Tiers, Markets, Sustainability: Trends in Rural Off-Grid Electrification

endev

Learning & Innovation

Main abbreviations

AI	Artificial Intelligence
ASER	Senegalese Rural Electrification Agency
BMZ	German Federal Ministry for Economic Cooperation and Development
CAPEX	Capital expenditures
DRC	Democratic Republic of the Congo
DKTI	German Climate Technology Initiative
EnDev	Energising Development
GDP	Gross Domestic Product
GIZ	German Corporation for International Cooperation
GOGLA	Global Off-Grid Lighting Association
IEA	International Energy Agency
kfW	German state-owned investment and development bank
kWh	kiloWatt-hour
LNOB	Leave No One Behind
MHPP	Micro-hydro power plant
MTF	Multi-Tier Framework (for measuring energy access)
PAYGO	Pay-As-You-Go
PUDC	Emergency Community Development Programme (in Senegal)
PUE	Productive Use of Energy
RBF	Results-based financing
SDG	Sustainable Development Goal
SENELEC	Senegalese national electricity utility
SHS	Solar Home System
SSA	Sub-Saharan Africa
STEPS	Stated Policies Scenario (by the IEA)

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Reading guide

The guide is structured as follows: Chapter 1 introduces this guide as well as the topics which are explored in the guide. Chapter 2 provides an overview of worldwide electricity access trends, with a focus in the SSA context, chapter 3 follows by setting the focus on the off-grid solar market in terms of sizing, evolution, typology of applied technologies as well as assessing key market trends; chapter 4 deep-dives on the key underlying factors ensuring projects' sustainability, assesses prevailing challenges and identifies lessons learnt; finally, the learnings identified serve as the foundation to a set of recommenda-tions presented in chapter 5.

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EnDev at a glance

Around 4 billion people have no access to electricity or modern cooking technologies. This has a dramatic impact on quality of life, environment, health, education and income opportunities. EnDev's involvement focuses on providing access to modern, renewable energy. This is a pivotal factor in strength-ening socio-economic development and combatting climate change.

EnDev's drive is to improve the lives of the most vulnerable people, ensuring no one is left behind. Economic opportunities and green jobs are created by building markets for modern, renewable energy. EnDev con-tributes to reducing greenhouse gas emis-sions to protect our planet's climate. Its ap-proach is to empower structural, selfsustaining change; kickstarting market and sector development that evolves further without support by EnDev.

EnDev's work is about people. Results are monitored and reported rigorously. EnDev's achievements on helping peo-ple, schools, health centres, andcompanies gain access to electricity or improved cooking technologies can be found in this report. This report also presents EnDev's impacts on gender, job creation, and reduced carbon emissions. EnDev is a strategic partnership. Dedicated donors, partners and individuals work together to support social develop-ment and economic growth by providing access to modern,renewable energy in more than 20 countries around the globe. The driving force behind EnDev is the partnership of Germany, the Netherlands, Norway, and Switzerland; donors who are committed to accelerating energy access and socio-economic development.

Learning & Innovation Agenda

Energising Development (EnDev) is one of the largest on-the-ground technical assistance programmes for energy access in the world. At present, EnDev is striving to further develop and structure its learning and innovation (L&I) agenda with the intention of sharing its results with the wider SDG7 community. The aim is that this shared knowledge can lead to both a higher pace of implementation and increased impact of the EnDev programme. The results shared can also inform similar initiatives in the field.

Through the EnDev L&I Agenda, EnDev supports EnDev implementers in the collection, analysis and sharing of findings and experiences of the implementation of energy access activities. In addition, it aims to provide learnings to a wider audience of energy access practitioners. This report focuses on lessons learned from the EnDev programme managed by GIZ and RVO, and from EnDev implementers such as SNV, GIZ, HIVOS, Practical Action, AVSI, ADES, NIS and CLASP.

GIZ is leading the EnDev Learning & Innovation Agenda on Rural Electrification within EnDev. This Practitioners' Group on Rural Electrification aims to bring together EnDev implementers and other organisations to share and exchange successful approaches to accelerate electrification in rural areas.

This knowledge product aims to:

- Contribute to an increase of sustainability practices within EnDev and other interventions in the field of rural electrification through off-grid technology,
- Expand the knowledge and understanding of innovative and successful approaches resulting in the implementation of sustainable off-grid energy projects, as well as related barriers to overcome,
- Actively strengthen EnDev's new programming phase (2021 to 2024), pilots and other interventions.

This report first introduces the methodology employed to develop this guide and provides an overview of different off-grid technologies. Following this, an overview of the current situation on access to electricity is provided, followed by an outlook of the off-grid sector and current market trends that shape the latter. Finally, sustainability indicators that directly contribute to reliable and affordable electricity access are derived

Executive summary

SDG 7 – Universal access to electricity – is to be achieved within the current decade. Despite significant progress, we are however currently off-track to meet the target. This guide showcases that key market trends in the off-grid electrification sector and sustainability indicators should be considered to accelerate the deployment and maximise the impact of off-grid electrification projects. The guide focuses on Sub-Saharan Africa, the region with the largest gap towards universal access.

Unprecedented efforts in the off-grid sector are needed to meet SDG 7

To be able to connect the close to 600m people without access to electricity in Sub-Saharan Africa (SSA) by 2030, an unprecedented effort is required. The current COVID-19 pandemic has led to an increase of the people without access to electricity in the region for the first time since 2013, and a decline of energy access by 2% or 13 million people in 2020 compared to 2019.[1] Current policies on electricity access will be unable to outpace the region's population growth.

Off-grid funding is significantly lower than funding for the main grid, with only one quarter of all funds for electricity access targeted at connecting residential customers. Yet, off-grid electrification solutions present a viable and sustainable option for access to electricity for more than 50% of SSA's population.[2]

The majority of off-grid products sold and installed are still only meeting Tier 1 or below of ESMAP's Multi-Tier Framework, despite plug-and-play solar home systems (SHS) having gained significant traction over the last decade. More and more mini-grid companies are also delivering access to electricity that is close to, or even better than, grid quality.

1 The Covid-19 crisis is reversing progress on energy access in Africa – Analysis - IEA

2 IEA, ESMAP and the Mini-Grid Partnership all project slightly different figures for the contribution of off-grid technologies to access to electricity, but all are projecting a contribution beyond 50%

Digitalised systems, integrated energy solutions and rural industrialisation are the future of the off-grid sector

Within the off-grid sector, key market trends beyond a reduction in the cost of technology are improving companies' effectiveness in delivering reliable and affordable electricity to customers. Some of the current trends include productive use, the digitalisation of the sector, and the drive for SHS companies to offer increasingly diverse products and services.

The future of the off-grid space is determined by the leveraging of digitalised solutions and existing value chains to sustainably industrialise rural areas, and provide integrated electrification solutions that are renewable, technology-agnostic and demand-based.

Inclusion of market trends and sustainability indicators in off-grid projects will result in reliable and affordable electricity access

The ultimate goal of off-grid projects is the delivery of sustainable, reliable and affordable electricity access. By recognising and including the key market trends in off-grid projects, and by leveraging specific sustainability indicators, organisations can accelerate and enhance the realisation of their access targets. This implies integrating the considerations stemming from the financial, institutional, social, technological and ecologic dimensions of sustainability into projects' conceptualization and implementation.

