa and South Asia, as these are regions with high electricity access deficits.

In addressing this broad topic, the report deliberately avoids going into detail into certain matters. Notably, mini-grid electrification systems are excluded from the scope of this report because of the variety within mini-grid electrification projects. Mini-grid projects typically power multiple clients and loads. Therefore, project sustainability depends on additional factors—namely the magnitude and reliability of payments from anchor customers—that are unrelated to the human and financial resources available to public facility project planners. As such, this report has a focus on standalone solar PV solutions, which are currently the dominant model for electrifying public institutions. The report also excludes an in-depth analysis of environmental sustainability.

RATIONALE FOR THE REPORT

A growing number of standalone solar systems are being installed in health and education facilities across sub-Saharan Africa and South Asia. However, many of these systems prematurely fail or underperform, leading to the perception that renewable technologies are too new and unreliable to continuously serve the needs of communities. According to the Photovoltaics for Community Service Facilities study conducted by the World Bank (2010), it is estimated that many PV systems become inoperative after 3–5 years if maintenance and repair services are not provided. Reliable, long-term operation requires that PV systems are not just well-designed and installed, using equipment of sound quality, but that institutional arrangements are in place that

[3] *Arvidson, A., Songela, F., Syngellakis, K. (2006). The role of energy services in the health, education and water sectors and cross-sectoral linkages. European Commission. Retrieved January 2019, from https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/enable_cross_sectoral_linkages.pdf*

[4] *Finucane, J., Purcell, C. Photovoltaics for community service facilities: guidance for sustainability, Energy Sector Management Assistance Program (ESMAP), Washington, DC: World Bank, 2010.*

ensure resources and funding for ongoing system maintenance and repairs. Furthermore, despite rural electrification projects being implemented in emerging countries, there are few published, in-depth evaluations[5] of the continued performance of these installed projects.

This report attempts to address these challenges by identifying specific and actionable insights that contribute to the sustainability of solar PV systems in health and education facilities.

TARGET AUDIENCE

The primary audience for this report is decision-makers and other stakeholders involved in electrifying public institutions, particularly in the inception, design, installation, operation or management of PV electrification projects. These actors may seek different outcomes, but project efficiency and sustainability leading to more reliable electricity service at public facilities improves outcomes for all stakeholders, in particular for public facility users. The report focuses on "Champions" across key stakeholder sets. Champions are those individuals who take extraordinary interest in and responsibility for the inception, delivery, and ultimate outcomes associated with PV-powered public facility electrification. More specifically, these include the following:

- Public sector Champions, commonly Ministries of Energy, Health, and Education, carry the mandate and the responsibility for delivering public services. They are thus frequently involved in the inception, planning, and implementation of public facility electrification projects.

- Development partner Champions, such as the World Bank and the UN (and its various agencies), as well as other multilateral and bilateral agencies, often support public sector (i.e., government) project Champions with the design and funding of PV electrification projects. They can share and adopt best practices across a multitude of geographic contexts.

- Philanthropic Champions, namely non-profit entities whose mission statements drive them to fund and/or support public facility PV electrification, engage in project inception and design and thus retain considerable power to influence project sustainability.

- Private, for-profit Champions typically have limited control over key elements of public-facility electrification program design, but may learn from the challenges faced and potential mitigation activities highlighted throughout this report.

DEFINING SUSTAINABILITY AND SCALE

For the purposes of this report, "sustainability" is defined as the reliable delivery of energy services over time. Standalone PV installations on public facilities typically have an expected technical lifetime of 10 to 15 years, based on current technologies. "Scale" refers to the number of facilities and beneficiaries served by public facility electrification projects over time and the replicability of the delivery model. This report focuses on extracting insights from PV electrification projects that are broadly applicable, regardless of local context, and thus relevant to a wide array of project planners.

KEY QUESTIONS UNDERPINNING THE REPORT

This report identifies decisions that most critically impact the sustainability of energy service delivery to off-grid public facilities. It flags the key insights of delivery models that contribute toward, or undermine, long-term sustainability based on four questions:

[5] *Suhlrie, L., Bartram, J., Burns, J., Joca, L., Tomaro, J., & Rehfuess, E. (2018). The role of energy in health facilities: A conceptual framework and complementary data assessment in Malawi. PloS one, 13(7), e0200261.*

- What are the critical decisions made at each stage of a project's lifecycle that most significantly influence project sustainability?
- What are the drivers of these decisions?
- What are the consequences of these decisions?
- What innovative approaches and insights have been observed?

STRUCTURE

The following is a brief overview of the study's structure: Chapter 1 gives a brief overview of the study's objective, scope, rationale, target audience, definitions of sustainability and scale, and key questions. Chapter 2 provides context and background by examining the essential role of electricity in health care and public education, taking stock of current understanding of needs at facilities in emerging countries. Chapter 3 explains the report's analytic framework and methodology. Chapters 4 to 6 present the key insights from the analysis, as informed by a set of retrospective case studies, presenting organizational, technical, and economic key insights, respectively. In Chapter 7, several emerging practices in the delivery of off-grid PV projects for public facilities are evaluated, offering additional insights into what can contribute to a project's sustainability and replicability. Finally, Chapter 8 presents the study's key conclusions and recommendations.

2. BACKGROUND

Providing modern health care and public education is virtually impossible without access to reliable electricity in health and education facilities. This chapter provides context for the later chapters, describing the levels of energy demand for various types of health and educational facilities and providing country-specific and regional energy access rates based on the latest research. Chapter 2 concludes with a discussion of key challenges to expanding electricity access, including limited access to high-quality data, the lack of strong leadership in defining and carrying out program goals, operational budget requirements, and assurances of PV system maintenance over an extended time.

ENERGY AS AN ENABLER OF IMPROVED HEALTHCARE AND EDUCATION

THE ENERGY-HEALTH NEXUS

Access to electricity in health facilities is critical to achieving universal health care and key development goals, including improving maternal health, reducing child mortality, and disease prevention. Many health clinics, particularly those in rural areas, lack reliable, affordable electricity supplies for powering basic services such as lighting, communications, refrigeration, diagnostics, and the medical devices required for health services. Stable access to electricity supports core facility operations, resulting in a variety of benefits to patients and communities including:

MEDICAL SERVICES AND LIGHTING

Energy, particularly electricity, is required for the operation of basic amenities, including lighting, ventilation, ICT, and life-saving medical devices. Energy access also enables expanded operating hours, increased night-time health provision, and increased opportunity for health clinic visits.

DISEASE TREATMENT AND PREVENTION

In health centers, access to reliable electricity is essential for ensuring the cold chain to safely preserve and store vaccines, blood, and other critical medicines requiring refrigeration.

MATERNAL CARE AND OBSTETRICS SERVICES

During pregnancy and childbirth, adequate and continuous lighting along with medical equipment such as a fetal heart rate monitor or an ultrasound can be a life-saving measure for many women and children.

COMMUNICATION, EDUCATION, AND OUTREACH

ICT is a critical enabler of wider "telemedicine" strategies, which have been extremely effective in supporting activities such as remote health worker consultations and ongoing training and education. Additionally, communication is a critical enabler of access to public health education and information in an era of rapid global and regional disease transmission, pandemic alerts, and extreme weather.

FACILITY OPERATIONS AND PERSONNEL

Efficient management of patient records and referrals, as well as collection and reporting of health statistics, is greatly facilitated when computer-based services, software, and solutions are enabled by electricity access. Additionally, inefficient use of energy technologies (for instance, powering small medical devices with oversized generators) contributes significantly to fuel waste and costs. Also, there is increasing evidence that community electricity access is a key factor in attracting and retaining qualified health workers and reducing employee absenteeism in health facilities.

THE ENERGY-EDUCATION NEXUS

Electricity access enables global educational goals and long-term economic development. The United Nations Department of Economic and Social Affairs (UNDESA), in a multi-study review of the impacts that energy access can have on education and schools, identified five key categories of benefits[6] :

LIGHTING AND EXTENDED STUDYING HOURS

Reliable electricity access enables continuous lighting, which presents multiple opportunities for schools, including extended study hours, hosting of evening classes and community events, and facilitation of lesson preparation and administrative tasks for teachers.

FACILITATION OF ICT

Electricity facilitates access to ICT services that can help improve student and teacher educational experiences, including through the use of audiovisual teaching aids and equipment such as computers and printers. Potentially the most transformative impact, however, is access to the internet.

ENHANCED STAFF RETENTION AND TEACHER TRAINING

Evidence shows the positive impact rural electrification has on retention of teachers. When general quality of life increases due to electrification of facilities and staff houses, teachers are willing to relocate to rural schools, helping mitigate the problem of teacher shortages.

BETTER SCHOOL PERFORMANCE

Stable electricity improves basic amenities in school such as access to clean water, sanitation, lighting, and cooling, and can also enable training for vocational trades (e.g., engineering, welding, carpentry, mechanics, electronics) and professional/technical skills (e.g., computer literacy).

ENABLING COMMUNITY CO-BENEFITS

School electrification can produce multiplier effects such as improved community sanitation and health benefits, gender empowerment, and even reduced migration and strengthened resilience. UNDESA highlights that electrification can have positive impacts on gender equality by improving attendance, test scores, and matriculation to secondary education for girls.

[6] *UNDESA. (2014). Electricity and education: The benefits, barriers, and recommendations for achieving the electrification of primary schools. UNDESA.*

POWERING PUBLIC FACILITIES: WHAT IS NEEDED

The electricity needs of health and educational facilities depend on a number of factors including the number of expected beneficiaries, physical size of the facility, current and planned health services, available technology and equipment, operational hours, country-specific needs, socioeconomic context, and national standards and budgets. Accordingly, site- and community-specific needs assessments have become a critical component in designing energy solutions for off-grid health and education facilities.

HEALTH FACILITY ELECTRICITY NEEDS

There is no global standard regarding the energy needs of health facilities. Standards vary by country, context, circumstance, and the level of care provided. The World Health Organization (WHO) maps service and energy requirements across three broad types of health facilities commonly found in emerging countries:[7]

- 'Health posts,' very small facilities operating mostly as distribution centers for medical supplies and sometimes to treat basic illnesses and injuries, have limited electricity demand.

- 'Health centers' focus on provision of essential primary health services, often including maternity care, basic surgeries, and treatment of diseases like malaria and HIV/AIDS. This can include blood banks, pharmacies, and standalone laboratories. Electricity needs of roughly 4 to 10 kWh/day stem from basic lighting, vaccine refrigerators, and lab and sterilization equipment.

- 'District hospitals' and 'Regional/Provincial hospitals' offer more extensive services including surgeries, blood testing, and advanced diagnostics. They deploy a wider array of technologies, particularly for diagnostic and surgical activities. Hospitals tend to be more fully equipped and located in on-grid or 'weak-grid' urban areas, serving as central treatment centers for surrounding rural areas. Electricity demands for these facilities vary widely but are estimated at 15 to 200 kWh/day or more.

In addition, the growing need for cold storage space in the health sector and the rise of e-health platforms and applications are expected to drive additional energy requirements at all levels of health care.

EDUCATIONAL-FACILITY ELECTRICITY NEEDS

The electricity needs of educational facilities depend on types of consumption and the number of users. Consumption includes lighting, air circulation, computers, tablets, and televisions. The Poor People's Energy Outlook (2013) estimated that the electricity needs of a school for 100 children would be similar to that of a small health center: around 5-10 kWh per day. In comparison, the World Bank's Photovoltaics for Community Service Facilities study (2010) found that a school with 200-400 children would require just 2-5 kWh per day. Going forward, as ICT devices become cheaper and more widely deployed, the electricity demand at schools is expected to rise.

PUBLIC FACILITY ELECTRIFICATION: CURRENT STATUS

ELECTRICITY ACCESS RATES FOR HEALTH FACILITIES

Current data on access to electricity in health facilities is limited. A 2015 WHO report shows a wide range of electricity access rates in health facilities, from 9% in the Democratic Republic of Congo (2014) to over 67% in Tanzania (2016)

---

[7] *World Health Organization; World Bank. (2015). Access to modern energy services for health facilities in resource-constrained settings: a review of status, significance, challenges and measurement. WHO.*

and Burkina Faso (2014).[8] Various assessments[9] show significant differences in electricity access among urban and rural facilities, public and private facilities, and different-sized facilities. Countries have focused on the electrification of hospitals and other large health centers, which are more likely to be in urban or peri-urban areas where grid connections are often available, though unreliable. Smaller health clinics and health posts tend to be located farther from the grid and therefore more difficult to electrify. These facilities have consistently lower access rates.[10] These facilities exist in areas where there is significant demand for maternal and child health services. Obtaining up-to-date access rates for health facilities remains challenging. A 2013 study published in Global Health: Science and Practice[11], with some data sources that are 15 years old, shows that an average of 28% of health facilities in select sub-Saharan African countries have reliable electricity.[12] A 2018 paper from the International Journal of Hygiene and Environmental Health featuring a survey of 78 countries found that only 41% of low-and middle-income country healthcare facilities have reliable electricity.[13]

ELECTRICITY ACCESS RATES FOR SCHOOLS

Access to electricity at educational facilities has been growing slowly. According to UNESCO estimates in 2017, only 35.1% of sub-Saharan African primary schools and 50.7% of those in Southern Asia had access to electricity. Access rates in sub-Saharan African secondary schools are also well below 60% overall (see Table 1).

TABLE 1. ACCESS TO ELECTRICITY IN PRIMARY AND SECONDARY SCHOOLS[14]

School Type	Region	2012	2013	2014	2015	2016	2017
Primary	Sub-Saharan Africa	--	--	--	34.%	34.5%	35.1%
	Southern Asia	49.0%	49.5%	50.0%	50.4%	50.6%	50.7%
	World	66.4%	67.1%	67.7%	68.4%	69.0%	69.1%
Lower Secondary	Sub-Saharan Africa	--	--	--	49.1%	49.3%	--
	Southern Asia	63.9%	64.2%	64.6%	65.1%	65.6%	65.8%
	World	77.3%	77.8%	78.3%	78.9%	79.7%	79.5%
Upper Secondary	Sub-Saharan Africa	--	--	55.1%	56.0%	57.1%	--
	Southern Asia	83.8%	85.0%	86.1%	87.1%	88.1%	88.2%
	World	87.7%	88.1%	88.4%	88.8%	89.4%	89.5%

[8] *WHO. (2010-2016). Service Availability and Readiness Assessments (SARA). Retrieved December 2018, from https://www.who.int/healthinfo/systems/sara_reports/en/. Information for DRC and Burkina; USAID. (n.d.). DHS SPA Final Program Reports. Retrieved December 2018, from The DHS Program: https://dhsprogram.com/publications/Publication-Search.cfm?shareurl=yes&year11=&year21=&language1=&topic1=&country1=&pubTypeSelected=pubtype_21&keyword1=&pubid1=&showall=yes&PubTypeLogID=1. Information for Tanzania.*

[9] *Ibid*

[10] *Adair-Rohani et al. (2013). Limited electricity access in health facilities of sub-Saharan Africa: a systematic review of data on electricity access, sources, and reliability. Global Health: Science and Practice, 1(2), 249-261.; There is significant variation by country, but out of eleven countries with data provided, none have greater than 10% of hospitals without electricity. On the other hand, nine out of eleven have double digit percentages of 'other' facilities without access.*

[11] *Adair-Rohani et al. (2013). Ibid.*

[12] *Ibid.*

[13] *Cronk, R., & Bartram, J. (2018). Environmental conditions in health care facilities in low-and middle-income countries: coverage and inequalities. International Journal of Hygiene and Environmental Health, 221(3), 409-422.*

[14] *UNESCO. (2018). UIS.Stat. Retrieved December 2018, from UNESCO Institute of Statistics: http://data.uis.unesco.org/#*

KEY CHALLENGES TO ELECTRIFICATION VIA OFF-GRID SOLAR

The challenges to electrification via off-grid solar are well-documented in reports such as The World Bank's *State of Electricity Access Report – Modern Energy Access and Health*[15] and are summarized below:

- Information and actionable data: The central role of energy access in enabling health care and education services is not well understood. Energy is largely treated as a facility, operations, and infrastructure issue, rather than a determinant of health and education. Policymakers lack data, tools and guidance to monitor links between electricity access and education and healthcare, as well as to identify electricity access gaps.

- Sectoral leadership: Powering public facilities falls between sectors, leaving unclear leadership and a need for better coordination, capacity and policies. Management structures need to be in place so that specific entities and stakeholders maintain a concerted level of interest in the continued successful operation of systems. Ownership is particularly important for financing operations and maintenance activities, including component replacements.