Sector coupling that leverages synergies between the rural electrification and industrialization sectors, conducive regulatory frameworks, an enhancement of the role of women as active agents of change and the creation of mechanisms that enable scalable circular economy principles in remote rural areas are all identified as pre-requirements for timely achieving SDG7.

1

Introduction

This guide on the major factors impacting the sustainability of off-grid projects is a result of the EnDev Learning & Innovation Agenda. Its intention is to provide EnDev practitioners and the broader community in the off-grid energy space with practical insights, lessons learnt and knowledge applicable to the implementation of sustainable off-grid projects.

1.1 What is this guide about?

Despite the efforts of EnDev and many other international organisations (World Bank, AfDB, UN, USAID, etc.), the goal of universal access to electricity by the end of this decade remains elusive. Particularly in rural areas of Sub-Saharan Africa, universal access is not within reach, although good progress has been made in selected countries.

Therefore, universal electrification efforts ought to be accelerated and designed as effective as possible to achieve maximum impact within a short timeframe. The guide analyses key market trends and sustainability indicators in the picoPV, SHS, nano-grid and mini-grid sectors that can contribute towards the achievement of delivering reliable and affordable electricity access.

1.2 Who is this guide for?

Stakeholders benefitting from this report include:

- The EnDev practitioners' group, which has been consulted at various stages of the project. This practitioners' group includes representatives of GIZ, RVO, SNV, Practical Action and AVSI.
- Practitioners in the off-grid space who would like to implement sustainable projects delivering long-term access to reliable and affordable electricity.

1.3 How was this guide developed?

Beyond desk-based research, the main contents for this guide were developed through conducting targeted interviews with staff of EnDev or its partners in EnDev countries that have placed a particular focus on off-grid energy interventions. These countries are: Ethiopia, Mali, Senegal and Uganda. In addition, an interview was conducted in the DRC with AVSI, an implementer of EnDev. Insights from the interviews have been utilised throughout the guide, and relevant tables are highlighting some of the key learnings from these exchanges.

Brief interviews were also conducted with off-grid practitioners for the development of case studies which are interspersed throughout the guide.

1.4 Framing access to electricity

While the traditional definition of energy access involves a connection to an electricity distribution network, the definition in the rural electrification sector has evolved to acknowledge that access to energy is not a binary variable. Instead, access to energy can be measured through dimensions such as reliability, affordability, quality, duration and health & safety. In 2015, the World Bank developed the Multi-Tier Framework for Measuring Energy Access (MTF), which complements the binary definition of energy access through this multi-dimensional approach. The MTF classifies access to electricity for households through the following criteria:[3]

- Tier 0: no or insufficient access to energy.
- Tier 1: reliable and affordable access to task lighting and phone charging.
- Tier 2: electricity access for general lighting, phone charging, television and fan if needed.
- Tier 3: Tier 2 applications and any medium-power appliances (i.e. fridge).
- Tier 4: Tier 3 applications and any high-power appliances.
- Tier 5: Tier 4 applications and any very high-power appliances.

The following section presents off-grid electrification technologies and how each fulfils the demands of the outlined tiers.

3 ESMAP, 2015.

1.5 Introduction to off-grid technologies

The off-grid technologies considered within the guide are picoPV systems, solar home systems, nano-grids and mini-grids. Collectively, the picoPV systems and solar home systems are referred to as "stand alone systems".

PicoPV systems are low-capacity devices providing either only light (solar lanterns), or combine these with small-scale applications, such as phone charging, radios or loudspeakers. The systems are composed of either singular units containing a solar panel and lamp(s), or units with a single lamp separated from a solar panel. PicoPV systems roughly range in size between 1 and 50Wp.[4,5] In the MTF[6], picoPV systems can generally provide only Tier 0 or Tier 1 access.

Solar home systems (SHS) are PV systems with a separate solar panel, battery and usage points, such as lamps or plugs, connected to the battery through cables. SHS can serve several lighting points and larger systems allow multiple uses, including phone chargers, radios, small fridges, fans and TV sets. Typical SHS range in size between 20Wp and 800Wp, though smaller and larger SHS do exist. Solar systems for institutions and commercial applications installed in facilities such as schools, health centres, other public institutions and travel lodges are considered within the category of "solar home systems" for the purposes of this report, although these are losing traction in favour of plug-and-play systems. SHS typically provide Tier 2 or Tier 3 access to electricity in ESMAP's MTF. Very large SHS mostly for commercial applications or applications within social infrastructures can be argued to provide Tier 3-4 access.

4 https://energypedia.info/wiki/Features_of_PicoPV_Systems

5 https://energypedia.info/wiki/Features_of_PicoPV_Systems World Bank Document

6 https://mtfenergyaccess.esmap.org/

Nano-grids are generally DC systems of power capacity between 500Wp and 10 kWp installed in comparatively smaller communities that serve only a few customers at a time from each node. In some instances, nano-grids can also be based on the AC principle. Nodes may be interconnected to each other to make the utilisation of batteries more efficient. Nano-grids often cover Tier 2 or Tier 3 electrical loads and can be able to serve small-scale productive loads. By intelligently distributing power, some nano-grids can, for a limited number of customers, also provide Tier 4 access.

Mini-grids serve multiple users connected to a single source of electricity, from two to several thousand users. Mini-grids can provide alternating current (AC) electricity, with some mini-grids enabling users to utilise large-scale productive use equipment, such as freezers, milling machines, woodwork and metalwork equipment. Mini-grids range in sizes between 10-20 kWp up to 1MWp and can provide Tier 3, Tier 4 and even Tier 5 access to electricity. While the most common technology in Sub-Saharan African (SSA) is solar energy coupled with battery storage, other power generation sources (such as wind, biomass, hydro and diesel generators or combinations as hybrid) can also be utilised for mini-grids.

An off-grid project is defined, for the purpose of this guide, as a project implemented with the goal of promoting technologies and facilitating market development in the off-grid electrification space in SSA. Such a project can include the distribution/ retail of SHS or picoPV, or the implementation of singular or multiple nano-grids or mini-grids. From the angle of applicable business cases, the above outlined systems can be distinguished between *individual systems* sold and subsequently owned by the beneficiary and *communal systems* that are installed by an external operator who in turn sells electricity as a product to the beneficiaries.

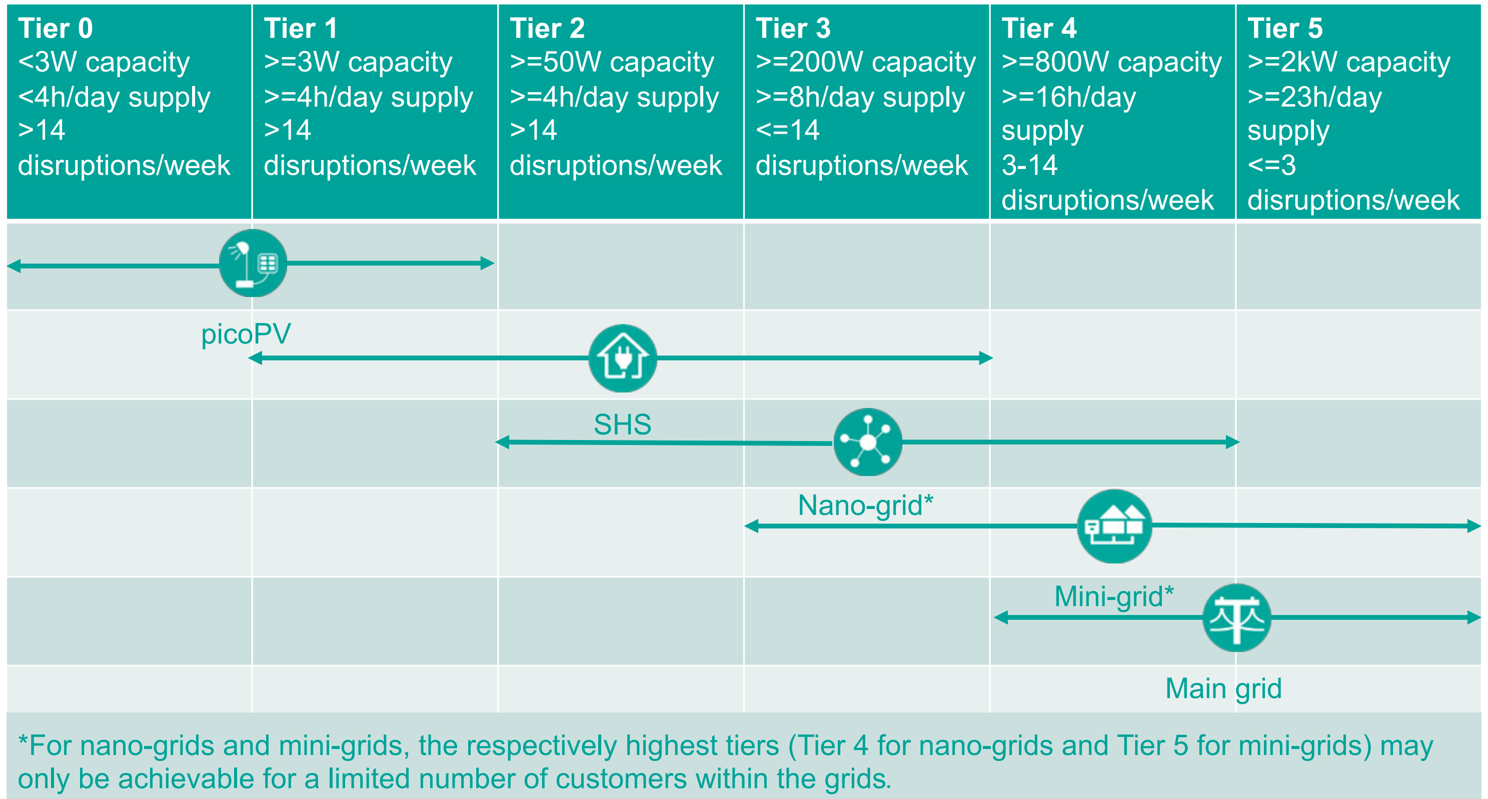

Figure 1. Applicability of different off-grid technologies within the Multi-Tier Framework for Measuring Energy Access

1.6 Market overview of EnDev countries

Within the off-grid energy space, EnDev is currently active in 13 different countries in Sub-Saharan Africa. For the purposes of this guide, representatives from AVSI, an implementer of EnDev projects, were also interviewed with regards to their activities in the DRC.

Five countries were chosen for interviews as each one is/has been planning off-grid electrification activities in the upcoming EnDev programming period. They also have ambitious targets for access to electricity, with the majority of these countries aiming for universal access to electricity by 2030. By comparison, the DRC's target of 30% electrification by 2030 is low, however unlikely to be achieved given current progress and challenges in country.

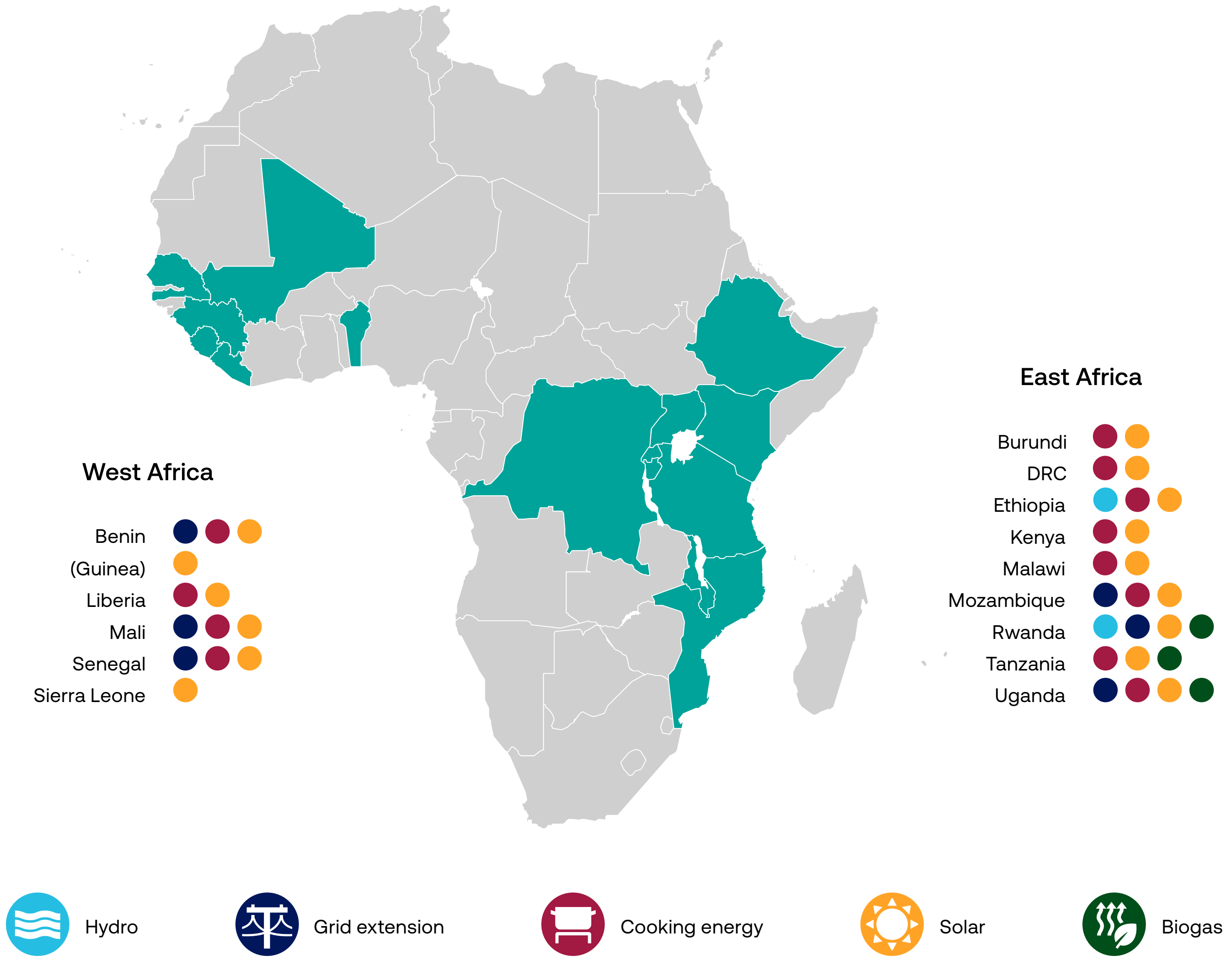

Figure 2. Overview of EnDev countries in Sub-Saharan Africa with a focus on off-grid energy projects

2

Electricity Access trends

The vast majority of people without access to electricity now lives in Sub-Saharan Africa. The ongoing COVID-19 pandemic is reversing some of the progress on energy access made in the last decade, however decentralised energy solutions remain one of the most viable solutions for rapidly electrifying millions of people.