- Capital expenditure: Even though the cost of off-grid solar technologies has decreased substantially in recent years, initial design, procurement, installation, and other upfront costs of PV-battery systems remain higher than longstanding alternatives such as generators. While savings from PV systems should accrue thanks to avoided fuel use, early system failure due to insufficient O&M activities often nullifies these long-term benefits. Upfront budgeting for system maintenance and component replacement is increasingly recognized as critical to long-term system sustainability.

- Sustainability: Project implementers tend to focus on the shorter-term aspects of projects over which they may have direct control, namely the key elements of the design and build stages. (e.g., system design, field surveys, preparation of the technical specifications of PV systems, and procurement.) Problems arise due to an overall lack of informative data, poor system sizing based solely on current expected needs, subpar installation, and insufficient knowledge of best practices in design. Furthermore, healthcare and education facilities often lack adequate capacity to operate and maintain these systems. Theft and vandalism are also notable challenges.

[15] *World Bank; United Nations Foundation; World Health Organization. (2017). State of Electricity Access Report – Modern Energy Access and Health. World Bank.*

3. ANALYTIC FRAMEWORK & METHODOLOGY

What contributes to the sustainability of solar PV systems in off-grid, public health and education facilities? This report centers on answering this question by identifying key insights about delivery models that support long-term sustainability, leveraging an analytic Framework for Sustainability built around:

- Three fundamental pillars of sustainability: organizational, technical, and economic; and
- Four project lifecycle phases: inception, design, build, and operations and maintenance (O&M).

This framework was applied to seven case studies to generate practical and actionable “Key Insights”, representing critical learnings that can impact sustainability. With these insights, the report then looks at two emerging cases currently under design in Africa and two hypothetical cases that were developed for this report, intended to stretch the current thinking around delivery models for electricity in off-grid public facilities.

EXPLAINING DELIVERY MODELS

Electrification projects at public facilities fall on a spectrum ranging from pure public sector models to pure private sector models. The models driven by the public sector are noted for delivering social services through government agencies that lead the project from inception to O&M. The public sector administers funding, but financing might come from public budgets, loans from multilateral development banks, or grants from foreign development partners. Pure public models have produced few projects, since few governments have capacity to complete all requisite activities.

The model driven by the private sector is noted for delivering service through a profit-seeking enterprise. In its purest form, the private sector would conduct all phases of the project lifecycle. In emerging countries, private investors are generally unwilling to expend capital upfront without guaranteed regular payments for energy services. Other constraints, particularly around financing, inhibit their ability to tackle such a mandate. Interest rates tend to be prohibitively high, loan tenors are short (rarely exceeding seven years), and loan collateral requirements are stringent.

Most cases from emerging markets blend elements of the public and private sector models. The public sector may lead certain activities and assume certain responsibilities, typically covering at least project inception and design, but then leveraging the private sector to improve outcomes, such as by saving time or reducing costs, particularly in installation and O&M. Foreign development partners often contribute to design thinking and provide significant financing, particularly for equipment costs.

While this linear typology is useful, it fails to consider social and other impacts recognized by the philanthropic model, an alternative observed in emerging markets. Through this model, charitable foundations, high-net-worth individuals, and bilateral or multilateral organizations provide grants or donations to achieve a desired impact. Philanthropic organizations may participate in project implementation, though they often leverage civil society organizations, including non-governmental organizations (NGOs) and community-based organizations (CBOs).

BUILDING A SUSTAINABILITY FRAMEWORK: PILLARS & PHASES

Sustainability in off-grid solar is about ensuring that electric service delivery is maintained for systems' designed lifespans, including an effective contingency plan in the event of premature failure. The sustainability framework is built upon three pillars:

- **Organizational** sustainability—project stakeholder arrangements to preserve system functionality, including division of responsibilities, ownership and accountability, alignment of incentives, and capacity to carry out responsibilities.

- **Technical** sustainability—assurance that systems meet electricity needs of host facility and operate as designed.

- **Economic** sustainability—availability of financing and incentives to ensure satisfactory system installation, operation, and maintenance.

To be useful for practitioners, the framework adds another layer, the classic project lifecycle, which is briefly summarized below and depicted in Figure 2.

FIGURE 2. CLASSIC PROJECT LIFE CYCLE

Each pillar contains four project lifecycle phases—Inception, Design, Build, and Operation and Maintenance (O&M)	Define core goals and approach	Finalize facility siting, expected needs, and system sizing	Undertake procurement and execute installation contracts	Ensure system performance for its expected life
Project Lifecycle Phases	I. Inception	II. Design	III. Build	IV. O&M

PROJECT LIFE CYCLE PHASES:

- **Inception**: Define project goals and approach, including target outcomes and expected mandates and responsibilities of implementation partners.

- **Design**: Select facilities and assess needs, including system sizing. Draft procurement documents and other project development materials for contract bidding.

- **Build**: Procure hardware, execute installation contracts, deploy PV assets.

- **Operation and Maintenance (O&M)**: Conduct or contract out routine and ad hoc maintenance. Replace components, including batteries, as necessary. Continue until asset has completed 10- to 15-year lifetime. At this point, assets are either considered obsolete, and would either be extensively refurbished or replaced entirely (more typical). This would then signal the return to the lifecycle inception phase.

The project lifecycle phases cut across each of the sustainability pillars. Each pillar and each lifecycle phase deals with a separate set of issues in the examined cases, as shown in Figure 3.

FIGURE 3. MODEL SUSTAINABILITY FRAMEWORK

Sustainability Framework Pillars	Organizational	Technical	Economic
Three "pillars" of sustainability—Organizational, Technical, and Economic	Arrange project stakeholders to preserve systems' long-term functionality	Make certain installed systems are robust and fit for purpose	Ensure financing and incentives are structured for the long haul

MODEL SUSTAINABILITY FRAMEWORK

Each pillar contains four project lifecycle phases—Inception, Design, Build, and Operation and Maintenance (O&M)	Define core goals and approach	Finalize facility siting, expected needs, and system sizing	Undertake procurement and execute installation contracts	Ensure system performance for its expected life
Project Lifecycle Phases	I. Inception	II. Design	III. Build	IV. O&M

A CASE-STUDY APPROACH TO UNDERSTANDING SUSTAINABILITY

Each off-grid solar public facility project has a unique approach to system design and delivery. As context plays an important role in the design of any project, no two sets of circumstances and actors are alike. For these reasons, this report derives core content from a series of case studies based on an interview protocol grounded in the key features of the Sustainability Framework. Summaries for each of the seven cases can be found in Annex A. Extensive interviews were held with people who were directly responsible for design and implementation of each of the cases. The list of interviewees can be found in Annex B.

RETROSPECTIVE CASES

The seven cases that were selected represent past and current practice, in particular via large-scale and/or prominent initiatives, often with development partners serving as key stakeholders. The report covers a variety of geographic localities, size of electrification programs, and approaches to achieving the same goal. Some of the programs have concluded, while others are still in the early stages of implementation. They offer insights into challenges for off-grid solar installations across the four lifecycle phases. Most importantly, each illustrates a distinct approach to commingling public, philanthropic, and private actors and their associated models. Detailed analysis will be found in Chapters 4 through 6.

A brief summary of each retrospective case study is included in Table 2. Each summary outlines the project's targeted outcomes, key actors (including the Champions and implementation partners), the core structure of the delivery model as it relates to both supply and installation and operations and maintenance, as well as any other unique elements of the approach.

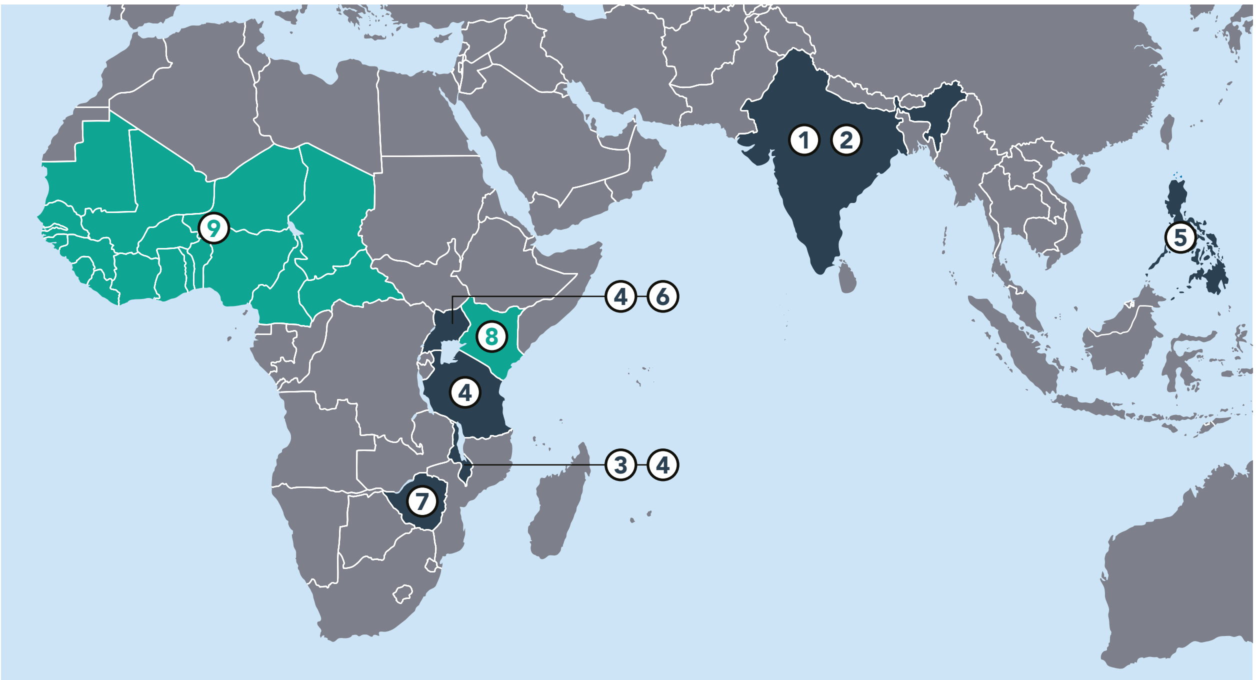
EMERGING CASES

In Chapter 7, the report incorporates an analysis of two emerging and two hypothetical case studies for public facility PV electrification. For the emerging models, the objective is to identify key opportunities and recommendations as these projects move through inception and design, leaning on the sustainability framework and key insights.

The hypothetical models showcase new approaches to sustainability challenges with divergent levels of government involvement and responsibility.

Figure 4 shows locations of the retrospective and emerging cases.

FIGURE 4. MAP OF FEATURED CASES



Retrospective cases

India
1 CREDA
2 SELCO

Malawi
3 CEDP

Malawi, Tanzania, Uganda
4 IA

Philippines
5 SSMP

Uganda
6 ERT-II

Zimbabwe
7 S4H

Emerging cases

Kenya
8 KOSAP

West Africa
9 ROGEP

VISUALIZING MODEL FEATURES OF EACH CASE

Each case is unique, and blends features of public, private, and philanthropic models. To illustrate this, a visualization has been developed for each case (see example in Figure 5) that shows the blend of these models across the project phases (Inception through O&M). The proportions ascribed to each model are approximate, and are for illustrative purposes only. The example in Figure 5 shows a blend that is heavily philanthropic at the outset, but shifts to a more private model that also involves the public sector during O&M.

This visualization is used in Table 2 below and in Chapter 7 to illustrate the case studies featured in the report. These visualizations and the corresponding analysis in the following chapters will show that all the cases examined are true hybrids, drawing upon public, private, and philanthropic features.

FIGURE 5: CASE VISUALIZATION

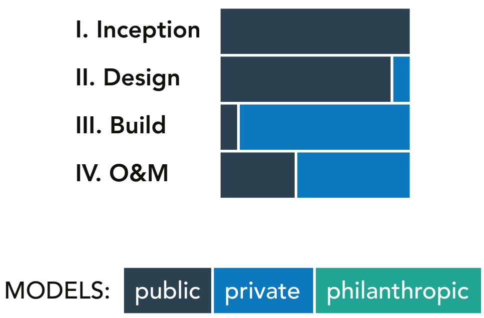


TABLE 2. CASE STUDY OVERVIEWS

Project Name	Country(ies)	Dates	Target(s)	Project Scale	MODELS: pub. priv. phil.
Chhattisgarh State Renewable Energy Development Agency (CREDA)	India	2011 - Ongoing	Health	984 facilities electrified to date	I. Inception II. Design III. Build IV. O&M 
SELCO Foundation-Karuna Trust (SELCO)	India	2016 – Ongoing	Health	15 facilities electrified to date	I. Inception II. Design III. Build IV. O&M 
Community Energy Development Programme (CEDP)	Malawi	2012-2015	Education (and one health facility)	26 facilities electrified (25 edu. and 1 health)	I. Inception II. Design III. Build IV. O&M 
Innovation Africa (IA)	Malawi, Tanzania, Uganda	2008 – Ongoing	Health and Education	110 facilities electrified to date	I. Inception II. Design III. Build IV. O&M 
Sustainable Solar Market Packages (SSMP)	Philippines	2003-2012	Health and Education	2,083 facilities electrified	I. Inception II. Design III. Build IV. O&M 
Energy for Rural Transformation – II (ERT-II)	Uganda	2008-2016	Health and Education	1,082 facilities (560 education and 522 health)	I. Inception II. Design III. Build IV. O&M 
Solar for Health (S4H)	Zimbabwe	2015 – Ongoing	Health	405 facilities electrified to date	I. Inception II. Design III. Build IV. O&M 

Case Summary
In the Indian state of Chhattisgarh, the state renewable energy development agency (CREDA) and the Ministry of Health (MoH) have partnered to PV-electrify 984 health centers. The PV systems are customized for each health facility, and the sizing process considers existing and future services to be provided (including the need for energy efficient appliances). Private-sector contractors identified and certified by CREDA are then deployed to provide installation and five years of O&M. At the end of the contract, O&M responsibility will pass back to CREDA, who manages a comprehensive O&M department and has kept all systems functional. Financing for the partnership is provided through a line item in the MoH budget, and their financial commitment reinforces the joint commitment of both agencies to the success of the partnership.
The SELCO Foundation has partnered with Karuna Trust in India to PV-electrify 15 health facilities. Each PV arrangement is unique to the health facility and was designed based on a novel joint Health-Energy audit. The audit process considers both existing and future service needs (including cold chain, maternal health, dental/eye care, lab services), and respects government service provision standards. Private contractors trained and certified by SELCO Foundation were contracted to install the systems and provide five years of O&M. Afterwards, responsibility will be passed to Karuna Trust, who will manage responsibility through private-sector contracting and training of Primary Healthcare Center (PHC) staff. Financing for the first year of O&M was included in the project budget, and government funding has been identified to cover the remaining near-term costs.
Implemented by the University of Strathclyde with Scottish government funds, this project installed over 200 standalone PV systems at 25 Malawian schools and one health center. Given the short three-year project timeframe, the implementers entrusted community-based organizations (CBOs) with O&M responsibility and encouraged them to engage in revenue-generating activities to cover costs. CEDP also supported the establishment of Community Energy Malawi, a national non-profit whose development officers provided operators with guidance on O&M, and who had the task of delivering ongoing capacity building and support to CBOs. The project is notable for its use of a custom remote monitoring system that allowed for communication between multiple systems at a single facility, uploading data from a single GSM hub.
This international NGO has installed PV systems with remote monitoring at over 100 health centers and schools across ten African countries. Deployed systems are typically small, with a focus on lighting and refrigeration. Their model to date has involved encouraging local communities to use power to run revenue-generating businesses, with a community-elected committee taking responsibility for the systems and the business. Profits from activities are intended to cover O&M costs, but component reliability issues and revenue shortfalls have forced IA to backstop. Going forward, the organization is overhauling its design and procurement process to deliver more a resilient system in a box that uses lithium-ion batteries, with the hope that the shift will boost system lifetimes and reduce O&M needs.
The Government of the Philippines (with World Bank support) carried out the Rural Power Project, which electrified more than 2,000 health facilities, schools, and community halls in rural areas. The project introduced the Sustainable Solar Market Packages (SSMP) concept, in which private-sector bidders compete for the right to PV-electrify groups of public facilities and supply nearby households with solar home systems. PV installation requirements for each facility were specified in the bidding documents, based on an earlier energy needs assessment done by the SSMP development team. Successful contractors were responsible for O&M for the first five years before transferring it to local governments, but O&M activities were unsatisfactory, due to the remoteness of locations and poor government enforcement.
The Government of Uganda (with World Bank support) PV-electrified 560 schools and 522 health centers. The Ministries of Health (MoH) and of Education and Sports (MoES) took considerable responsibility during inception and design phases. Both opted for an approach whereby private contractors bid on lots of facilities, organized by geography, with winners signing contracts to supply, install, and maintain prescribed PV systems for a period of one year. Installers signed separate maintenance contracts covering years 2-5 of operation. However, these contracts were 'maintenance only' and did not cover component replacement, leaving the line ministries scrambling for funds as key components failed. After five years, O&M responsibility falls on local governments that typically have limited human and financial resources.
This UNDP-led program in Zimbabwe resulted in the installation of relatively large PV-battery backup systems at 405 district hospitals, polyclinics, and primary clinics, almost all of which had connections to an unreliable grid. The national UNDP team worked closely with the Ministry of Health and Department of Public Works as well as with selected suppliers on program design, including site assessments and mapping of PV-battery packages to facilities. Selected suppliers had to commit to a one-year warranty period to offer technical support, while component warranties range from 1 to 10 years. The Department of Public Works holds responsibility for O&M, while the capacity to provide O&M services and O&M funding is currently being studied. Installed systems have successfully stabilized critical power supplies, though the sustained delivery of power will depend on the long-term O&M plans.