2.1 Good progress on energy access was made in the last decade …

The International Energy Agency (IEA) defines a household as having electricity access when it has “reliable and affordable access to electricity, which is enough to supply a basic bundle of energy services initially, and with the level of service capable of growing over time“.[7] The IEA considers that this basic bundle contains several lightbulbs, phone charging, a radio and potentially a fan or television. Both access to electricity through the main grid and through decentralised systems, including SHS, nano-grids and mini-grids, are counted as ’access to electricity’. In contrast, the World Bank’s MTF Framework extends the definition of ‘access to energy’ to PicoPV products for Tier 1 as well, as long as they guarantee a high-quality, affordable, stable, sufficient (given size of household), convenient, healthy and safe electricity consumption.

Data from the IEA indicates that 90% of the global population now has access to electricity.[8] In Sub-Saharan Africa, despite electricity access outpacing population growth over recent years, the overall picture is still bleak. Less than 50% of the population is connected as of today, and close to 600m people still lack access.[9] Much of the recent progress can be attributed to a small number of countries, including Kenya, Senegal, Rwanda, Ghana and Ethiopia. In Kenya, the access rate rose from 20% in 2013 to almost 85% in 2019. The majority of progress in SSA is a direct result of grid connections, but off-grid systems have played an increasingly important role over recent years.

Around 15 million people were connected to mini-grids in Africa by 2019[10], while the number of people gaining access through SHS in SSA increased from two million in 2016[11] to almost five million in 2018.[12] The increase in SHS has been concentrated in a few countries: Kenya, Tanzania and Ethiopia accounted for almost 50% of new connections in 2018.

7 https://www.iea.org/articles/defining-energy-access-2020-methodology

8 https://trackingsdg7.esmap.org/data/files/download-documents/2021_tracking_sdg7_report.pdf

9 https://www.iea.org/topics/energy-access

10 ESMAP, 2019: Mini Grids for Half a Billion People

11 IEA, 2017: Energy Access Outlook 2017

12 IEA, 2019: Africa Energy Outlook

2.2 … however more work is left to be done following the COVID-19 crisis.

According to the IEA, the COVID-19 pandemic has significantly negatively impacted progress towards universal access to electricity, especially in decentralised energy. The pandemic has resulted in a shift in government priorities and supply chain disruptions. Necessary social distancing measures have rendered the installation and operation of off-grid projects increasingly difficult. The effect is yet to be fully quantified, however first estimates by the IEA indicate that the overall population without access to electricity in Sub-Saharan Africa has likely increased in 2020 for the first time since 2013.[13] Considering current population growth rates, it is estimated that to achieve universal access, approximately 940 million people would need to be connected to electricity by 2030.[14] The IEA has developed two different scenarios to project future energy access: The Stated Policies Scenario (STEPS) highlights likely energy access results if current and announced policies continue, and the Sustainable Development Scenario includes recovery plans and programmes that governments could launch to accelerate energy access.

Under STEPS, there is a slowdown in progress in 2020 and 2021 due to the crisis, and a projected 660 million people who still do not have access to electricity by 2030 due to Sub-Saharan Africa’s strong population growth. To bridge the gap, the connection rate would have to triple from its current level to nearly 90 million connections a year up to 2030.[15] The Sustainable Development Scenario considers that around $35 billion is needed annually from 2021 to 2030 on access to electricity, fully tapping decentralised solutions.[16] Under this scenario, it is estimated that almost two thirds of funding for electricity access should go to SSA.[17] Until 2019, only approximately one quarter of funding committed for access to electricity was directed towards electricity provision for residential customers[18], with the remainder serving commercial and industrial sectors, export and others.[19]

In both scenarios, countries such as Ghana, Kenya, Senegal, Ethiopia and Rwanda manage to achieve universal access by 2030 through the effective and ambitious policies and programmes they had already put in place prior to the crisis. In 2030, under the STEPS scenario, it is anticipated that close to 50% of the global population without access is concentrated in only seven countries – Democratic Republic of the Congo, Nigeria, Uganda, Tanzania, Niger, Sudan and Pakistan.[20] The six countries in SSA are among the 20 fastest-growing countries by population, making this a main impediment in limiting countries to achieve universal access to electricity.

Indeed, when comparing the required progress to be made by Sub-Saharan Africa with historic achievements, it can be posited that achieving universal access within this decade requires unprecedented efforts. China took more than 30 years to connect the final 600m people to electricity, and India has so far taken close to 20 years for the same feat, without having achieved universal access yet (see Figure 3).

13 https://trackingsdg7.esmap.org/data/files/download-documents/2021_tracking_sdg7_report.pdf

14 https://trackingsdg7.esmap.org/data/files/download-documents/2021_tracking_sdg7_report.pdf

15 ESMAP, 2019: Mini Grids for Half a Billion People

16 https://trackingsdg7.esmap.org/data/files/download-documents/2021_tracking_sdg7_report.pdf

17 https://trackingsdg7.esmap.org/data/files/download-documents/2021_tracking_sdg7_report.pdf

18 https://www.seforall.org/news/research-shows-world-at-a-tipping-point-to-meet-global-energy-goals-by-2030

19 https://www.seforall.org/data-and-evidence/energizing-finance-series/energizing-finance-2019