4. ORGANIZATIONAL SUSTAINABILITY

This chapter draws on seven case studies to present Key Insights about how project stakeholders achieve long-term operations and maintenance of PV assets through organizational sustainability, addressing the division of stakeholder responsibilities, incentives and capabilities, and system ownership and accountability. Organizational aspects of public facility electrification projects are critical since the finance provider, the system installer, and system owner are almost always different actors, and incumbent stakeholders are often expected to play new roles. As such, incentives are not necessarily aligned and responsibilities may be placed on institutions with no capability or desire to fulfill them. Careful planning, stakeholder engagement, and sensitization are therefore often required to achieve organizational sustainability at a given site.

INCEPTION PHASE (ORGANIZATIONAL)

In looking at the organizational sustainability of a public facility PV electrification project during its inception phase, key questions include:

- *What are the characteristics of the project "Champion" and how does this impact the project vision and management approach?*
- *What is the ultimate vision for system ownership, obligations, and resource management, and do all entities have sufficient capacity and motivation to deliver on their responsibilities?*

Key Insight #1: Project "Champions" should mitigate the risk of a responsibility vacuum or budgetary hole when exiting during O&M phase

In the majority of case studies examined in this report, "Champions" ultimately devolved responsibility for O&M to the local level as part of an effort to secure greater engagement and buy-in for the project, though varying degrees of long-term "backup support" from central entities were observed. CEDP was championed by the University of Strathclyde with capital expenditures (CAPEX) funded by the Scottish government, but system ownership was rapidly transferred to local communities in the form of 'community-based organizations' or CBOs, e.g., women's groups or local AIDS prevention committees. Towards the end of the University of Strathclyde's involvement, CBOs were encouraged to rely on a local partnership to ensure operational sustainability via Community Energy Malawi (CEM), a renewable energy lobbying group.

Though CEM's network of technicians and development officers proved a valuable resource to CBOs for ad hoc troubleshooting or advice, they did not have the financial resources, staffing, or mandate to fully backstop gaps in the CBOs' management capacity. Thus, it would have been preferable had the original "Champion" taken steps to ensure that CEM or a third party were in a position to provide deeper long-term support to the project's sustainability before exiting. Such an issue is particularly relevant to models where initial project Champions are philanthropy-driven or programmatically must work within specific project timeframes.

Key Insight #2: Passing the "Champion" role to local actors can be effective, but only if they have sufficient human and financial resources

In the Karuna Trust-SELCO Foundation case, donor funds for system purchases flowed through the SELCO Foundation to Karuna Trust, which manages public health facilities for the Indian government. Staff at Karuna's Primary Health Care unit and the state public health committee, Arogya Raksha Samithis (ARS), have responsibility for long-term O&M. Through this arrangement, operating expenditures (OPEX) are budgeted from ARS's Karnataka state funding and Karuna Trust invests in training healthcare workers to support PV O&M.

That such expectations of local capacity may go unrealized is well illustrated in the IA case. Ownership was passed to the local community with the vision that it would fund O&M through income-generating uses of the system beyond activities at the public facilities. Income was consistently generated but not enough to fully cover O&M costs. This speaks to the value and limitations of 'productive uses' of energy to advance sustainability.

DESIGN PHASE (ORGANIZATIONAL)

Sustainability Framework Pillars	Organizational	Technical	Economic	
Project Lifecycle Phases	I. Inception	II. Design	III. Build	IV. O&M

When it comes to system sustainability, many of the design-phase considerations are directly related to decision-making and assumption of responsibility during the design process. Key questions include:

- *How formally have responsibilities been allocated? Has adequate stakeholder consultation, sensitization and buy-in taken place?*
- *How is the procurement process established? Who has responsibility for making system and financial design choices? What is the rationale?*

Key Insight #3: The design process should align perspectives of external and internal "Champions"

In Uganda's ERT-II project, there was a division of financing for CAPEX and OPEX between the World Bank—which covered CAPEX and the first year of OPEX—and the government of Uganda—which covered OPEX for years two through five. While the government employed external consultants to develop a clear and systematic framework for the project's rollout, it is not clear if there was adequate consultation and coordination between technical consultants hired for the project and the government decisionmakers. This was true with respect to aligning long-term goals and planning for the transition of responsibility, particularly regarding minimum quality and technical standards for batteries.

This misalignment resulted in a higher need for battery maintenance and replacement than the government had anticipated. Had they been fully apprised of the up-front vs lifetime tradeoffs during technical consultation, they might have considered longer-life batteries. This case demonstrates the need for a clear understanding of the tradeoffs involved in key decisions in particular across all parties at a negotiating table, given that this choice carries material consequences for whomever carries O&M responsibility down the line.

Key Insight #4: Centralized design and/or procurement may introduce delays but also long-term benefits

In the CREDA case, centralized design and procurement significantly contributed to system sustainability, while Innovation Africa has shifted to such a model to improve sustainability outcomes.

CREDA is heavily involved in all aspects of system design and operation, from selecting central system specifications to ensuring components selected conform to national standards. All 984 systems installed under this program are operational, and more than 600 of these are over five years old. Success is likely driven by the clarity that exists over the long-term responsibilities for asset maintenance. Because CREDA provides maintenance after completion of a five-year installer warranty period, it has an incentive to ensure quality and invests resources accordingly.

Innovation Africa had some initial success with flexible local procurement, but it then faced greater-than-expected maintenance and replacement costs, which throttled expansion. The NGO pivoted towards bulk procurement of all components from international suppliers. Going forward, Innovation Africa will ship full systems to gain greater confidence in system lifetime service capabilities and costs in exchange for tighter 'up-stream' control of system design and procurement.

O&M PHASE (ORGANIZATIONAL)

Designing and delivering an effective strategy for managing operational and maintenance activities and costs in remote geographies is the single greatest challenge in ensuring the sustainability of PV installations. Key questions include:

- *Who is financially responsible for managing O&M costs over an expected lifetime of 10-15 years?*
- *What are the O&M providers' capabilities and costs? Are there mechanisms to monitor O&M?*
- *What mechanisms for the transfer of responsibilities and funds exist over expected lifetime assets, and how are O&M obligations enforced?*

Key Insight #5: Project Champions should conduct O&M planning for a 10 to 15-year time horizon, in line with standalone PV system lifespans

Given that many public facility electrification projects receive support from development partners over a finite time period, there remains a strong tendency for project Champions to plan on a time scale that falls well short of the 10 to 15-year lifespan of well-maintained PV systems. As a result, dedicated O&M funds too often dry up abruptly, typically just as O&M responsibilities are transferred to a new entity poorly positioned to assume them. Instead, Champions must resolve to develop true long-term, 10 to 15-year sustainability plans in close coordination with the various parties tasked with responsibility for O&M (including replacement when components fail prematurely or reach their end-of-life).

The Solar for Health Zimbabwe initiative deployed hundreds of systems, and while it included several project design features that contribute to technical and organizational sustainability, the economic sustainability is currently less clear. Financing options for long-term sustainability are currently being explored, including through a study being conducted to develop scalable solar for health financing models and identify potential social impact investors. Steps were also taken to ensure sustainability during the tender process, by ensuring that successful suppliers work with local companies to build in-country capacity and through close engagement with Public Works which has well-trained engineers to inspect, supervise and undertake basic maintenance. Under the ERT-II program, designers developed a plan for the first five years of O&M post-installation, but failed to design a robust sustainability plan that would come into effect beyond year five. CREDA assumes responsibility for O&M responsibilities after an initial five years of contracted service, but it is not clear whether it will have capacity to manage or reallocate the maintenance responsibilities.

Key Insight #6: Well-incentivized and resourced 'central' organizations competent in PV O&M can successfully manage significant asset portfolios

There is a common tendency for project Champions to cede O&M responsibilities to local actors at some point in project life. While this is often for practical reasons, there is also conventional wisdom that decentralization and achieving local buy-in necessarily improves sustainability outcomes. However, these local actors often lack the human, technical, and/or financial capacity to successfully deliver on these critical responsibilities. Increasingly, the value of O&M decentralization is being challenged as evidence emerges that well-resourced central organizations can effectively manage considerable asset portfolios. In the CREDA case, the Chhattisgarh state's renewable energy body manages a network of system integrators contracted to perform O&M. The program's success should also be attributed in part to the dedicated funding received through line items in the state health budget. In other cases where initial centralized O&M approaches have fallen short, namely ERT-II and SSMP, the culprit has been shortcomings in planning and program design and insufficient funding allocations for future upkeep.

5. TECHNICAL SUSTAINABILITY

This chapter draws on seven retrospective case studies to present Key Insights about choices and processes to ensure the installed system meets the public facility's current and future energy needs over the course of a project's lifecycle. These Key Insights directly relate to the technical pillar in the sustainability framework. This chapter addresses how installed systems are fit for purpose, i.e., that they not just operate as intended but that they also meet the key energy needs of the facility for which they were designed. This includes the efforts made to assess current and expected energy needs, the technical design of systems that will accommodate such needs (including quality standards for components), and the efforts made to facilitate system maintenance through both technical means (e.g. remote monitoring) and technical training.

DESIGN PHASE (TECHNICAL)

Sustainability Framework Pillars	Organizational	Technical	Economic	
Project Lifecycle Phases	I. Inception	II. Design	III. Build	IV. O&M

Innovation and technological advances are not always reflected in design specifications. System designers minimize risk of premature failure by engineering a technical fit for purpose, matching power generation to current and future load. Key questions include:

- *What is the expected energy demand at host facilities? How might demand change during the project lifecycle?*
- *Are systems appropriately sized? Do system components meet quality standards? Does project procurement require flexibility in system size or design?*
- *Can users operate the system? Do system operators have access to adequate training materials and training programs?*
- *Have system designers considered adopting latest innovations or technologies, such as system monitoring, energy efficient appliances, quality battery technologies or backup technologies?*

Key Insight #1: Ensure facility energy needs are understood and reflected in system design

PV system design is about picking the right type and size of core components to ensure the system's ability to operate well and meet loads long term. Energy audits are invaluable in technical design and procurement planning. This was the case in the example of CREDA and SELCO Foundation, where the loads assessed at the facility were of a relatively high energy intensity, driving the procurement of energy-efficient medical equipment.

When the incumbent system uses energy sources besides electricity, it is difficult to project the energy needs and define system requirements. In the CEDP, CREDA and IA cases, PV system sizing was challenging. National standards for health facilities can steer the projected system requirements. Simple questionnaires or SMS-based data collection can also provide useful basic information and proxies for energy needs, such as number and types of electrical devices in use.

Key Insight #2: Understand behavioral and usage-pattern changes PV systems may cause

In several case studies, estimates of anticipated load requirements failed to consider how the PV system would affect user behavior. This is particularly unsurprising in off-grid or 'bad-grid' environments where PV installations represent a significant shift in access to electricity. Retrospective energy assessments for CEDP, for example, found that they underestimated the effect that access to a reliable power source would have on staff behavior and appliance usage. A similar phenomenon was observed under the ERT-II program in Uganda, with the compounding factor that the presence of generators at many facilities indicated the likely prevalence of power-hungry electrical devices. Failing to anticipate for unplanned and unanticipated load growth resulted in systems to quickly overload – a real problem when facilities have no protocols for mitigating battery deep discharge.

Project designers are beginning to build in a considerable buffer to address unanticipated load growth. However, better research on the behavioral impacts of electrification at public facilities would improve the quality of demand forecasts. Remote monitoring equipment for O&M managers to identify and mitigate system overuse would also help. IA's answer to correctly sizing energy solutions suggests another approach: control the provision of energy by limiting power outlet installation or using load limiters.

Key Insight #3: Consider trade-offs between custom and standardized system packages

Standard system designs can simplify design and procurement, but they increase the risk of a mismatch with facility needs. That being said, custom systems may be viewed as combinations of standard component packages. Technical experts with knowledge of geographic areas should be consulted on cost-effective, reliable, and locally appropriate procurement options. The CREDA model offers a hybrid model of custom systems designed on the basis of site energy audits and efficient appliances to maintain a load buffer, including LED lighting, freezers, vaccine refrigerators, computers, centrifuges, fans, and microscopes.

Service contracts offer convenience, speed, and streamlined component, installer, and maintenance provision, but they require the technical ability to evaluate hardware and facility needs and match the two. In Uganda's hybrid ERT-II procurement, systems were taken from a set of five 'Standard Energy Packages' for schools and 15 variations for health facilities. While the systems may have been appropriately sized, the underestimation of electricity demand (and overestimation of local capacity to manage the systems) contributed to high failure rates, particularly at schools. Given the opportunity to customize, the ERT-II planners might have included control components to limit overuse, avoiding battery damage due to excessive discharge. Quality inverters can also limit the depth of battery discharge.

Key Insight #4: Deploy new technologies and flexible designs to counter early PV system failure

Given that batteries remain the most common point of failure in PV systems, it is remarkable that no large-scale project has opted to deploy more reliable lithium-ion solutions, particularly given how much their costs have dropped in recent years.[16] Innovation Africa, which plans to deploy lithium-ion batteries in 2019, can provide insights. Remote monitoring technologies are being deployed with uneven regularity, and when deployed, they are often under-utilized. A carefully designed remote monitoring regime can help manage preventive maintenance and troubleshooting, assess system demand trends and demonstrate sustainable system use, detect early signs of component failure, and generate insights for future project designers. However, reliable cell mobile network coverage remains a necessary precondition to deploying these systems and maximizing their potential.

Systems can also use controllers that prioritize energy for critical needs, such as vaccine refrigeration, as seen at

[16] *https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/*

times in the ERT-II program. Energy efficiency platforms that support AC and DC appliances have been readily accessible but not widely deployed, with designers often opting for simpler pure AC designs. A burgeoning household off-grid solar market has created an opportunity to deploy highly-efficient, low-cost DC appliances, such as LED light bulbs and energy-efficient fans. Energy-efficient medical appliances, however, are still lagging behind both in production and availability in resource-constrained settings. Finally, project developers can design systems for modular growth, allowing facilities to add generation and storage capacity as needs arise.

Key Insight #5: Enforce strict design and component quality standards backed by a competent oversight authority

Market growth is driving an increasing focus on component quality standards and robust system designs. Low-quality and mismatched components have often been cited as drivers of early system failure. Procurement specialists rely on IEC standards that are often difficult to interpret and not always relevant for small PV systems. The World Bank is developing a new quality-assurance framework for public facility systems to ease design and procurement challenges. However, instituting standards is not sufficient if the entity responsible for oversight does not have the resources and know-how to enforce them. Capacity building needs to be a part of any new quality assurance effort.

The retrospective cases showcase a diversity of issues related to component quality standards and system design. For IA and CEDP, low-quality components led to technical faults. The project developers attribute these quality lapses to local procurement, which is less likely to meet international standards, one reason why IA is moving to centralized procurement. The SELCO Foundation model used local procurement but upheld national standards, due to strong national ICT expertise.

BUILD PHASE (TECHNICAL)

After designing technical specifications, a project Champion initiates procurement and ensures proper installation and planning for on-site system monitoring. Key questions include:

- *Have systems been installed properly, including control or backup systems, if applicable?*

Key Insight #6: Use qualified technicians for installation and independent third parties for certification

To guarantee system quality early in project lifecycle, installers can use certified technicians and qualified, independent third parties to verify that installations meet component and installation standards. While upfront costs may increase, long-term O&M costs could go down.

The SELCO, CREDA, and CEDP cases illustrate good practices in ensuring competent and responsible system installation. The SSMP case fell short as the government lacked the capacity to visit remote and politically-volatile barangays to verify installation quality and make follow-up site visits, leaving those responsible for overseeing installations with little understanding of where and how to initiate corrections or invoke contractual penalties. Innovation Africa deployed its own installers, obviating the need for local contractor recruiting. IA retains quality control, and is further tightening this control as it transitions to centralized design and procurement.