20 https://www.iea.org/reports/sdg7-data-and-projections/access-to-electricity

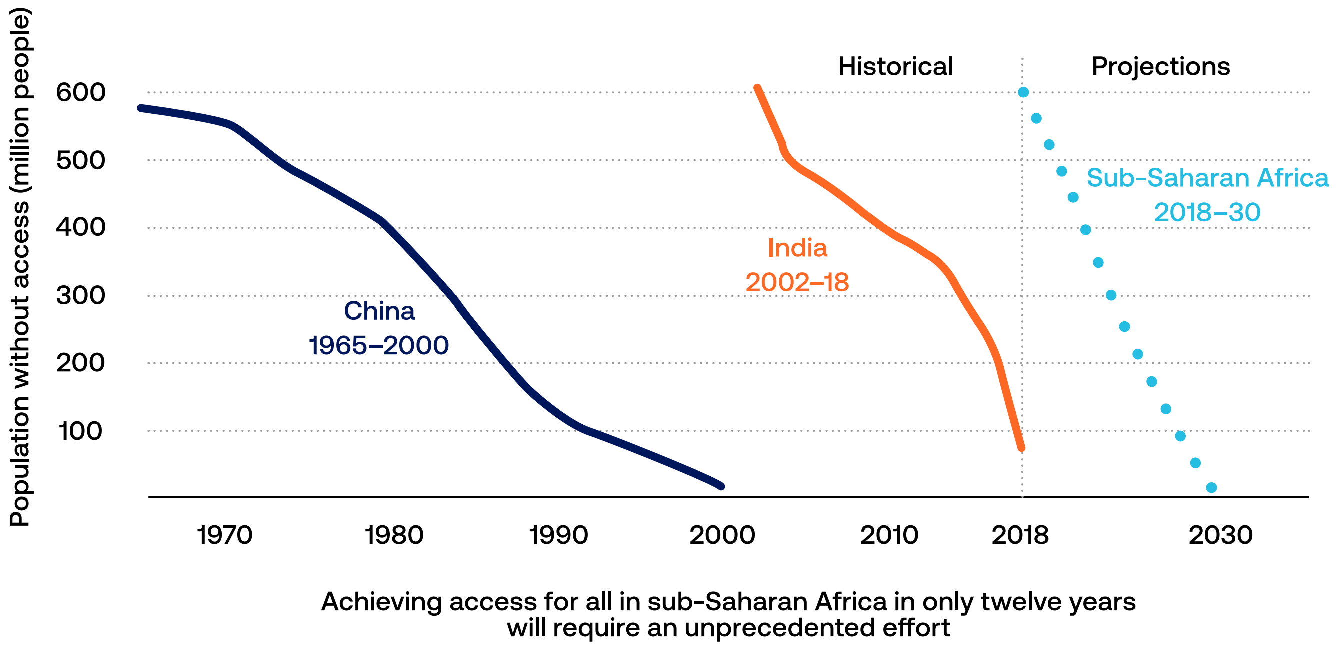

Figure 3 Historic achievements of India and China as compared to required achievement of Sub-Saharan Africa to realise universal access to electricity (IEA, 2019)

2.3 Projected contribution of off-grid systems to electricity access

In the Sustainable Development Scenario by the IEA, decentralised solutions will contribute to 55% of new connections realised between 2019 and 2030, with slightly more people being connected through mini-grids (31%) than SHS (24%) (see Figure 4).[21]

An analysis by the Mini-Grids Partnership (MGP)[22] presents a slightly more biased projection towards mini-grids, with the MGP projecting that, to reach universal access to electricity, approximately 46% of connections should be realised through mini-grids, and only 11% through SHS.[23] Finally, ESMAP estimates are putting electrification through mini-grids at approximately 41%, or close to 500m people total.[24] All analyses are however in agreement that decentralised solutions will play a major role in realising universal access to electricity. Decentralised solutions have multiple advantages over grid connections: They are faster to deploy, do not require significant infrastructure updates and allow technologies to be deployed based on the particular demand of a community.

21 https://trackingsdg7.esmap.org/data/files/download-documents/2021_tracking_sdg7_report.pdf

22 Who We Are | Mini-Grids Partnership

23 Mini-Grids Partnership 2020, State of the Global Mini-Grids Market Report

24 ESMAP, 2019: Mini-Grids for Half a Billion People

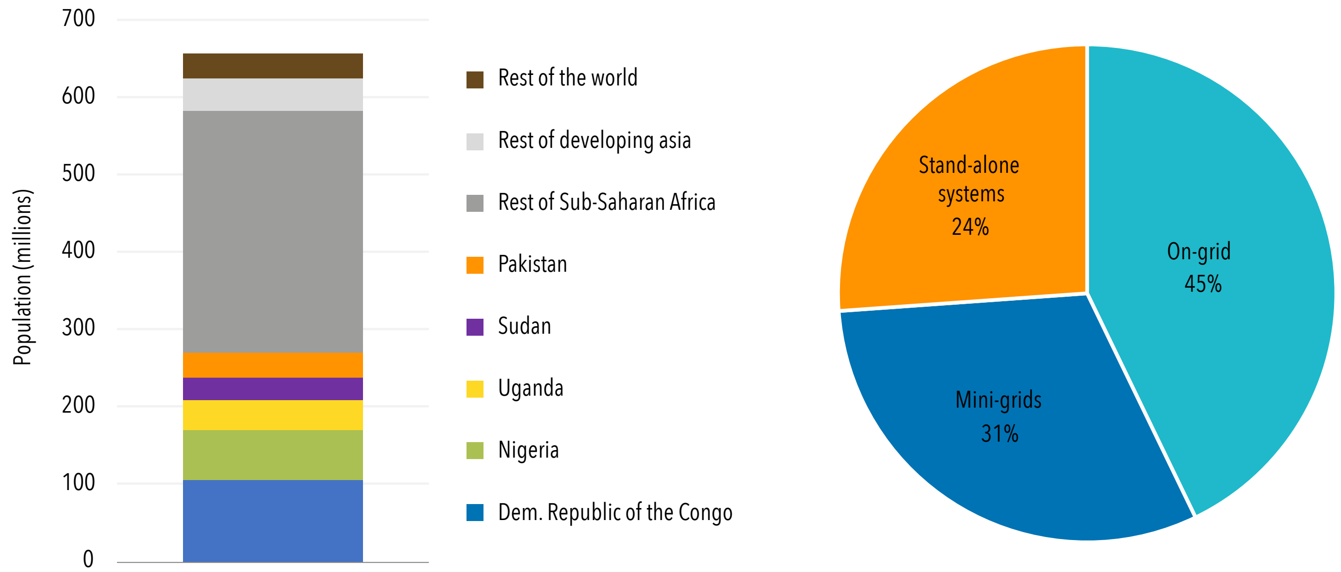

Figure 4. Population gaining access to electricity as per IEA projections in the STEPS and Sustainable Development Scenario, broken down by technology (IEA, 2019)

Topic	DRC	Ethiopia	Mali	Senegal	Uganda
Electrification situation[25]	According to IEA, around 9% overall, with 19% urban and less than 1% rural, however situation difficult to access due to size of country	47% access overall, 11% through off-grid solutions; 96% urban and 34% rural	50% overall access, 78% in urban and 28% in rural areas	71% overall access, 94% in urban and 50% in rural areas	29% overall access, 66% in urban and 17% in rural areas
Electrification planning[26]	• Target to reach 30% by 2030 very ambitious Mapping not done Focus on large-scale projects • *Essor project* in DRC with planned mini grids in 3 remote cities for a total of 25,000 household and SME connections (DFID, AfDB) might be a game changer	• Target of universal access by 2030 • Off-grid playing a part as pre-electrification and very rural areas • Most mini-grids to be developed by public sector with EPC tender	• No clear road to electrification, however mini-grids will play an important role	• ERIL approach in Senegal focused on incentivising local investments in small concessions in rural areas including SHS and mini-grids; Determination of technology following assessment • Access to electricity is highly political • Policy to cover remaining communities with 61% grid extension, 7% (1.000) mini-grids, 32% SHS	• Have electrification masterplan • 683 solar mini-grid sites included • SHS also outlined but companies 'go where business is' • Seeing potential of 25,000 mini-grids

Table 1. Electrification situation and electrification planning in the EnDev countries interviewed.

25 Source: IEA, World Energy Outlook 2020: https://www.iea.org/reports/sdg7-data-and-projections/access-to-electricity

26 Based on interviews conducted

3

Off-grid solar market and trends

Through the integration of key market trends in the design of off-grid projects, rural electrification practitioners can develop cutting-edge solutions that provide maximum results to beneficiaries. By fostering distinct market trends they can further shape the future of the sector.