O&M PHASE (TECHNICAL)

Viewing O&M considerations through the technical lens invites reflection on capacity building. As some O&M responsibility often passes to the local level, decisions that align with local capacity and help build and support it can contribute to system longevity. Key questions include:

- *Are system monitoring protocols being followed by the end user? Are users receiving ongoing support and training?*
- *Are systems being serviced regularly and as needed, in line with service contracts?*
- *Do users understand optimal system operations?*

Key Insight #7: Regular preventive maintenance protects system components and is good value for money

Preventative maintenance is a relatively low-cost measure that can have a high impact on sustainability by identifying and helping diagnose problems, such as component failure and system misuse, at an early stage. Preventative maintenance can also help keep facility staff engaged in system health and maintenance. While remote monitoring can complement routine maintenance, it is not a substitute. Innovation Africa and CEDP used remote monitoring to flag signs of system stress but did not identify causes of downtime. Assessing panels, wiring, batteries, or major changes in usage required on-site checks. For projects without remote monitoring, regular preventative maintenance allowed implementers to track system functionality and make appropriate updates to asset registries.

In the CREDA case, weekly visits to installed systems constituted part of its employees' job description. ERT-II also included preventative maintenance, with contractor payments tied to each visit. However, sufficient incentives and instruction were lacking for the head teachers, who were responsible for requesting ad hoc repair callouts. As a result, energy solutions were frequently left offline until the next scheduled preventive maintenance visit (twice a year).

Key Insight #8: Follow O&M protocols, supported by intensive and sustained capacity building

As evidenced by the case studies, local capacity to deliver on O&M protocols was often lacking. All entities tasked with O&M should be assessed for capabilities and supported by skill building. These capacity enhancements must then be properly costed out and financing needs to be secured to ensure that they are delivered. Cases often identified the need for capacity development, but underestimated the level of effort that this would require to ensure satisfactory knowledge transfer.

In Uganda, contractors were required to provide staff members with on-site training in basic system operation and first-line maintenance and supplied an illustrated user manual, but facility managers seldom initiated O&M call-outs. Malawi's CEDP program developed an O&M toolkit for health-clinic staff and provided a one-time, two-day training to system operators. A message gleaned consistently from stakeholder interviews was that project implementers, in hindsight, should have invested in more capacity building for system users, particularly those that had roles related to O&M.

Key Insight #9: Remote monitoring can enhance O&M, but its benefits are often limited by the capacity of those providing oversight

Remote monitoring, even in its most basic form, can collect and assess critical information about system performance.

When mobile networks are unavailable, staff can collect and transmit data. As mobile coverage improves, most PV systems can be fitted with remote monitoring hardware that allows central managers to monitor system vitals, such as battery voltage, charge current, load current, temperatures, and daily charge and load. This data can help identify issues before they cause downtime, troubleshoot with local staff, learn when batteries are nearing end of life, and broadly understand system usage. Remote monitoring adds upfront and ongoing costs, and its effectiveness depends on a central manager's ability to process data. Systems should feed into a centralized platform, minimizing management complexity.

Several case studies included remote monitoring. In some instances, such as the example of S4H Zimbabwe, hardware was installed and shown to be functional, with data collected and stored, but government concerns about data privacy has delayed transmission to national authorities. ERT-II did not use remote monitoring because of perceived technical complexity, instead opting for manual system monitoring by staff. CEDP followed an innovative approach, as the University of Strathclyde developed a custom local wireless protocol that enabled multiple connected sites to aggregate system usage data at a single GSM-enabled hub. However, because CEDP did not set aside funds to cover long-term mobile connectivity costs, real-time system data access is lost.

6. ECONOMIC SUSTAINABILITY

This chapter draws on seven retrospective case studies to present Key Insights about whether and how sufficient financing can be made available to allow for the required maintenance of installed systems. These Key Insights directly relate to the economic pillar in the sustainability framework. This chapter addresses financing for installation, operation, and maintenance of installed systems, allowing them to remain fully functional over the course of their planned lifetimes. The adequacy and reliability of O&M budgeting, especially as it pertains to the replacement of failed components such as batteries, is critical to project sustainability. Moreover, the pillar addresses the economic incentives that, if well-crafted and -aligned, will ensure key actors deliver on critical responsibilities pertaining to long-term system sustainability.

INCEPTION PHASE (ECONOMIC)

Financing is central to this assessment of PV system sustainability, but it is often overshadowed by the urgency to deploy new renewable energy resources at schools and health centers in need. Key questions include:

- *What are the tradeoffs between scale and sustainability, given budgetary constraints?*
- *What is the expected allocation of upfront and operational costs over system lifetime?*
- *Are the unit economics of the site(s) well understood?*

Key Insight #1: Program budgets should be optimized for system sustainability, not the number of systems deployed

Funder and project Champions face inherent resource constraints in project development. Given finite budgets, they must evaluate tradeoffs between sustainability and scale. Design choices that improve the chance of completing a 10- to 15-year lifecycle but reduce the number of facilities reached should be considered.

Concerned about a relatively high system failure rate, IA is turning to lithium-ion batteries. The cost is higher than lead-acid batteries, the standard in the market, but higher durability makes lithium-ion economically attractive in the longer term. Increasing capital expenditures may restrict IA's short-term expansion, but asset longevity is preferable to premature system failure. Furthermore, longevity affords the time to collect evidence of increased health outcomes, demonstrating benefits for end-users and social impact for project Champions.

Key Insight #2: Project Champions must account for, and consistently meet, financing needs over the expected lifespan of the deployed energy solution

Funding required for lifetime system maintenance is rarely assessed or secured. In ERT-II, planning and O&M funding was limited to five years with no coverage for component replacement. Projects require a clear sustainability plan and funding for lifetime O&M activities and component replacement. Few projects meet these criteria. The CEDP and Innovation Africa cases reflect the challenge of using local income-generating activities for long-term upkeep. Additional funds may be required, and should be secured early on. More upfront investment in O&M cost control may be warranted. CREDA secured recurring O&M funding from the government, representing a major step in sustainability. But the true test will come as installed systems require component replacement. If all project stakeholders frame success in terms of 'facilities sustainably electrified,' this would extend the program assessment period and deepen the commitment.

DESIGN PHASE (ECONOMIC)

Sustainability Framework Pillars	Organizational		Technical		Economic
Project Lifecycle Phases	I. Inception	II. Design	III. Build	IV. O&M	

Project design requires human capital, financing, and time. Economic considerations need to develop incentives for cooperation between champions, funders, project administrators, and technical advisers. Key questions include:

- *What are upfront and downstream budget allocations? Have tradeoffs in component quality costs been duly considered?*
- *Have appropriate financial incentives and penalties been designed for all obligations?*

Key Insight #3: Incentives for supply and install contractors are critical

Mechanisms should exist to prevent contractors from abandoning their responsibilities following installation. These mechanisms should be created during the design phase. The contractor's desire to maintain a strong reputation may be inadequate. Contracts need to give installers a clear financial interest to fulfill obligations (such as warranty claims) throughout the coverage period, until a third party assumes O&M.

The Solar for Health Zimbabwe program used some "supply and install" contracts that included a number of provisions in the tender document to ensure sustainability. For example, winning bidders were required to partner with a local agent registered with the national regulatory institutions to ensure national standards were maintained and national capacity was built. Final payment was contingent on provision of training during project handoff, tying the transfer of operational responsibility with knowledge transfer to the local agents, MoHCC and Public Works engineers and officers on the proper maintenance of the system, while also supplying manuals at the sites and a one-year technical warranty of installation and a multi-year warranty for individual parts. This approach aligns incentives and responsibilities, including O&M providers who may not have been identified at inception. In the SSMP case in the Philippines, however, the government did not provide resources to verify installations, limiting enforcement despite elegantly crafted fines for private-sector noncompliance. In the SELCO Foundation and CREDA cases, local contractors that maintain a high service quality get preferred bidding status on future projects.

O&M PHASE (ECONOMIC)

The economics of O&M are misunderstood and underestimated. Insufficient investment in procurement and user training can increase maintenance costs and shorten component lifespan. Key questions include:

- *What is the budget for O&M activities over a project's lifecycle?*
- *How are O&M budget shortfalls managed?*
- *What is the budget for battery replacement?*

Key Insight #4: PV system revenues are unlikely to cover ongoing O&M costs

Health clinics and schools are generally poorly suited to generating income from any surplus energy. In the case of the CEDP and IA examples, revenue was earmarked to defray O&M costs, but struggled to cover operations or battery replacement. IA attributed lower-than-expected revenue from its income generating activities due to competition from other service providers. This became particularly acute given the proliferation of small enterprises that used standalone solar systems that could offer similar services (e.g. mobile phone charging).

In contrast, CREDA took a very different approach, acting as an energy service manager, ensuring sustainable O&M funding through state health ministry and energy department budgets and taking on demand-side management through procurement. This case illustrates that it is possible for government sources of funding to consistently fill the funding gap needed to support long-term O&M.

Key Insight #5: If O&M is decentralized, project Champions must secure funding

System ownership and O&M responsibilities in public facility electrification projects tend to devolve to local organizations, such as community-based organizations or local governments. However, the handoff often does not come with funding. Local organizations, typically under-funded, cannot divert scarce discretionary funds to maintain systems.

In the ERT-II case, local governments become PV system owners without funds to maintain them. Line ministries, such as Health and Education, must step in to pay for component replacements. In the Solar for Health Zimbabwe case, local governments are to assume responsibilities, with the details of O&M staffing and coverage of costs currently under examination, including from savings realized from the lower electricity bills. To ensure sustainability, project Champions and funders need to ensure that sufficient resources (both human and financial) are made available to local actors who may take on responsibility for system operations and maintenance.

Key Insight #6: O&M outcomes must be directly tied to economic benefits or penalties

In remote locations, private sector service providers are often the only parties capable of regular and ongoing O&M, and these providers deliver value principally when incentivized with compensation or penalized for failure. It can be difficult to design appropriate carrots and sticks.

The Philippines SSMP project highlights two approaches. In the first phase, the government took a security deposit from contractors to discourage failure to fulfill obligations, and payment milestones were aligned with O&M delivery. Security deposits proved insufficient, however. The amount was too low, and the government did not provide oversight. In the second phase, local Energy Cooperatives provided O&M service under a simple fee structure with more success.

In the Ugandan ERT-II case, line ministries linked O&M contractor payments to biannual site visits. However, facility managers were tasked with initiating maintenance requests as needed and documenting that service had taken place. No compensation was tied to these responsibilities, and thus sometimes facility managers neglected to complete them, leading to frequent, and substantial, system downtime.

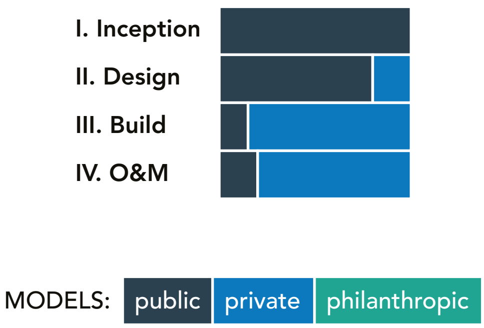
7. EMERGING MODELS

This chapter examines two emerging cases based on the Kenya Off-Grid Solar Access Project (KOSAP) for Underserved Counties and the Regional Off-Grid Electrification Project (ROGEP) in West Africa. Both projects, which are in the early stages of their development and implementation, take innovative approaches to organizational, technical, and economic sustainability. The report also examines two hypothetical cases that follow best practices in sustainability, one rooted in the public sector and another in the private sector. The hypotheticals are informed by existing practice and literature on organizational structure, in particular the work on public-private partnerships. Both hypothetical models aim to maximize sustainability by minimizing handoffs to third parties and securing financial and technical resources upfront to cover the full system lifetime.

EMERGING CASE #1: KENYA OFF-GRID SOLAR ACCESS PROJECT FOR UNDERSERVED COUNTIES (KOSAP) – KENYA

Overview and cross-cutting aspects: KOSAP is a USD 150 million World Bank-financed government of Kenya (GoK) project financed by the World Bank. It targets increasing access to modern energy services in Kenya's underserved counties, particularly in the north and northeast. The project has a USD 25 million component intended to provide standalone solar systems to community facilities (including approximately 800 health and educational facilities) in the target counties. A further 200 facilities are expected to be served by new mini-grids. The critical parties under the component are private service providers (PSPs), Kenya Power (the Kenyan national power utility), and the local governments. PSPs will competitively bid for the right to supply, install, and maintain solar PV systems at community facilities in a given geographic service territory, signing back-to-back supply and installation agreements and 10- to 15-year O&M contracts. World Bank financing will cover supply and installation. Kenya Power will make O&M payments funded by a service tariff charged to local governments. The capacity of local governments and Kenya Power to hold contractors accountable and the contractors' trust in Kenya Power to consistently make O&M payments will impact long-term success.

FIGURE 6. KOSAP VISUALIZATION



Organizational sustainability: Most government-led public facility electrification models involve three critical stakeholders: national government, contractors, and a local government or community group. KOSAP adds another stakeholder, Kenya Power, responsible for electricity service, payment collection, and managing the PSP O&M obligations.

The model requires open communication between the clients, Kenya Power, and contractors. Contractors have an incentive to provide service because O&M payments will be performance-based, but it is currently not clear how performance will be measured. Remote system monitoring is not required. Local governments or facilities are not accustomed to manually tracking downtime and service quality.

Critical Design Features

- 10- to 15-year O&M plan with operational and financial responsibilities passed to third parties, including Kenya Power, private contractors, and local governments
- PSPs responsible for installed assets over their expected lifetime
- Kenya Power to monitor and pay PSPs, collect payments from electrified facilities
- Competitive bidding for bundled project sites within geographic zones

Key Sustainability Considerations

- Kenya Power capacity to oversee PSPs
- PSP trust in Kenya Power to provide O&M payments

Technical sustainability: To date, KOSAP designers have spent limited time on key technical considerations. A study on electricity demand at secondary schools, vocational training centers, and Level 2 and 3 health facilities is underway. Designers estimate systems will range from 800 to 1,000 Wp at education facilities and 1,200 to 3,600 Wp at health centers. It remains to be seen if the Ministry of Energy or Kenya Power will have sufficient information to prescribe technical specifications for each facility.

Component standards are also unclear. PSPs might voluntarily use quality components, but they could also abandon O&M if many components fail and the replacement cost is high. Kenya Power will need to verify installation quality, but training may be required due to the company's lack of experience with standalone systems. Remote monitoring could support performance-based contractor payments, though mobile network coverage limits might stand in the way.

Critical Design Features

- Detailed design packages for each facility
- Long O&M contract period and the use of a 'performance security' mitigates risk of poor system quality or upkeep

Key Sustainability Considerations

- Opportunity to leverage remote monitoring technology to enhance PSP monitoring
- Third-party certification upon installation will be critical
- No current preventative maintenance plan
- Incentives for local government to monitor PSP performance need to be strengthened

Economic sustainability: The KOSAP model uses several economic incentives. Contractor selection will be based on the lowest net present value of total supply, installation, and maintenance costs over the full 10- to 15-year contract period. This encourages competition on cost and promotes accountability. Contractors also must submit a performance security for supply and installation and maintenance contracts. This comprehensive approach should give PSPs incentives to install high-quality systems and maintain them. However, it remains unclear how many PSPs will participate in the bidding process because Kenya Power funding for O&M may be considered unreliable. KOSAP has created a reserve fund covering 6 to 12 months of payments for PSPs in the event of payment delays or default, but this may be insufficient. Kenya Power revenues from the tariff for electricity service to public facilities may not cover O&M costs, and local governments may not pay Kenya Power for electricity service.

Critical Design Features

- Lowest net present value of total supply, installation, and maintenance costs over the full 10- to 15-year contract period to determine winning PSPs
- Performance security for supply and installation and maintenance contracts
- Performance-based O&M payments, as tracked by local governments and Kenya Power

Key Sustainability Considerations

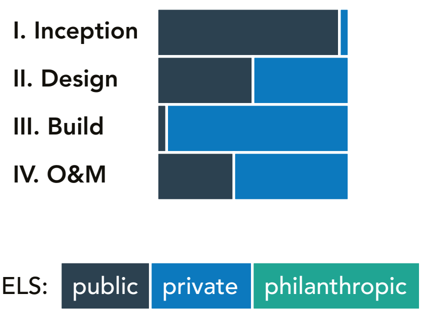
- Kenya Power carries off-taker risk based on local governments' ability to pay for electricity
- Capacity of Kenya Power or facility managers to monitor O&M contractors

EMERGING CASE #2 – REGIONAL OFF-GRID ELECTRIFICATION PROJECT (ROGEP) – WEST AFRICA

Overview and cross-cutting aspects: The Regional Off-Grid Electrification Project (ROGEP), spearheaded by the ECOWAS Regional Centre for Renewable Energy and Energy Efficiency (ECREEE), supports electrification of public facilities, including health centers and schools, in 19 West African countries. Using part of an estimated USD 200 million budget from the World Bank, the project supports project finance for energy service companies (ESCOs) backed by a Multilateral Investment Guarantee Agency (MIGA) guarantee underwriting future revenues. The ROGEP model shifts responsibility to ESCOs and ties O&M payments to performance, including system uptime. The ESCOs' willingness and ability to raise capital is unknown, as is investor appetite for off-grid projects at public facilities.

Organizational sustainability: ROGEP attempts to overhaul stakeholder responsibilities. While the participating government ministries will select project sites, perform energy audits, and set electricity service levels, ESCOs will accept nearly all remaining responsibilities for an estimated 5-7 years or at least through one battery replacement, including raising capital, procurement, installation, and O&M. Payments to ESCOs are tied to system performance, including uptime. The approach to O&M beyond the ESCO contract period is unknown. Facility staff and line ministries may not have the capacity to provide maintenance. ROGEP architects must consider how to match O&M service with asset lifetime.

FIGURE 7. ROGEP VISUALIZATION



Critical Design Features

- 5- to 7-year ESCO contracts
- MIGA guarantee for government payments to ESCOs
- ESCO O&M performance-based payments measured via remote monitoring

Key Sustainability Considerations

- No plan for O&M and capital replacement beyond ESCO contract period
- Capacity of local actors to assume O&M responsibilities after ESCO departure

- ESCOs may be unable to raise private funds, particularly for CAPEX, even with MIGA guarantee

Technical sustainability: ROGEP could add flexibility in system design, enabling installation of more innovative components or systems. It is expected that minimum technical specifications will be required given that governments will assume ownership of assets at the end of the an ESCO's contract period. Systems sizing challenges are not necessarily solved by this model. Government line ministries will probably continue to perform energy audits, though undersizing of systems remains a risk. Meanwhile, ESCOs may be partial to larger systems, as they can increase profits as well as reduce risk of premature failure due to overuse.

Critical Design Features

- Government to determine facility electricity needs
- ESCOs have flexibility over system design and specifications, encouraging innovation
- ESCO contracts incentivize investment in quality
- Reliance on remote monitoring

Key Sustainability Considerations

- 5- to 7-year contract period may discourage deployment of high-quality components, such as lithium-ion batteries
- Minimum requirements for preventive O&M would further mitigate risk
- No existing plan for handoff to local government or facility managers
- Remote monitoring across West Africa remains untested

Economic sustainability: Government agencies must budget for long-term ESCO payments. If ESCOs do not trust the process, including their ability to act upon the MIGA guarantee, they might not participate.

Participating ESCOs also must estimate true O&M costs over 5 to 7 years, offering a competitive bid without undercutting their bottom line.

Critical Design Features

- Direct line ministry payments to ESCOs backed by a MIGA guarantee
- ESCO payments to cover CAPEX and OPEX costs over the contract period
- Performance-based payments measured by remote monitoring

Key Sustainability Considerations

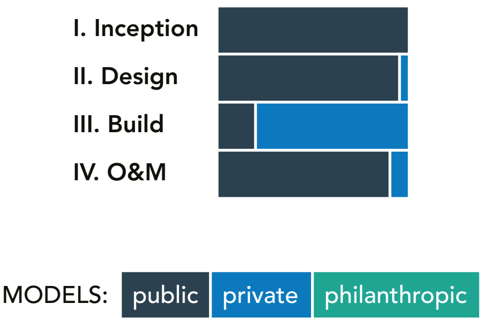
- ESCOs' trust in governments' ability to pay or access to MIGA guarantee, if necessary
- O&M and capital replacement financing beyond ESCO contract period to be clarified
- Bid competition may be limited due to uncertainty in long-term O&M planning

HYPOTHETICAL CASE #1 – PUBLIC UTILITY

The hypothetical public utility model centralizes responsibility for all aspects of off-grid electrification at public facilities within a single entity. A clear mandate and dedicated funding would drive human and financial resources. The CREDA case study comes closest to resembling this approach.

Organizational sustainability: As a government-owned entity, the public utility would work with line ministries but maintain asset ownership and responsibilities for design, supply and installation, and O&M, enlisting private contractors only to support system installation. The utility would consult with line ministries during inception and design with oversight from a utility board of directors representing line ministries and the national utility. Centralized procurement could drive down component costs. Establishment of the public utility would require support from energy ministries or equivalent authorities and national utilities that may be ceding control of electrification. Centralization of responsibilities may prove especially challenging where central governments are transferring power to local authorities and where fiscal and administrative decentralization has occurred.

FIGURE 8. PUBLIC UTILITY VISUALIZATION



Technical sustainability: Under the public utility model, government-led working groups would set service levels by facility type. Utility technicians would take over system design and procurement with an emphasis on component quality and high standards, reflecting long-term asset ownership and the utility's assumption of risk. Private contractors would provide scalable, efficient installations under utility oversight. The utility would track system performance through remote monitoring. Utility technicians would manage O&M. Early capacity building would be needed to staff the utility and set policies to promote sustainability, including incentives for innovation and efficiency. Where limited network coverage prevents remote system monitoring, local actors can help with system monitoring.

Economic sustainability: The public utility would secure total lifetime funding for projects before deployment with capital from public entities, including financing from development partners. The national budget would fund lifetime operations. Public facilities would not pay directly for energy, eliminating off-taker risk and the need for local revenue generation. Utility management and staff incentives can encourage organizational efficiency, particularly with O&M. Policies should also discourage manipulating O&M costs to inflate the budget.

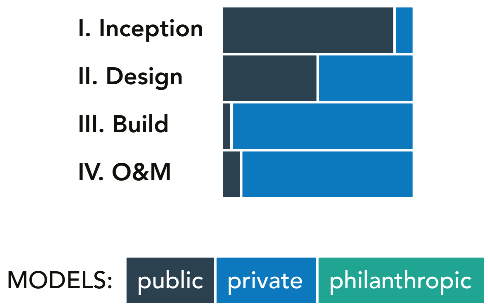
HYPOTHETICAL CASE #2 – PRIVATE CONCESSIONS

The private concessions model provides exclusive territorial rights for companies to deliver electricity for off-grid public facilities during 10- to 15-year terms. Providers receive guaranteed government payments for service delivery. The government manages the bidding process and oversees service quality. The model shares several features of the ROGEP example—including payment for service, bidders' need to bring outside financing, long-term contracts, and bundled sites for bidding and economies of scale—though importantly it diverges on some of the economic sustainability considerations.

Organizational sustainability: This model requires government oversight for bidding, contracting, and monitoring. Authorities would set minimum service levels by facility type, qualify bidders based on technical and financing capabilities, track system performance, and issue payments for electricity service. Key roles and responsibilities do not pass to local actors. Planners would need to allocate resources for O&M. They would also have to build support from national utilities and other public entities while addressing grid expansion into concession territories.

Technical sustainability: During inception and design, a government committee would perform needs assessments for public facilities and set minimum service levels by facility type. Concessionaires would handle design, procurement, and installation according to safety and performance

FIGURE 9. PRIVATE CONCESSIONS VISUALIZATION



standards. Due to the assumption of risk, the concessionaire has an incentive to invest in quality components, installation workmanship, and preventative maintenance. Companies might enlist local actors for O&M support. Requirements for O&M and quality standards are nonetheless advisable. Remote monitoring may not be feasible due to poor network coverage in some rural areas, thus requiring more resource-intensive alternatives.

Economic sustainability: Concessionaires would be required to secure funds for all capital expenditures with partial repayment after installation to buy down the cost of financing and preset incremental payments tied to service delivery. The government would secure funding upfront, minimizing risk for bidders and their investors. However, the ability and willingness of private-sector operators to pre-finance large capital expenses and accept repayment over a long time is unknown.

8. CONCLUSIONS & AREAS FOR FURTHER INVESTIGATION

This report examined a variety of delivery models, yielding a variety of individual insights for policymakers, financiers, project designers, and service providers. However, there are no universal solutions for all stakeholders in all circumstances. In examining these delivery models, the report surfaces more questions than answers. Importantly, however, it presents a framework for sustainability that may resonate with practitioners. This framework should be valuable to practitioners as they design, implement, and evaluate off-grid public facility electrification initiatives. The report's key insights, while not generalizable across every context, should also be useful to practitioners. The emerging cases showcase different approaches to tackling the sustainability challenge, in particular with distinctive ways of addressing organizational and economic considerations. On balance, the report demonstrates that there is no one-size-fits-all solution, and that each context demands a distinct approach to ensuring long term sustainability and scale.

This report identifies the following common elements, which are fundamental to sustainable off-grid energy service delivery to public facilities.

1. **Sustainability requires an all-encompassing definition of success**. Project Champion engagement and funding for O&M often follow separate timelines that do not always match the lifespan of the asset. The transfer of responsibilities from Champion to system owners and operators affect long-term sustainability, but often it is not well planned and executed. Though well-maintained PV systems can operate for 15 years or more years, project designs are setting 5- to 7-year O&M plans, at best, with no plans or incentives for further service. Project Champions and designers must design programs around the full operating potential of their assets.

2. **Sustainability demands integrated knowledge and sector-specific expertise**. Capacity building that integrates social service knowledge with electricity planning and technology is critical for sustainability and scale, especially for long-term O&M. Case studies showed a wide variety of capacity among health and education stakeholders responsible for performing or overseeing O&M. Energy professionals can specialize service for the health and education sectors to achieve scale.

3. **Sustainability requires alignment of public and private sector incentives**. Private contractor responsibilities varied from case to case but generally on providing equipment and maintenance services. Accountability, particularly related to O&M contract terms and oversight procedures, also varied dramatically. The contractor's role must include incentives for long-term engagement and oversight. Project risks and stakeholder capacity affect the types of incentives that should be created during project design. The emerging cases in this report may yield insights on incentives that promote accountability.

4. **Philanthropic models and actors can contribute to sustainability**. Philanthropists can bring a purpose and financial and human resources to these projects, but an overreliance on philanthropy may undermine sustainability. Philanthropic actors typically depend on local actors, either in the public or private sphere, to execute their impact vision. Those that do engage directly in the delivery of services do so at a small scale, piloting approaches and innovations at a limited number of sites. The challenge then becomes how to apply these learnings to structure the organizational, technical, and economic elements of the model in such a way that solutions can be rolled out to hundreds (or thousands) of sites instead of a small handful.

5. **Sustainability is enhanced when energy is a core element in facility planning**. Some cases demonstrated strong

partnerships between line ministries and the energy service providers, but public facility construction and retrofit projects should further integrate energy planning. Details on the social and economic impact of PV systems are needed to increase public funding for sustainable electricity access. Developing and deploying technical standards for off-grid electrification systems also enhances facility design. Health and education service organizations can partner with energy specialists to facilitate sustainable electricity solutions. End-user engagement provides for accurate demand forecasting and planning for the rollout of new technologies.

6. **Sustainability requires both the ability and willingness to pay for electricity**. Depending on revenue from electricity sales can threaten the sustainability of public facility off-grid PV projects. Firstly, assuming facilities will pay for electricity services or O&M associated with it is risky, particularly given that facilities frequently have very limited budgets, and are often unaccustomed to having to pay for electricity. Also, requiring facilities to develop ancillary income generating activities is difficult, given that this requires strong technical inputs, resources and accountability. Ringfencing funding from government budgets may prove most reliable, although it requires a commitment on the part of budget holders not to divert those resources away from electricity service-related expenditures.

AREAS FOR FURTHER INVESTIGATION

This report identifies several gaps in understanding and opportunities for further research, as follows.

- Data collection and assessment covering facilities with various levels of energy needs, available services, and access, including unelectrified, under-electrified, and unreliably electrified facilities.

- Assessment of site auditing tools highlighting best practices and the value of site audits. A rigorous understanding of a facility's future energy needs is critical to sustainable service delivery. Oversized systems limit scalability and drive up costs. Undersized systems fail to address facility needs and often suffer premature failure.

- Holistic policy and regulatory planning for public-facility electrification covering fiscal policy, technical standards, and enforcement.

- Analysis of installation costs and trade-offs beeen technologies, components, and system sizes with decision-making models for practitioners, such as simple system design tools and a calculator for long-term revenues and operating costs.

- Development of Key Performance Indicators for off-grid public facility electrification programs, including impact-oriented energy service, social service delivery, and resource efficiency and economy.

- Development of an environmental sustainability toolkit focused on PV system disposal and recycling, including guidelines for countries with limited access to recycling or disposal facilities.

- Development of a comprehensive guide based on the sustainability framework covering process and approach to designing for organizational, technical, and economic sustainability.

While there is substantial work left to be done by researchers and off-grid PV program designers, the case studies in this report offer a meaningful blueprint for the development and implementation of new delivery models. Stakeholders in emerging markets can lay the foundation for a significant improvement in electricity service to off-grid public facilities by aggregating many or all of the key insights that apply to operational, technical, and economic sustainability, in all phases of project lifecycle. The case studies altogether reflect a solid foundation on which practitioners can build. In future years, when researchers conduct case studies on the latest approaches to off-grid PV project development, they will likely reveal a notable evolution in sustainability and scale, with credit due to all the project Champions and line ministries, O&M providers, and other stakeholders whose work gave cause to produce this report.

ANNEX A: CASE STUDY SUMMARIES

CASE STUDY 1: INDIA — CHHATTISGARH STATE RENEWABLE ENERGY DEVELOPMENT AGENCY (CREDA)

Fact Sheet	
Implementer(s)	CREDA (Chhattisgarh State Renewable Energy Development Agency) and the Indian Ministry of Health
Location(s)	India
Project time period	Pilot in 2008; 2011 – Ongoing
Facility types targeted	Health facilities
Source of CAPEX funds	Central and State Ministry of Health Budgets
O&M model	O&M for the first five years is provided by the installer; after five years, O&M is managed by CREDA and its network of operators
Incumbent power source(s)	Grid, supplemented by diesel and UPS systems
Cost of operating incumbent power source	Considerable existing expenditures on grid electricity and, in some cases, diesel
Type of systems installed	Standalone PV Systems are customized for each health facility
Key technical specifications of systems	Systems are customized for each health facility, but all systems have 24 200 Ah/48 V batteries; energy-efficient appliances were also installed
Number of systems installed / facilities electrified	984
Services delivered via systems	LED Lighting, freezers, vaccine refrigerators, computers, centrifuges, baby warmers, fans, and microscopes
Status of installed systems	All systems are still functional, and the installation work is still ongoing
Status of O&M funding for future years	O&M funding is financed through a line item in the State's Department of Energy budget, and this budget has always been fulfilled

Organizational aspects

The Chhattisgarh National Health Mission (NHM) was aware of the severe limitations in the delivery of dependable healthcare that result from the lack of reliable electricity - one-third of the PHCs in Chhattisgarh are either un-electrified or without regular power supply. NHM became aware of CREDA's work in electrifying via solar PV power systems tribal ashrams, hostels, and schools in remote areas of the state. This fostered a collaboration, whereby NHM would identify health centers that would most benefit from the decentralized electricity and CREDA would be responsible for the full system development, installation and O&M, which CREDA contracted out to local contractors. A pilot program began in 2008 and developed into a program that since 2011 has installed more than 900 PV power systems, all of which are operational. The inter-agency collaboration is highlighted as a key strength of this program and a model for replication.

The "out-sourcing" of the PV power plants to the full responsibility of CREDA was critical to NHM's involvement in order to insulate the health centers from day to day management and O&M. CREDA's experience and expertise with renewable energy systems and the presence of technical staff throughout the state who could respond as needed was a source of confidence to NHM.

Technical aspects

CREDA's network of systems integrators install standalone PV systems in each of the selected health facilities based on CREDA's design. Though the Ministry of Health initially envisioned this as a lighting project, CREDA proposed a much more comprehensive solar electrification approach that included the installation of energy efficient appliances in addition to lighting and power. This allows the facilities to run 24/7, as required by Indian law, and even brings additional services to facilities that previously had no power. Appliances supported through the project include LED Lighting, freezers, vaccine refrigerators, computers, centrifuges, baby warmers, fans, and microscopes.

Each of the 900 systems installed to date have been customized and range in size from 2-10 kWp. Each system comes with a five-year warranty, twenty-four 200 Ah/48 V batteries, and locally sourced components. Health facilities that have grid access are also equipped with a changeover system to allow both grid and solar power access. CREDA runs a competitive bidding process to select the systems integrator and verifies the quality of installation. Ten percent of the system installer's fee is retained for five years to ensure they honor the O&M contract and warranty replacements.