3.1 Market size of the off-grid solar market

The off-grid solar sector, including picoPV, SHS, nano-grids and mini-grids, has grown considerably over the last decade. As of 2019, approximately 84m stand-alone systems (picoPV and SHS) were in utilisation by customers, and more than 5,000 nano-grid and mini-grid projects had been implemented.[27] Of the 84m stand-alone systems, approximately 18m were SHS and 66m picoPV systems.[28]

In the mini-grid space, most projects so far have been implemented in Asia, with the majority of projects currently under development being located in Sub-Saharan Africa. Technology has equally undergone a shift over the last decade. In 2009, only 10% of mini-grids were PV, in 2020 55% are purely solar PV.[29] While the average mini-grid capacity (taking into account the total of 2.37 GW) is at 427 kW/mini-grid, the majority of solar mini-grids falls under 100 kW.

27 Mini-Grids Partnership, 2020: State of the Global Mini-Grids Market Report

28 GOGLA Off-Grid Solar Market Trends Report 2020

29 Mini-Grids Partnership, 2020: State of the Global Mini-grids Market Report

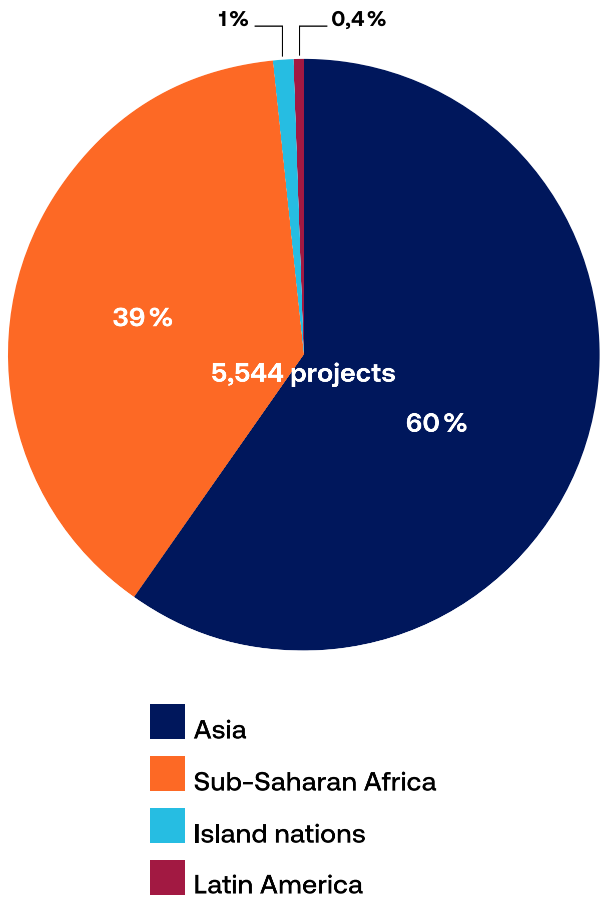

Figure 5. Installed mini-grids by region (MGP, 2020)

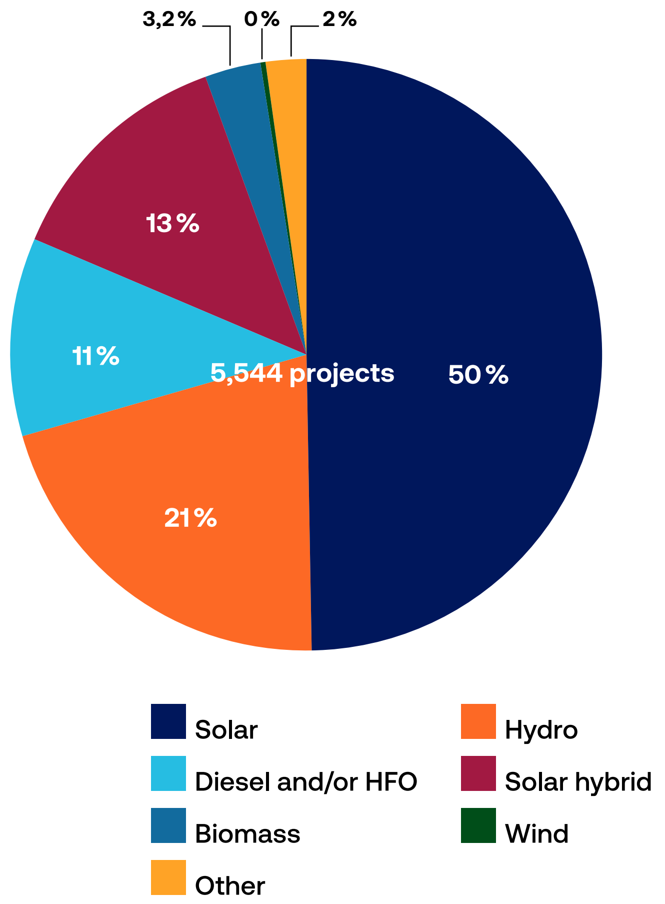

Figure 6. Installed mini-grids by technology (MGP, 2020)

The implementation of mini-grids is differing vastly between countries. There are 'early sector developers', such as Mali and Senegal, who have each implemented over 200 mini-grids over the last decade, but are struggling with operations and maintenance (see chapter 4 for more detail). There are 'current focal points' like Nigeria and Sierra Leone, who are rapidly implementing a large number of mini-grids. Finally, there are 'high potential' markets such as Uganda and Ethiopia, which have not yet experienced the implementation of a significant number of mini-grids, but are undergoing preparations for scale-up in the (near) future. Of all EnDev countries assessed for this guide, the DRC appears to be the only one not fitting squarely into any category, considering its unique characteristics in terms of size, security situation and logistical challenges. The situation across the DRC is very scattered, and it is difficult to estimate progress on electrification in general as well as total number of mini-grids implemented. Table 2 on page 20 provides an overview of the number of mini-grids implemented and planned in the EnDev countries interviewed.

The market for stand-alone systems equally remains on a strong growth trajectory, with the sector being projected to serve 823 million users globally by 2030.[30] Over the next decade alone, annual sales of stand-alone systems are projected to increase from 35m to 72m annually.