After the five-year period, the systems integrator's balance is paid out, and O&M responsibility is passed on to CREDA. CREDA has a comprehensive O&M department, and one of their main activities is weekly monitoring of all systems. CREDA maintains a network of technicians that can be deployed if any issues arise. Staff members at each facility are also trained to do basic maintenance and escalate issues directly to CREDA. To date, all systems installed are still functional and CREDA credits this to the complete support and buy-in of the Ministry of Health, a focus on long term O&M, and their commitment to training and performance monitoring.

Economic aspects

The state of Chhattisgarh is heavily forested, which makes extension of the central electricity grid difficult and expensive, resulting in off-grid health facilities using diesel generators for power. A cost comparison shows that the cost of electricity from a diesel generator is about INR 24–26/kWh (USD 0.34-0.36/kWh), while using solar with battery storage costs around INR 12–14/kWh (USD 0.17-0.20/kWh). With about one-third of all primary health centers having either no electricity or unreliable power, with voltage fluctuations and power cuts, the decision to incorporate solar PV plants was made on both economic and quality health care principles.

The financial support for the PV power systems flows through the state National Health Ministry (NHM) for system procurement and installation, both of which are managed by CREDA. The health centers themselves do not contribute to the installation of the PV systems, its O&M nor pay for electricity generated on site. The budget allocations for the PV electrification program are allocated annually as a line item in the state budget and has been fully funded to date.

At the start of the program in 2011, the Ministry of New and Renewable Energy provided a 30% subsidy to the NHM, which provided the balance of the capital cost. While the subsidy has since been removed, the benefits to the health facilities were evident and the NHM decided to continue the program, funding 100% of the capital costs.

Cross-cutting aspects

The cross-sector collaboration between the NHM and CREDA is the strength of this program. The NHM prioritizes and selects the health facilities and engages CREDA to assess the facilities' power needs, size systems, including enabling a grid-interface, procure equipment and initial O&M services, and ultimately take on responsibility for long-term O&M. CREDA delivers this through a dedicated O&M cell, weekly monitoring of systems and dispersed technical staff for prompt service. CREDA is functioning like a renewable energy company, and NHM is the client.

In striving to meet the Indian Public Health Standards, the NHM prioritizes the provision of reliable energy to meet 24x7 health services. Through the partnership with CREDA, PV power plants prove to be the most efficient and economical source. Both organizations have been fully funded to date by the state to implement the program. However, the long-term sustainability of the health facilities that have received the systems could be threatened if the budget allocation to CREDA is either reduced or eliminated. Similarly, further expansion of the program through the NHM facilities (totaling about 5,000 sub-health centers, primary health centers and community health centers across the state) would be in jeopardy, as would the health of the citizens who rely on these health centers for care. Seeking multi-year budget authorizations and incorporating electricity payments into the monthly operating budgets of the health facilities could be explored to begin to mitigate these risks.

CASE STUDY 2: INDIA — SELCO FOUNDATION-KARUNA TRUST (SELCO FOUNDATION)

Fact Sheet	
Implementer(s)	Karuna Trust and SELCO Foundation
Location(s)	India
Project time period	2016 - Ongoing
Facility types targeted	Health facilities
Source of CAPEX funds	Good Energies Foundation and IKEA Foundation
O&M model	O&M services are provided by a combination of PHC staff and the staff of the contractor used for installation
Incumbent power source(s)	Grid, supplemented by diesel and UPS systems
Cost of operating incumbent power source	Considerable existing expenditures on grid electricity and, in some cases, diesel
Type of systems installed	Standalone PV Systems are customized for each health facility and a Joint Health-Energy Audit process has been pioneered to accurately size the system provided
Key technical specifications of systems	Systems are entirely customized but lead acid tubular batteries and remote monitoring software are standardly used
Number of systems installed / facilities electrified	15
Services delivered via systems	Lighting, basic office services, cold chain, maternal health services, dental care, eye care, and laboratory services
Status of installed systems	All systems are currently functional; there have been no major maintenance issues to date
Status of O&M funding for future years	O&M costs are budgeted, and the first year of O&M was included in the project budget, and financing is secured for the immediate future through government funding via the ARS/RKS

Organizational aspects

Karuna Trust (KT) is a public charity, with a primary focus on healthcare. The Trust operates through a public private partnership model, with direct management of more than 90 PHCs in 5 states in India. KT was approached by SELCO Foundation, a public charitable trust that advances integrated sustainable energy-development solutions, to develop a program that would prove the viability and impact of decentralized, alternative energy as the power source for PHCs. The synergies of mission and vision between KT and SELCO Foundation provides a strong foundation for this collaboration, with both organizations targeting intersectoral holistic solutions for the underserved and the poor in remote areas of India.

In the early PHC projects, selected from the KT PHCs, SELCO Foundation facilitated the energy audits, which were undertaken by local solar companies that had been incubated through the Foundation's programs; these companies installed the systems and initially provided the O&M. This has evolved to a responsibility of the local Arogya Raksha Samiti (ARS)/Rogi Kalyan Samithi (RKS) management committee, comprised of local Panchayat Raj Institutions (PRIs), government and civil society representatives who have public health responsibilities, and are government funded. A core characteristic of the KT model is the ownership of O&M responsibilities by each PHC, delineated through an MOU between the ARS and the installation company. KT integrates energy system training with health skills training provided to PHCs via its mobile training unit. Goal is to demystify energy as a component of the PHCs.

Technical aspects

Karuna Trust and SELCO Foundation have pioneered a joint health and energy audit process to determine the specifications of each installed system. The process takes into account traditional energy audit information like space, building material, daily loads, and incumbent energy sources, but it also pays attention to health specific functions such as footfall, HR needs, and health services. Most of the PHCs are using a combination of grid, diesel generators, and UPS prior to the installation of the PV system and experience regular power cuts. This is especially difficult when PHCs are expected to operate 24*7.

For the pilot projects, SELCO Foundation runs a comprehensive bidding process for each of the PHCs, and all selected solar companies doing the installation and O&M have received certification from SELCO Foundation's training program. This ensures a quality bidding process and a more reliable installation. The PV systems are completely customized based on the outcome of the health-energy audits and utilize components approved by the Ministry of Renewable Energy, including lead acid tubular batteries, and real time data loggers. Energy efficient lighting and cold chain appliances are also furnished. Each installation comes with a 5-year warranty and two annual maintenance visits.

The solar companies initially handle O&M, but the solar companies also train the PHC staff to handle basic O&M processes. The PHC (ARS) then signs a MOU with the solar company to provide O&M in the long term.

KT felt strongly that PHCs, as the owners of the PV systems, should have a role in their long-term operation, so they have separately launched a solar health technician program to empower and train PHC staff. The project is still quite young, but both SELCO Foundation and KT feel that their focus on sound design, energy efficiency, and sustainable, long-term O&M will lead to long-term project success.

Cross-cutting aspects

The integration of improved health and sustainable energy drives the project design from the start. The sponsors, KT and SELCO Foundation, address the dual drivers from the initial PHC facility health-energy audit, through to the delivery of PHC training. This has also fostered a partnership on the on-going R&D of energy efficient medical equipment, e.g., a neo natal resuscitation center and solar powered ambulatory vehicles. The involvement of the PHC committee (ARS/RKS) has been central to the implementation, management and O&M of the PHC PV power systems, and a core underlying philosophy is the on-going financial requirement of the PHC committee, through their funding of on-going O&M and contracting of services.

This is a pilot effort and while KT and SELCO Foundation are designing a 10-year, integrated PHC and community decentralized electrification program, there is acknowledgement that the upfront PHC CAPEX costs will need to be funded via government, which aligns with the KT model of public-private partnership. The partners are well positioned to advocate for government funding. Until such a government program is implemented, scale up will be dependent on philanthropic grant funds.

The local PHC ownership of O&M is dependent on the continuing receipt of NRHM and state funding, as well as the agreement to allocate such funding to the PHC O&M costs. The improved health care delivery enabled because of the PV power system will be a critical motivator for that budgetary allocation, and the initial 2-year O&M provision included in the overall project funding facilitates that system demonstration.

Economic aspects

The KT model has developed through the application of private foundation funding for the CAPEX, while O&M funding has been through primarily local government sources, either through the KT or via the local ARS/RKS committees. For the 6 PHC pilots, SELCO Foundation facilitated funding from the Good Energies Foundation and the IKEA Foundation for the energy audits and installation of the equipment as well as the first two-years of the O&M. The inclusion of the O&M funds allows confidence that the PHC power system will be operating, demonstrating to the PHC Committee the value of the 24*7 power supply and reinforcing the rationale for allocating budget to the O&M requirements.

It is recognized that the scalability of the KT approach is dependent on continued funding from philanthropic sources or a defined government program, which could include a World Bank funding line, for the CAPEX components of the PV power systems. The project sponsors are advocating for such dedicated funding streams, as well as integration of quality standards and systems guidelines in the National Rural Health Mission policy.

The first two years of O&M are included in the project grant funding, after which, O&M (including battery replacement) is funded through the local ARS/RKS committees, through an MOU between the ARS/RKS committees and the installation companies. An economic analysis was undertaken on incumbent power, including back-up UPS for those PHCs on-grid, which evidenced cost efficiency of the O&M and running costs of the PV solar power systems. The CAPEX was not a component of the cost comparisons.

CASE STUDY 3: MALAWI — COMMUNITY ENERGY DEVELOPMENT PROGRAMME UNDER THE MALAWI RENEWABLE ENERGY ACCELERATION PROGRAMME (CEDP)

Fact Sheet	
Implementer(s)	University of Strathclyde
Location(s)	Malawi
Project time period	Program timeframe of 2012-2015, with the bulk of installations occurring in 2014
Facility types targeted	Predominantly schools (including staff houses) but also one health facility
Source of CAPEX funds	The Scottish Government
O&M model	The facility, with the support of a selected community-based organization takes O&M responsibility and manages revenue-generation activity to fund O&M needs
Incumbent power source(s)	Typically candles and battery-powered torches, supplied by the facility or students/patients
Cost of operating incumbent power source	Variable, but relatively high given quality of service provided
Type of systems installed	On average, nine smaller standalone PV systems per facility, with three rooms lit per system
Key technical specifications of systems	Typically DC with 200 Wp of PV per system / 1.7 kWp per facility, and 240 Ah of 12V SLA batteries per system / 2,100 Ah per facility; remote monitoring capability via GSM and wireless connection between standalone systems
Number of systems installed / facilities electrified	Systems installed at 21 primary schools, 4 secondary schools, and 1 health clinic
Services delivered via systems	Lighting and mobile phone charging (in most cases)
Status of installed systems	All systems were functional at the end of 2016; more up-to-date figures not available as remote monitoring systems no longer have active data plans
Status of O&M funding for future years	Facility and community expected to cover O&M costs via revenue-generating activity

Organizational aspects

The University of Strathclyde (UOS) has, for nearly a decade, been active in the electrification of public facilities in Malawi. The Community Energy Development Programme (CEDP), launched in 2012 under the broader Malawi Renewable Energy Acceleration Programme (MREAP), aimed to improve on the earlier Community Rural Electrification & Development Project (CRED). Under CEDP, approximately 225 standalone PV systems were installed at 21 primary schools, four secondary schools, and one health clinic, predominantly in 2014.

The CEDP organizational model revolved around the selection of a community-based organization (CBO) as a champion for systems and their upkeep, funded by revenue-generating activities. Selected CBOs would have an existing interface with the local community, with AIDS-prevention organizations proving common partners. The idea was for the CBO to make all project decisions following installation of the systems, including designing and managing the revenue-generation schemes and an associated bank account, as well as all decisions and payments related to O&M of the system.

Following installation of the systems, UOS moved to an oversight role, and ended up supporting the establishment of Community Energy Malawi (CEM), whose development officers (DOs) were armed with a toolkit that provided operators with guidance on O&M, and who had the task of providing ongoing training and support to CBOs. Overall, the model emphasized broad stakeholder engagement and sensitization, with evidence that stakeholders meet at least every two months. Beyond the CBO, UOS recruited local groups (e.g., the school PTA, local leadership, and other CBOs) to support the project and help it meet its objectives.

Technical aspects

Under CEDP, the service delivery targets for new systems varied from location to location but always included lighting and charging for core facilities and staff houses. While a full needs assessment was almost always completed, a UOS sustainability study completed in 2017 determined that systems (and particularly batteries) tended to be undersized, with installation of the PV systems themselves significantly changing the behavioral patterns and associated energy use of the beneficiaries.

CEDP installations typically comprised nine standalone PV systems per facility, with three rooms lit per system, for an average total of 1.7 kWp of PV and 2,100 Ah of 12V SLA batteries. An innovative, custom-built remote monitoring system using the Zigby protocol allowed for communication between multiple systems at a single facility, which sent data to a single GSM-enabled hub. In addition to logging data for research purposes, the system was designed to alert the local DO via text message when problems were detected. They could then contact the relevant CBO or facility head directly.

With regards to quality control, CEDP experienced considerable divergence between the quality of system components procured and that of the installation and O&M work itself. For procurement, by relying on local capacity, corners were often cut resulting in use of low-quality components with little to no warranty. This is thought to have had a direct impact on system sustainability by reducing battery and charge controller expected lifetimes. However, for installation and O&M activities, only contractors accredited the Malawian Energy Regulatory Authority (MERA), were hired, and MERA itself conducted post-installation inspections. As such, issues related to contractor quality were mitigated.

Economic aspects

While installations under CEDP were fully funded by the Scottish Government, the UOS target was for economic self-sufficiency of systems once operational. The plan was to achieve this by encouraging the CBO to engage in income-generating activities at facilities within six months of installation, with the goal of raising funds to cover O&M costs, including component replacement. This was considered particularly critical given that, at inception, the CEDP was only funded through 2015, i.e., for just one year beyond when most installations would occur.

Like other micro-enterprise models, there was a gravitation towards barbershop and mobile-phone-charging services. And, indeed, these services proved to generate the largest monthly revenues, averaging USD 91 and USD 74 per month. Lantern rental and sales schemes were also piloted but generated less revenue and actually cannibalized income from mobile charging activities, since clients could also use the lanterns to charge phones.

Compared to other public-facility off-grid electrification projects in Malawi, CEDP installations have proven to have far superior economic self-sufficiency, with overall net income at facilities averaging over USD 500 per annum vs. the norm of, at best, break-even. However, while enough to cover basic O&M expenditures, no CEDP sites are generating sufficient income to be fully sustainable in the long run, i.e., able to cover the replacement of the most expensive, short-lifetime components such as the lead-acid batteries. Of note, following the closing of the project, an additional ongoing cost was eliminated with the suspension of the data-intensive remote monitoring feed. While the benefits of such systems are often cherished by implementers, they too risk falling foul of limited funding.

Cross-cutting aspects

The CEDP, in key ways, has shown that thoughtful organizational processes and local stakeholder engagement can improve PV system sustainability outcomes at public facilities. In particular, the success of the income generating activities vis a vis similar projects is notable. Also, the establishment of CEM, to support facility managers during and beyond the life of the project, was prescient. That said, it should be noted that without dedicated funding, operations at the latter would immediately be jeopardized.

In spite of these key successes, parties involved with the CEDP were quick to point out that there has been no silver-bullet project under the program and that instilling discipline in revenue generation—while important—is not likely to be enough when installations are large. As such, programs could consider 'starting small', expanding systems once the ability to save for future investments is proven. Similarly, slowing down the overall process, could allow better stock-taking of existing local skillsets as well as those that need to be developed to help troubleshoot and maintain a larger system, and run a profitable solar-powered business.

An additional risk arises from having key facility staff in decision-making roles regarding the PV system and/or associated income-generating activities. Not only can it distract them from their core responsibilities, be it teach or tending to patients, but it can result in revenues being diverted to core operational costs of the facility rather than upkeep of the PV system. Such outcomes may be avoidable through more careful allocation of responsibilities amongst stakeholders, but will likely remain an issue while schools and health facilities remain heavily underfunded.

CASE STUDY 4: MALAWI, TANZANIA, UGANDA — INNOVATION AFRICA (IA)

Fact Sheet	
Implementer(s)	Innovation Africa
Location(s)	10 Sub-Saharan African countries, but predominantly Uganda, Malawi, and Tanzania
Project time period	2008 – Ongoing
Facility types targeted	Health centers and schools, including staff houses for each
Source of CAPEX funds	Private donations from individuals and organizations, including foundations
O&M model	The facility, with the support of a community committee takes O&M responsibility and manages revenue generation activity to fund O&M activities; IA provides backstop funds
Incumbent power source(s)	Typically kerosene, candles, and battery-powered torches, with students and patients often bringing their own; vaccine refrigerators running on kerosene/gas
Cost of operating incumbent power source	Relatively high cost given quality of service, but with burden often on beneficiaries; at health facilities, fuel supply for vaccine refrigerators was often unreliable
Type of systems installed	Single centralized PV system at facilities, but typically with separate systems for staff houses
Key technical specifications of systems	Systems are usually DC with 400Wp of PV and 400Ah of 12V SLA AGM batteries; staff houses get 100 Wp of PV and 100Ah battery; remote monitoring at all systems installed over past three years
Number of systems installed / facilities electrified	Systems installed at 50 health centers and 60 schools and orphanages
Services delivered via systems	At health centers, lighting and vaccine refrigeration; at schools, lighting and sometimes power for computers
Status of installed systems	Approximately 85% of systems with remote monitoring currently functional vs. ~70% of older systems without remote monitoring; non-functional systems are typically awaiting battery replacement
Status of O&M funding for future years	Facility and community expected to cover O&M costs via revenue-generating activity

Organizational aspects

Innovation Africa (IA) is an Israeli NGO focused on leveraging solar power to improve service delivery in rural African villages. Their model leans heavily on community engagement and sensitization, with both system ownership and O&M responsibilities transferred to the community following installation. Further to this emphasis on 'local buy-in', IA deploys a micro-enterprise model whereby a small electricity-powered business (e.g., phone charging, barbershop, photocopying, etc.) generates revenues to fund O&M activity, including component replacement.

In the early stages, IA's in-country team works with local partners (e.g., the local district health officer) to identify and assess facilities that meet their criteria. If the decision is made to proceed with an installation, the key step is the creation of a community-elected committee, typically composed of representatives from the elders, women's groups, the school, and the health facility. This committee is given considerable autonomy, and has responsibilities including creation and management of the micro-enterprises and associated revenues, selection of locals to be trained in basic O&M during the installation, and—critically—coordination of all O&M, including component replacement.

Up to and during installation by the IA technicians, considerable sensitization work is done to ensure there's a rapport with the community and the committee, who then understand that they can leverage IA experts as O&M issues arise. That said, if systems fail, the committee is responsible for both summoning and paying for a contractor and any new system components out of the dedicated account's funds. While they are not prescriptive, IA maintains oversight over these processes and the bank account, and act as a back-stop in the event that major issues arise.

Technical aspects

Innovation: Africa has been installing modest PV systems at health centers since 2008, with the technical processes employed largely unchanged but system designs evolving. The IA technicians do not conduct a full energy needs assessment, instead offering a standard system package that is adjusted based on the number of rooms to be served with lighting, and whether a health center's vaccine refrigerator or school's computer lab will be powered.

Over the past few years, they have moved towards installing DC-only systems with typically 400Wp of PV and 400Ah of 12V sealed lead-acid gel batteries, with components stored in custom-built metal cages. Meanwhile, staff houses get their own 100 Wp PV systems with a 100Ah battery. Notably, GSM-enabled remote monitoring hardware has been installed at all systems deployed over past three years (approximately 40% of all systems), allowing real-time system assessment.

Procurement is done locally by the IA country team, with oversight from HQ. The primary upsides of this approach are that it helps avoid importation bottlenecks and eases engagement with local O&M contractors, who are more familiar with locally-sourced components. However, it makes quality control considerably more challenging, with low-quality components occasionally being employed.

The deployment of remote monitoring hardware has considerably eased delays and challenges in troubleshooting systems, as it allows the IA team to remotely identify issues and work with the trained locals to remedy them. However, it can do little to address the technical 'elephant in the room': the 2-2.5-year lifetime of SLA batteries, whose failures account for the majority of downtime.

Economic aspects

To date, the Innovation Africa economic model has leveraged private donations from individuals and organizations to fund system CAPEX and overheads, with the responsibility for O&M funding placed on the local community, with revenues generated through a micro-enterprise powered by the facility's PV system—typically a phone-charging business or barbershop.

This micro-enterprise model is often considered favorable to the more traditional approach of expecting government funds to cover O&M costs because it engenders local buy-in and the facility is not held hostage to government budgets.

Historically, the funds raised from these micro-enterprises were sufficient to cover all O&M expenses, including component replacement (namely light bulbs and batteries). However, over the last couple of years, as the prices of solar PV panels and other components have dropped precipitously, IA has witnessed a significant decline in the amount of revenues being generated by the facility micro-enterprises. This is as a result of competition from other entrepreneurs, resulting in reduced demand for the micro-enterprises' services and/or the need to offer lower prices.

In most case, micro-enterprise funds are now no longer enough to cover the full cost of long-term O&M, with battery replacement costs proving particularly unaffordable. As such, IA has been forced to step in and cover shortfalls themselves. However, as internal funds are limited, immediate replacement of batteries and other components is not possible, resulting in a considerable share of downtime, particularly at facilities with older systems

Cross-cutting aspects

The strengths of Innovation Africa's approach span organizational, technical, and economic pillars, namely through: an emphasis on strong community engagement, including training and building stakeholder interest in long-term system sustainability; the deployment of remote monitoring technology to facilitate system troubleshooting and limit downtime; and local revenue generation to reduce reliance on outside sources of funds.

When considering the struggle their facilities now face against system downtime, the IA team was able to pinpoint two root causes: the erosion of the revenue-generation potential of micro-enterprises and the persistently low reliability of key system components, particularly lead-acid batteries. Remedying the former, while feasible, is likely to be challenging and could vary from one district to another. Instead, IA is moving to overhaul its technical solution in a bid to improve reliability and reduce O&M costs.

The IA engineering team has developed a new offering dubbed the 'energy box', an all-in-one solution housing core system components, notably employing a lithium-ion battery and other high-quality components. Under this approach, only the solar PV panels will need to be sourced separately, thereby greatly standardizing system quality. By also bundling long-life, energy-efficient LEDs, the expectation is that these new systems will be able to operate 6-10 years with only light-touch maintenance. By investing more heavily in quality—the energy box CAPEX is expected to be 140% of traditional systems—costs are being moved upfront. In turn, this delays the need for component replacement and gives the micro-enterprises more time to raise funds for such eventualities.

CASE STUDY 5: PHILIPPINES — SUSTAINABLE SOLAR MARKET PACKAGES (SSMP)

Fact Sheet	
Implementer(s)	Government of Philippines
Location(s)	Philippines
Project time period	2003-2012
Facility types targeted	Health facilities and schools
Source of CAPEX funds	Government (including World Bank financing), Private Funds, and Local Government Funds
O&M model	O&M services provided by the SSMP contractor; local community assumes responsibility after a period of five years
Incumbent power source(s)	A mix of un-electrified facilities, diesel generators, car batteries, etc.
Cost of operating incumbent power source	Varied considerably by source
Type of systems installed	Standalone PV systems
Key technical specifications of systems	Battery Type: Modified SLI, deep-cycle and tubular plate flooded lead acid batteries
System Sizing: Small DC-bus system providing 12 V DC electricity for lighting and 220 - 240 V AC electricity for energy efficient appliances	Systems installed at 21 primary schools, 4 secondary schools, and 1 health clinic
Number of systems installed / facilities electrified	2,083 (as of 2010)
Services delivered via systems	Lighting, basic office services, basic medical services, basic education equipment
Status of installed systems	Maintenance issues varied by area but included challenges with batteries, parts replacement, and long-term O&M service provision by the SSMP Contractor. Local Government authorities were given training in 2011 as part of the public facilities handover process
Status of O&M funding for future years	O&M funding for five years was allocated through the project, but post-project O&M financing was to be sourced by the Local Government upon project completion

Organizational aspects

The World Bank in partnership with the Government of the Philippines (GOP) launched the Rural Power Project in 2003. The Department of Energy and Development Bank of the Philippines were the two implementing partners. The project introduced the Sustainable Solar Market Packages (SSMP) model for the first time in 2005 as a way to provide sustainable electrification to un-electrified barangays (communities) and help the Philippines achieve its goal of 100% electrification.

These market packages consisted of a bundled group of barangays that the successful private-sector bidder would need to provide with both solar home systems for domestic use as well as the electrification and maintenance of pre-identified public facilities, including schools, health facilities, and meeting halls. Financing for the electrification of public facilities would come from a mix of national government support, donor funds, and local government financing, while individual households were expected to finance their own solar home systems, either through cash or credit.

Each package had specific requirements for the types and size of PV systems that should be installed in the public facilities along with a minimum sales target for residential solar home systems. The successful bidder was expected to do the installations and provide O&M for five years before transitioning this responsibility to the local community and local government.

Though a great deal of emphasis was placed on planning and design, several key issues made the project difficult to implement. These issues include the community's disinterest and distrust in solar (they saw it as an inferior and unreliable form of electrification), the inability of SSMP contractors to provide long-term O&M services in these hard to reach areas, and the long-term sustainability of the SSMP contractors.

Technical aspects

Each public facility identified in the bidding documents came with specifications for the standalone PV system and appliances that should be installed in it. The PV systems were expected to provide lighting and basic office services and any other services indicated in the bidding documents. These specifications were based on a rapid rural appraisal completed in each barangay and their existing services as well as high-priority needs like water pumping and electrification of staff housing. In most cases, the facilities did not have an incumbent source of power besides some diesel generators or car batteries. All identified areas were unreachable through grid extension or mini-grid options, leaving only solar systems.

All PV systems had to meet international standards for components, and a list of viable product parts was included in the bidding documents along with detailed specifications for maintenance and training. The package of bidding materials even included a sample maintenance schedule and template for an O&M manual and routine visit records. Successful bidders were expected to set up a service center in each service area, so that spare parts and maintenance were easily accessible. There was a five-year warranty for the system. The bidding process was hands-on to make installation and implementation as effective as possible. The SSMP contractor was expected to provide O&M for a five-year period before passing off O&M responsibilities to the local government and local community, however, many of the contractors failed to fulfill this obligation, because they lacked the staffing, financing, and interest to maintain local presence, and insecurity due to remote location. This led to project implementers partnering with local energy cooperatives over the private sector.

Economic aspects

This project brought together a diversity of funding sources from the World Bank, local and national government, and private donors. Project implementers felt that the diversity of funding sources would ultimately ensure the long-term sustainability of the installations. The World Bank contributed funds along with funds from the Global Environment Facility.

The budgeting for each installation took into consideration the function of the facility, services that would attract talent to work at the facility (like pumped water or electricity in the staff housing space), quality components, and five year's warranty and O&M. More than ten percent of the capex costs was budgeted for O&M. Feasibility studies were conducted, but individual PV systems were the only energy source considered, as the installation of diesel generators, mini-grids, or grid was not practical or feasible given the remote locations.

Despite the emphasis on quality and sustainability in the design, both the government and SSMP contractors underestimated the financing required to support the project. The government did not have enough financing to provide long term capacity building and supervision over contractors or to hire adequate staff to manage the project, and payments to contractors were sometimes delayed. The contractors were disinterested in providing long term O&M, and project incentives (and supervision) were not strong enough to encourage them to focus resources on this. Maintenance costs were also especially high given the insecurity in some barangays, regular political turnover, remoteness of the locations, and poor economies of the barangays. Finally, a private fund that originally committed funds had their budget cut and had to reduce their contribution.

Cross-cutting aspects

The SSMP model was a pioneering approach for its time- bringing together a diveristy of funders, engaging the private sector, and focusing its design on long term sustainability. The project helped to train and develop local solar installation and maintenance capacity, electrified thousands of community buildings, and promulgated the use of solar as part of an integrated electrification strategy. However, despite the novelty of design, a number of challenges surfaced throughout the project implementation period. Issues included:

- Area selection: All areas were remote, poor, and insecure, which made it difficult for outsiders to operate and the costs of O&M extremely high
- Contractor Quality: Though payment milestones for contractors were tied to service delivery, companies did not deliver on installation, O&M, and after sales care
- Competitiveness of the Bidding Process: Despite holding workshops for potential contractors, only a few applications were received, and one company won the majority of lots
- Project Planning: Though the GOP was very bought into the model, there was a very short timeline for planning and implementation and shortsightedness on project budgeting, making contractors distrustful about payment upon service delivery
- Reputation of Solar: Solar was seen as inferior to the grid and many politicians promised to delivery grid access; the government failed to suppress these promises and adequately educate communities on the quality of energy that could be provided through PV system.

CASE STUDY 6: UGANDA — ENERGY FOR RURAL TRANSFORMATION – II (ERT-II)

Fact Sheet	
Implementer(s)	Government of Uganda (Ministry of Health and Ministry of Education and Sports for health- and school-related activities)
Location(s)	Uganda
Project time period	2008-2016
Facility types targeted	Health facilities and schools
Source of CAPEX funds	The World Bank
O&M model	System installers signed back-to-back maintenance-only contracts for year 1 and then years 2-5. GoU responsible for O&M beyond year 5 except when contracts are extended
Incumbent power source(s)	Typically, kerosene for lighting and LPG/kerosene for vaccine refrigerators (at health centers). A small share of facilities had diesel generators
Cost of operating incumbent power source	High variance in cost depending on power/lighting source employed, with a similar variance in how the cost burden is borne (facilities, patients/students, etc.)
Type of systems installed	Mostly standalone PV systems sized in accordance with assessed energy needs
Key technical specifications of systems	30 different AC solar energy packages ranging from 75Wp of PV with a 100 Ah 12V SLA battery to 1,280 Wp with a 1,500 Ah 24V battery system; most installs were 100-400Wp of PV
Number of systems installed / facilities electrified	560 schools (including 60 computer labs) and 522 health centers electrified
Services delivered via systems	For schools: lighting, basic device charging, and sometimes computers. For health centers, lighting, refrigeration, lab and AV equipment
Status of installed systems	In mid-2018, 87% of health -facility systems were still functional; at schools, batteries have begun failing en masse; lack of remote monitoring hardware limits visibility
Status of O&M funding for future years	O&M costs are neither budgeted nor secured for the future

Organizational aspects

The Energy for Rural Transformation (ERT) program is an initiative implemented by the Government of Uganda (GoU) with funding and technical assistance from the World Bank. It was launched in 2003 and targets the improvement of incomes and quality of lives in rural areas. Since its first phase, the program has leveraged off-grid solar solutions to electrify health facilities and schools. The second phase of the program (ERT-II) ran from 2008 through 2016, with 560 schools (including 60 computer labs) and 522 health centers electrified, exceeding initial program targets.

The ERT-II public-facility electrification model put the bulk of decision-making and management responsibilities in the hands of the relevant line ministries—the Ministry of Health (MoH) for health facilities and the Ministry of Education and Sports (MoES) for schools. Both ministries adopted similar strategies during the design and build and early O&M phases of the program. Namely, eligible private contractors bid on lots of facilities, organized by geography, with winners signing contracts to supply, install, and maintain prescribed PV systems for a period of one year. Separate extended maintenance contracts were signed covering years 2-5 of operation. However—and critically—these contracts are 'maintenance only' and do not cover component replacement.

O&M has occurred relatively smoothly to date, but the question of O&M responsibility now looms large as contracts begin to expire. Ownership of the PV systems was transferred to the district governments following installation, but they have yet to assume O&M responsibility. MoH and MoES continue to handle ongpoing O&M responsibility, concerned district governments have neither the human nor financial capacity to assume this responsibility

Technical aspects

The public-facility electrification activities under ERT-II were planned and rolled out in a relatively structured manner. Clear siting criteria were employed that prioritized high-impact facilities that were unlikely to receive electricity in the medium term due to their distance from existing grid infrastructure. For health facilities, this meant prioritizing HC-IVs (larger facilities with operating theaters), HC-IIIs (which offer maternity service), and the subset of HC-IIs that perform emergency deliveries. For schools, post-primary educational facilities were prioritized, with only 30 primary schools electrified under ERT-II.

MoH and MoES hired consulting firms to assess typical facility needs and design a collection of 'solar energy packages' (SEPs) for different applications, including staff houses. All SEPs were designed to provide lighting and charging, while some were tailored to more specific uses, including refrigeration, ICT, etc. Schools were assigned systems from a set of five SEPs ranging from 110-660Wp, while health centers each received a more fine-tuned offering from a set of 25 SEPs, ranging from 75-1,280Wp. While these sizing efforts were consistent, there is a general consensus that systems are undersized and overloaded due primarily to unplanned load growth—which remains challenging to account for.

While the procurement process employed defined minimum system specifications and quality standards, winning bidders were allowed to procure and install components of their choice as long as they met or exceeded these requirements. In reality, due to limited government capacity, sub-par components we sometimes accepted, which has impacted system reliability. More critically still, deep cycling requirements for batteries were not stringent enough, resulting in early failure in some cases.

Economic aspects

The World Bank provided the funds for system CAPEX (as well as the first year of O&M) for all ERT-II installations. The bulk procurement process employed and the flexibility offered to winning bidders likely limited upfront costs and helped meet installation targets. However, after year one, with the line ministries assuming responsibility for all additional costs related to O&M, including component replacement, serious questions are being asked about the adequacy of project design and budgeting.
By signing four-year maintenance contract extensions upfront, the government likely minimized costs associated with routine maintenance and call-outs. In addition to the benefits from competition and economies of scale, it gave the ministries clarity over budget requirements for maintenance activities in the initial years of the project. However, overlooking the sizeable economic cost of component replacement (particularly batteries) has jeopardized the functionality of many of the installed systems.