30 GOGLA, 2020: Off-Grid Solar Market Trends Report

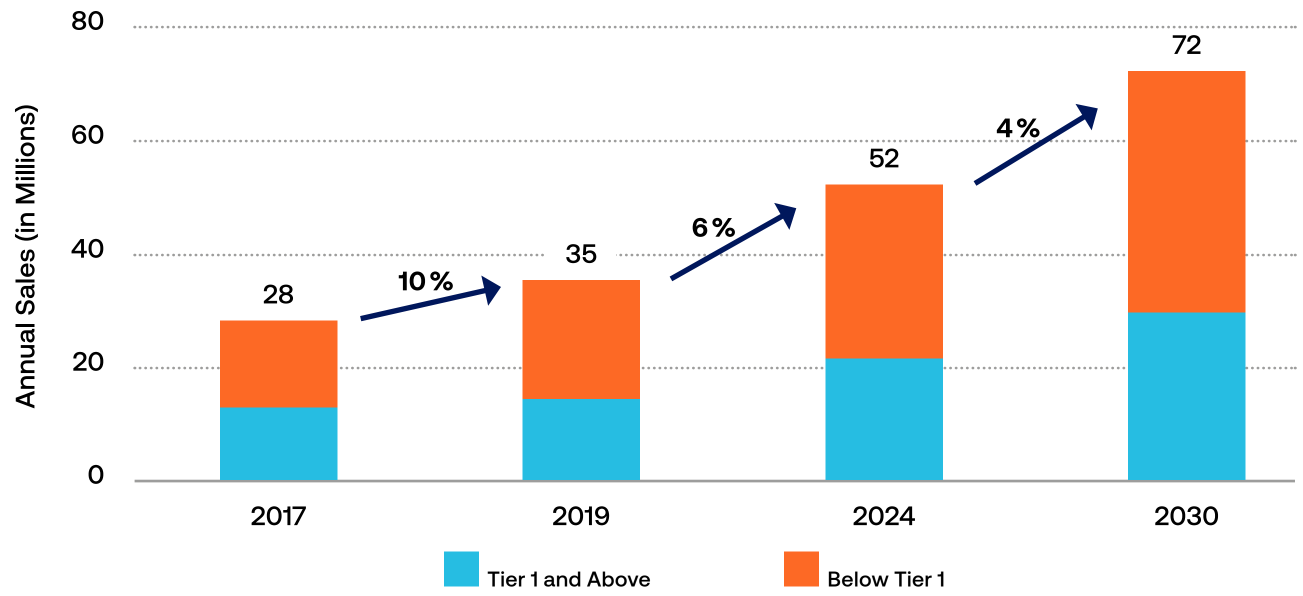

Figure 7. Projected sales of stand-alone systems by access level tier (GOGLA, 2020)

3.2 Evolution of the off-grid solar market and technologies

The strong growth of the off-grid sector is anticipated to continue in the near- and mid-term future. Despite a slow move towards larger systems, the majority of systems sold is still small-scale (Tier 1 or below). As more and more communities are being connected to the grid and receiving electricity through nano- and mini-grids, the unelectrified population is increasingly remote. This contributes to the remaining popularity of picoPV systems, as well as the continuously falling costs of technology. By now, the market for picoPV systems, in comparison to other technologies, is significantly more crowded in terms of active players and ability to supply, including manufacturers who sell non-brand systems at prices close to branded systems. Regrettably, the quality of these systems is not always on par with those that are quality certified (e.g. VeraSol), contributing to a low consumer confidence in solar products in some Sub-Saharan African markets (e.g. Ethiopia).

Nano-grids are comparatively CAPEX- and technology-intensive when compared to individual SHS for households, and their commercial viability yet remains to be proven in Sub-Saharan Africa. So far, they have only been proven successful in Asia, where rural areas typically have a higher population density compared to villages in SSA. A similar approach, whereby SHS are interconnected to one another, is called “swarm electrification”, which has proven to be workable where technology is of sufficient standard and adequately installed. Examples of these have been FlexGrid, SolShare in Bangladesh, PowerBox in Mozambique, Solergie in Togo and other countries in SSA and South-East Asia.

Full-scale mini-grids nowadays mainly use solar PV as a source of electricity, with some mini-grids still integrating a back-up diesel generator, making them solar hybridised systems. The advantage of hybridising solar mini-grids is that the PV and battery banks can be scaled down, saving valuable CAPEX investments and improving commercial viability. The reduction in CAPEX investments can also be passed on to end consumers through reduced tariffs, which is one of the key challenges in mini-grids (see chapter 4.2.1). However, some of the interviewees have noted difficulties with operating hybrid mini-grids, considering that the gensets require constant attention by operators who need to purchase and refill fuel. The fuel itself is also vulnerable to theft. In some cases, the operational challenges of gensets have led to these gensets finally not being used or maintained by the operators, leading to quick deterioration and ultimate failure.

Similar to many donors, EnDev now follows a 100% renewable energy policy. However, electrification from grid extensions and grid densifications are often based on a partial fossil fuel mix. Similarly, as discussed above, off-grid (diesel) hybrid systems still present the most viable commercial case for mini-grids. These technologies may be accepted by EnDev, but only as part of an explicit broader transition of technology towards 100% Renewable Energy.

Where suitable geographical conditions allow for this, micro-hydro power plants (MHPP) are regarded as an effective solution to ensuring 24/7 electricity access without the need to rely on the diesel hybridisation approach or (still) expensive battery banks. MHPP technology has traditionally been successful in Nepal and has successfully been piloted by EnDev in countries such as Indonesia, Ethiopia and Rwanda. Nevertheless, it is important to note the site-specific nature of this technology and the relatively higher operational capacities compared to solar nano- and mini-grids.

Case Study: SolShare – Swarm Electrification

SOLshare’s foundation was inspired by a team of PhD students’ findings that the 4.3 million SHS deployed in Bangladesh produce a surplus of 30% energy totalling USD 1 billion in unused energy value every year. The peer-to-peer (P2P) electricity trading solution developed by SOLshare is based on interconnecting these solar home systems to enable consumers and producers to trade electricity directly, without the need for an intermediary.

The IoT-driven software platform SOLbazaar that was developed by SOLshare is a dynamic energy marketplace that allows SHS users to sell their excess energy to other SHS users or non-users who lack their own home systems. SOLshare’s direct clients are the microfinance institutions and NGOs that sell solar home systems to rural consumers on microloans. Hence, SOLshare leverages existing distribution channels instead of selling products or services directly to end users.

Figure 8. Interconnected solar home systems on Bangladeshi roof tops

3.3 Technology focus in EnDev countries

By 2019, EnDev had directly contributed to access to electricity for close to 3.9m people through off-grid solutions (1.9m picoPV, 1.7m SHS and 0.3m mini-grids), in addition to 1.5m people reached through grid and limited grid interventions.[31] Table 3 on page 21 provides an overview of the technology focus of the countries interviewed for this guide.

Interestingly, the EnDev program in Mali has developed a novel approach that does not focus on the deployable technology (e.g. picoPV or mini-grids) as the primary driver of which systems to implement. Instead, the decision on the optimal technology to be installed follows the evaluation of energy demand in the particular community to be addressed as well as related parameters (distance to grid, density, accessibility etc.), known as a technology-agnostic, demand-based, or push approach.

The fundamental advantage of a demand-based approach is that the deployed technological solution matches the demand, and costs are optimised. Instead of finding the right context for a specific technology (which is a time-intensive process), the right technology is picked for the targeted community, saving substantial financial resources and efforts.

31 EnDev Progress Report 2019

DRC	Ethiopia	Mali	Senegal	Uganda
• Difficult to give exact figure • EnDev supported one • Developers mostly target business/ commercial customers	• EEU has 29 diesel mini-grids, all operating. 11 in the process of being grid connected • 5 micro-hydro power mini-grids by EnDev, of which 2 operational • Limited number of private mini-grids • Ministry of Water, Irrigation and Energy now implementing 37 mini-grids total	• Approx. 256 diesel mini-grids implemented, 150+ of which are being hybridised, and 80% of which are not operational • Mini-grids start working when hybridised • Very few soar mini-grids • One mini-grid supported by EnDev so far, a further 8 in development	• 260 installed by 2018 (83 operational) • 302 under construction (300 GAUFF; 2 ASER) • 272 planned (Islamic Dev. Bank, PUDC, EU, Abu Dhabi Fund) • Some mini-grids starting to be interconnected by SENELEC • 48 of the 87 mini-grids implemented by EnDev still operational	• Less than 20 currently implemented (mostly hydro) • New 40 implemented by GIZ Pro Mini-Grids will be 100% solar • kfW to implement 100 hybrid mini-grids

Table 2. Mini-grids implemented in selected EnDev countries

Case Study: Greenlight Planet – Innovation in PicoPV

Greenlight Planet, one of the world's largest manufacturers and distributors of picoPV and SHS products by number of customers, has confirmed that "innovation in picoPV is not dead". The company develops a new range of picoPV (and SHS) products approximately every two to three years, with the latest updates to the products having included the add-on of pay as you go modules, the inclusion of a radio in a solar lantern and regular improvements to the lamp's performance while keeping price points stable.