The lack of a component-replacement plan and associated budget, either embedded in the O&M contracts or otherwise, has indeed led to increasing downtime, particularly at schools. MoES was able to contract for the replacement of batteries at 64 schools, and a further 107 will see replacements in 2019. However, this accounts for just a quarter of schools. MoH has also begun to replace components at its facilities, but with a mid-2017 study showing that 25% of batteries are already failing, the cost of doing so may prove prohibitive. It is little wonder that both ministries are uncomfortable hastening the transfer of O&M responsibility to district governments, given that it would perhaps further threaten the economic sustainability of installed systems.

Cross-cutting aspects

ERT-II has, in many ways, proven the workability of longer-term private-sector-led O&M contracts while further highlighting the perennial challenges facing the majority of public-facility electrification programs, namely devolution of system ownership and responsibility, and sufficient budgeting for O&M, including component replacement.

A potential solution seen as desirable by the implementers is to include the cost of component replacement in O&M contracts. This ensures that the service provider has real skin in the game, since premature failure of equipment comes at a direct cost to them. Moreover, the complicated logistics related to the stocking and dispersal of spare parts can be transferred to entities better able to deal with them. Such models also work better under programs where centralized systems with remote monitoring are deployed. Such systems are typically more resilient, since it's easier to focus on the quality of components, and to protect them from theft and vandalism in a single, central area. And remote monitoring systems allow the government to hold contractors accountable for downtime.
Such a solution could take significant pressure off of district governments, which are currently not well prepared to assume O&M responsibilities for systems. Either way, better engagement with the districts during project design and rollout is critical, as is incorporating a capacity-building component in future projects. It may also make sense to encourage districts to employ well-trained technicians to conduct troubleshooting and M&E activities while private O&M contracts are active, and to provide a back-stop if they lapse. This would help future-proof systems, including by simply sensitizing districts to the importance of long-term sustainability of public-facility electrification assets.

CASE STUDY 7: ZIMBABWE — SOLAR FOR HEALTH (S4H)

Fact Sheet	
Implementer(s)	Government of Zimbabwe
Location(s)	Zimbabwe
Project time period	2015 – Ongoing
Facility types targeted	Health facilities (including district hospitals, polyclinics, and primary clinics)
Source of CAPEX funds	The Global Fund to Fight AIDS, Tuberculosis and Malaria
O&M model	One-year warranty provided by installers; Department of Public Works within Ministry of Local Government, Public Works and National Housing responsible for O&M thereafter
Incumbent power source(s)	Grid electricity in 99% of cases (400 out of 405), with generators, candles, and other sources as backups
Cost of operating incumbent power source	Grid electricity prices paid by health centers are not specifically subsidized; power bills were thus non-negligible and paid out of facility budgets
Type of systems installed	Centralized, grid-tied AC systems with battery back-up
Key technical specifications of systems	Relatively large PV systems of 5, 7, 10, and 40 kWp depending on facility type and needs; assortment of VRLA battery types deployed (24-150 kWh); remote monitoring hardware installed but only active at 48 sites; progress is underway to ensure all sites are covered
Number of systems installed / facilities electrified	405 systems installed over two phases (156 in 2017 and 249 in 2018)
Services delivered via systems	In addition to basic needs, phase 1 targeted supporting cold chain needs (medicine and lab reagents); phase 2 included facilities with health information offices and maternity wards
Status of installed systems	All systems are less than two years old, and most are still under warranty, therefore functionality levels are high
Status of O&M funding for future years	A consultant has been identified and recommend to carry out a feasibility study and sustainability plan, which is expected to be adopted by the end of 2019
Status of O&M funding for future years	O&M funding for five years was allocated through the project, but post-project O&M financing was to be sourced by the Local Government upon project completion

Organizational aspects

The Solar for Health (S4H) program is a multi-country initiative of the United Nations Development Program (UNDP) which supports governments in increasing access to quality health services through the installation of solar PV systems. In Zimbabwe, significant grid reliability issues in 2015 disrupted the pharmaceuticals cold chain as well as the operations of labs at a large swathe of the country's approximately 1,700 health facilities. In response, UNDP approached the Global Fund to Fight AIDS, Tuberculosis and Malaria for funding to install PV-battery back-up systems at 156 of the most negatively-impacted facilities in 2017. A later round of funding allowed a further 256 facilities to be electrified, namely those with health information offices that have significant ICT power needs and a functional maternity ward.
The S4H model in Zimbabwe required the UNDP team to work closely with the Ministry of Health (MoH) and Department of Public Works (DPW)—housed within the Ministry of Local Government, Public Works, and National Housing. Together, UNDP, MoH, and DPW performed site assessments and mapped PV-battery packages to identified facilities. Large, international tenders then assured considerable economies of scale in procurement and installation activities. The winning bidders were international firms partnering with local contractors.

One-year post-installation warranties have been provided by contractors. Longer-term O&M plans remain outstanding. UNDP is preparing to conduct a multi-country feasibility study focused on sustainability in early 2019 to address this. In the meantime, health facility staff can leverage DPW for O&M, as they would with any other technical faults at their buildings. The process for facilitating or paying for component replacements will be resolved in the longer term O&M plan.

Technical aspects

The solar and battery systems installed under the S4H program are relatively large, centralized designs ranging from 5 to 40 kWp of PV capacity. Over 80 percent of facilities were assigned 5 or 10 kWp systems, with just 27 of the largest receiving more than 10 kWp installed. All but five of the facilities already had grid access, meaning that, in almost all cases, the systems serve as the primary source of energy, with grid power acting as a backup.

A question of efficiency is raised given the current rules against feeding PV power into the grid. While a feed-in option is currently being considered, one might expect at the project design phase that this constraint, whereby grid power can be used to charge batteries but excess power from the PV system cannot be fed into the grid, would have led to a relative over-sizing of battery systems relative to PV arrays. However, for the lots in Phase I and IIa, the autonomy of battery systems ranged from 0.5 to 1 day. During Phase IIb, systems with battery autonomy of 3 days were deployed. A total of 48 sites have had Remote Monitoring Systems installed and progress is underway to ensure that all the sites are covered given that the MOHCC has allowed the system to use the cloud for transmission of the data collected by the system.

Economic aspects

Installations under S4H in Zimbabwe were funded by the Global Fund to Fight AIDS, Tuberculosis and Malaria, hence the initial focus on cold chain preservation. Following expiry of the one-year contractor warranty period, O&M responsibilities pass to the Department of Public Works, with MoH responsible for major CAPEX costs, including core component replacement.

Given that nearly 3.7 MW of solar PV was installed in Zimbabwe under the S4H program through just four major lots, and that the average installation was 9 kWp, considerable economics of scale were achieved. Installed cost was a relatively low USD 3/Wp.

With nearly all the recipient facilities having previously been grid connected, there are reports that some of the larger facilities are saving hundreds of dollars per month on their electricity bills. Even a small facility, if using its system efficiently could save nearly USD 100 per month on its bills. That said, national regulations set limits on feeding in power to the grid. A framework to pervvmit PV power exports to the grid from these facilities could channel savings into an O&M fund, either at a facility level or more broadly. In the absence of a framework for power export and savings dedicated for O&M, the beneficiaries of additional funding from any electricity bill savings are yet to be determined. The forthcoming feasibility study is expected to assess savings and expenses related to the solar systems and to develop financial models for sustainability. One idea is to set up a revolving fund to help pay for component replacements in future.

Cross-cutting aspects

While initial indications are that the solar-battery systems installed under the S4H program in Zimbabwe have achieved their intended target, namely to stabilize electricity supply for key elements of the country's health value chain, long-term sustainability is a work in progress.

The preparation of a feasibility study focused on sustainability illustrates the implementers' desire to ensure longer-term functioning of the PV systems. And perhaps grid reliability challenges justified installation of systems prior to the development of a sustainability model. As a sustainability model requires strong buy-in from key stakeholders—particularly those who are assuming financial responsibilities—implementing one ex post may add complexity. To address this, the S4H team is ensuring that the study is participatory, with consultative meetings with all the different involved entities. In doing so, they hope to convince the partners to agree to responsibilities in relative accordance with their overarching mandates.

Certain critical decisions were made that may help with sustainability until a holistic O&M framework is put in place. The installers, to receive their final payment, must provide basic training to staff-members of the facility and the local Public Works engineers. Also, once the remote monitoring system is fully functional at all facilities, MoH will have an additional means by which to ensure that systems remain functional and attended to.

ANNEX B: CASE STUDY INTERVIEW LISTS

Case	Interviewees
India - Chhattisgarh State Renewable Energy Development Agency	• Sainjeev Jain, CREDA
India - SELCO Foundation-Karuna Trust	• Huda Jaffer, SELCO Foundation • Dr. H Sudarshan, Karuna Trust
Kenya - Off-Grid Solar Access Project	• Arsh Sharma, World Bank • Rodney Sultani, Ministry of Energy
Malawi - Community Energy Development Programme	• Peter Dauenhauer, University of Strathclyde (former) • Damien Frame University of Strathclyde
Malawi, Tanzania, Uganda — Innovation Africa	• Bar Riese, Innovation Africa • Meir Ya'acoby, Innovation Africa
Philippines - Sustainable Solar Market Packages	• Therese Hindman Persson, Pöyry Group (former) • Alan Townsend, World Bank • Jim Finucane, World Bank
Uganda - Energy for Rural Transformation – II	• Brian Odongo, Ministry of Education and Sports • Sita Mulepo, Ministry of Health
West Africa - Regional Off-Grid Electrification Project	• Rahul Srinavasan, World Bank
Zimbabwe - Solar for Health	• Pfungwa Mukweza, UNDP • Emmanuel Boadi, UNDP

ANNEX C: REFERENCES

Arvidson, A., Songela, F., Syngellakis, K. (2006). The role of energy services in the health, education and water sectors and cross-sectoral linkages. European Commission. Retrieved January 2019, from *https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/enable_cross_sectoral_linkages.pdf*

Adair-Rohani et al. (2013). Limited electricity access in health facilities of sub-Saharan Africa: a systematic review of data on electricity access, sources, and reliability. Global Health: Science and Practice, 1(2), 249-261. Retrieved December 2018, from *https://www.ncbi.nlm.nih.gov/pubmed/25276537*

Crossland, AF.; Anuta, OH.; Wade, NS. A socio-technical approach to increasing the battery lifetime of off-grid photovoltaic systems applied to a case study in Rwanda, Renewable Energy, 83, pp 30-40; Retrieved December 2018, from *https://eprint.ncl.ac.uk/file_store/production/212552/F5421998-81C3-4869-B6EB-0BE322B3FF0F.pdf*

Cronk, R., & Bartram, J. (2018). Environmental conditions in health care facilities in low-and middle-income countries: coverage and inequalities. International journal of hygiene and environmental health, 221(3), 409-422. Retrieved January 2019, from *https://doi.org/10.1016/j.ijheh.2018.01.004*

Franco, A., Shaker, M., Kalubi, D., & Silvia, H. (2017). A review of sustainable energy access and technologies for healthcare facilities in the Global South. Sustainable Energy Technologies and Assessments, 22, 92-105. Retrieved December 2018, from *https://www.sciencedirect.com/science/article/pii/S2213138817301376*

Finucane, J., Purcell, C. Photovoltaics for community service facilities: guidance for sustainability in Energy Sector Management Assistance Program (ESMAP), Washington, DC : World Bank, 2010.

Gustavsson, M. (2006). Educational benefits from solar technology—Access to solar electric services and changes in children's study routines, experiences from eastern province Zambia. Retrieved December 2018, from *http://www.mtonga.se/documents/2007%20ENERGY%20POLICY%20Educational%20benefits%20from%20solar%20home%20systems.pdf*

Hirmer, S., & guthrie, P. (2017). The benefits of energy appliances in the off-grid energy sector based on seven off-grid initiatives in rural uganda. Retrieved December 2018, from *https://www.sciencedirect.com/science/article/pii/S1364032117307797#bib30*

IEA PVPS. (2014). PV Systems for Rural Health Facilities in Developing Areas: A completion of lessons learned. Retrieved December 2018, from *http://www.iea-pvps.org/fileadmin/dam/intranet/ExCo/IEA-PVPS_T9-15_2014_PV_for_rural_health_facilities.pdf*

Karekezi, S., S. McDade, B. Boardman and J. Kimani, 2012: Chapter 2 - Energy, Poverty and Development. In Global Energy Assessment - Toward a Sustainable Future, Cambridge University Press, Cambridge, UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 151-190.

ODI, GOGLA, Practical Action, Solar Aid. (2016). Accelerating access to electricity in Africa with off-grid solar. Overseas Development Institute. Retrieved December 2018, from *https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/10229.pdf*

Practical Action. (2013). Poor people's energy outlook 2013 - Energy for community services. Warwickshire: Practical Action Publishing Ltd. Retrieved December 2018, from *https://www.developmentbookshelf.com/doi/pdf/10.3362/9781780441023.000*

SEforALL. (2018). Energy and Women's Health. Retrieved December 2018, from SEforALL: *https://www.seforall.org/hio_energy-and-womens-health*

Smart Villages. (2017). Electrification of health clinics in rural areas: Challenges and Opportunities. Retrieved December 2018, from *https://e4sv.org/wp-content/uploads/2017/05/TR12-Electrification-of-health-clinics-in-rural-areas-Challenges-and-opportun*

Suhlrie, L., Bartram, J., Burns, J., Joca, L., Tomaro, J., & Rehfuess, E. (2018). The role of energy in health facilities: A conceptual framework and complementary data assessment in Malawi. PloS one, 13(7), e0200261.

UNDESA. (2014). Electricity and education: The benefits, barriers, and recommendations for achieving the electrification of primary schools. UNESDA. Retrieved December 2018, from *https://sustainabledevelopment.un.org/content/documents/1608Electricity%20and%20Education.pdf*

UNESCO. (2018). UIS.Stat. Retrieved December 2018, from UNESCO Institute of Statistics: *http://data.uis.unesco.org/#*

USAID. (2018). Cold Chain and Refrigeration. Retrieved December 2018, from Powering Health: *http://www.poweringhealth.org/index.php/topics/technology/cold-chain-and-refrigeration*

USAID. (n.d.). DHS SPA Final Program Reports. Retrieved December 2018, from The DHS Program: *https://dhsprogram.com/publications/Publication-Search.cfm?shareurl=yes&year11=&year21=&language1=&topic1=&country1=&pubTypeSelected=pubtype_21&keyword1=&pubid1=&showall=yes&PubTypeLogID=1*

USAID. (n.d.). Powering Health - Electrification Options for Rural Health Centers. USAID. Retrieved December 2018, from *http://www.poweringhealth.org/Pubs/PNADJ557.pdf*

WHO. (2010-2016). Service Availability and Readiness Assessments (SARA). Retrieved December 2018, from *https://www.who.int/healthinfo/systems/sara_reports/en/*

World Bank. (2010). Photovoltaics for Community Service Facilities - Guidance for Sustainability. Washington DC: World Bank. Retrieved December 2018, from *http://siteresources.worldbank.org/EXTAFRREGTOPENERGY/Resources/717305-1266613906108/PV_Toolkit_FINAL_12-14-10.pdf*

World Bank. (2017). Special Feature SEAR: Modern Energy Access and Health. Washington DC: World Bank. Retrieved from *http://documents.worldbank.org/curated/en/756131494939083421/pdf/BRI-P148200-PUBLIC-FINALSEARSFHealthweb.pdf*

World Bank. (2018). Service Delivery Indicators Database. Retrieved December 2018, from World Bank Development Indicators: *https://databank.worldbank.org/data/reports.aspx?source=service-delivery-indicators#*

World Bank; United Nations Foundation; World Health Organization. (2017). State of Electricity Access Report – Modern Energy Access and Health. World Bank.

World Health Organization; World Bank. (2015). Access to modern energy services for health facilities in resource-constrained settings: a review of status, significance, challenges and measurement. WHO. Retrieved December 2018, from *http://apps.who.int/iris/bitstream/10665/156847/1/9789241507646_eng.pdf*

Smart Villages. (2017). Electrification of health clinics in rural areas: Challenges and Opportunities. Retrieved December 2018, from *https://e4sv.org/wp-content/uploads/2017/05/TR12-Electrification-of-health-clinics-in-rural-areas-Challenges-and-opportunities_web.pdf*

United Nations Foundation (Washington, DC Office)
1750 Pennsylvania Ave. NW Suite 300
Washington DC 20006 USA
www.unfoundation.org

Andromeda Tower 15th Floor
Donau City Strasse 6
1220, Vienna, Austria
www.SEforALL.org