Greenlight Planet is now intending to further segment its customer base to enable the company to better target individual customers with products beyond picoPV and SHS. Whereas the sale of solar products requires companies to simply 'cast a net' over potential customers, the sale of add-on products requires a more targeted approach. Already, customers can upgrade from one SHS to another with the company's dedicated 'upgrade' program. Further products such as pay as you go phones are now starting to be marketed to customers.

Figure 9 The Greenlight Planet's 'BOOM', a picoPV product with integrated radio

DRC	Ethiopia	Mali	Senegal	Uganda
• Provision of technical support to local entrepreneurs and financing of stand-alone systems for productive use (20) • Facilitation of access to finance • Focus on island (Idjwi)	• picoPV, SHS and mini-grids • For picoPV and SHS, EnDev supports market (and demand) • Planning to implement 8 solar mini-grids with EU, to be managed by cooperatives	• Demand-based focus, not technology-based • Currently mostly SHS with PUE • Focus on building technical capacity • Developing mini-grids for 2 villages with high residential and PUE demand • Also looking at nano-grids	• EnDev started as pioneer for ERIL in 2006 (18 hybrid mini-grids and 55 communities with SHS from 2008-2010) • Scaling by EnDev from 2010-2016 (69 hybrid mini-grids and 144 SHS villages) • Consolidation and development of new solutions from 2016-2021, and focus on sustainability challenge of existing systems • 2021+ EnDev as pioneer for „mini-grid 2.0"; Complimentary actions to strengthen market for stand-alone systems and shift to maintenance • COVID Relief Fund for lost revenues of mini-grid operators	• EnDev focus until 2024 on SHS, some picoPV • EnDev strongly RBF-focused, large scale for HHs, smaller for refugees, social institutions (schools/ health centres) and PUE • Technical assistance (coaching, enabling environment, associations, awareness) • COVID-19 Economic Relief Fund for solar & cookstove companies including covering payments from PAYG customers for a limited period. • RBF: 'smaller for refugees and host communities' • GIZ Pro Mini-Grids is installing 40 mini-grids (EU and BMZ financed) • KfW implementing 100 mini-grids under GetAccess (EU and BMZ financed) • GIZ preparing a proposal to the Green Climate Fund for another 600 mini-grids. • Government is revising the masterplan which will reflect mini-grids potential.

Table 3. Focus of interventions by EnDev in the selected countries

3.4 Key market trends

Seven key market trends have been identified that are already shaping the off-grid sector and will continue to do so in the future (refer to figure 16 on page 40 for an overview).

3.4.1 Productive use

The productive use of energy (PUE) is a strong enabler for moving households up the energy ladder. While access to electricity *per se* can increase the quality of life (through e.g. lighting at night) and provide households with savings, it does not automatically imply an increase in household income. Through the productive use of energy, access to electricity is used to perform a value-added process, enabling the person with electricity access to provide a product or service that can be sold in the community. It is this additional income stream deriving from the productive use of electricity that enables the customer to increase its overall monthly budget for electricity expenditures, thus enabling a step up in the energy ladder. It should be noted that higher tier access is not in all cases more expensive than lower tier access, and that payments for higher tier access differ significantly for payments for lower tiers (for example, electricity from mini-/nano-grids is typically sold per kWh while SHS are paid off on a monthly basis). However, the move from picoPV to SHS as well as a move up the energy tiers within technologies (e.g. from low to high consumption within nano-grids or mini-grids), usually implies additional expenditures.

The integration of PUE into SHS and mini-/nano-grid programs is already well underway, including the fostering of welding, freezing, milling and woodwork activities. DC appliances have been developed for most of these activities, allowing productive use to also play an increasingly important role for SHS. Interestingly, the wider inclusion of PUE into SHS/nano-grids is also increasing the incentives for mini-grid developers to pilot new business models (see Case Study 1 in page 26). Contrary to SHS/nano-grids, mini-grids' main selling point has been to serve large productive loads. Nevertheless, in its essence SHS/nano-grids and mini-grids remain complementary in the type of customer they are each best placed to serve.

EnDev has collected innovative approaches, trends and learnings connected to PUE approaches in an analysis as part of its Learning & Innovation agenda.[32]

32 https://endev.info/moving-to-scalable-business-cases-in-productive-use-of-energy-endev-presents-practical-analysis/

3.4.2 Digitalisation

Digitalisation in SHS is already far advanced and was initially developed out of the necessity of being able to track and monitor systems as well as payments. By digitalising SHS, companies have been able to allow customers to pay off products using mobile money, and remotely switch them off in case of a payment default. Combined, these features resulted in the "pay-as-you-go" revolution that has significantly accelerated the distribution of SHS. In spite of its strong growth in the last years, the "pay-as-you-go" approach must however still prove its success and profitability, given the large levels of indebtment that several pioneering companies have incurred, as well as a few bankruptcies in the sector (most notably Mobisol). Incorporating digitalisation also enables companies to locate SHS using GPS coordinates, facilitating customer follow-up and potential repossessions. Some of these features are also employed in picoPV systems, mostly to the extent the products are financed on a pay-as-you-go basis.

The digitalisation of nano- and mini-grids has advanced slower than for SHS and is still ongoing for many projects. Nano- and mini-grids have a limited radius of delivery within specific locations that are well-known to the developers, making customer follow-up easier than for SHS, which are far more scattered. Therefore, the pressure to digitalise operations early on was lower for nano- and mini-grids than for SHS. The remote monitoring of mini-grids initially focused on the generation assets, with component suppliers also providing software solutions and remote monitoring equipment together with their products. Over time, mobile money and the integration of smart meters also allowed the monitoring of customers. However, monitoring of individual customers through smart meters is adding CAPEX costs as well as ongoing costs for data delivery and analysis. Therefore, some developers continue to prefer traditional meters over smart meters, relying on mobile money payments from customers as a proxy to determine consumption.

With time, we are going to observe an increased application of artificial intelligence (AI) and machine learning in SHS, nano- and mini-grids, informing generation assets when to use direct power from the sun, when to recharge and discharge batteries and when to switch on diesel gensets (for hybrid mini-grids). Artificial intelligence in SHS also allows these companies to now offer products & services beyond electricity (see section 7.4.3 below).

With digitalisation, operating and maintaining mini-grids becomes increasingly simple (and is justified in terms of increased up-front capital investment as long as operational expenditures are sufficiently reduced and increased accuracy in billing and mini-grid monitoring enable the operator to optimize the system's operation), allowing traditionally non-electrical industrial companies with sound technical and financial management to also operate mini-grids.

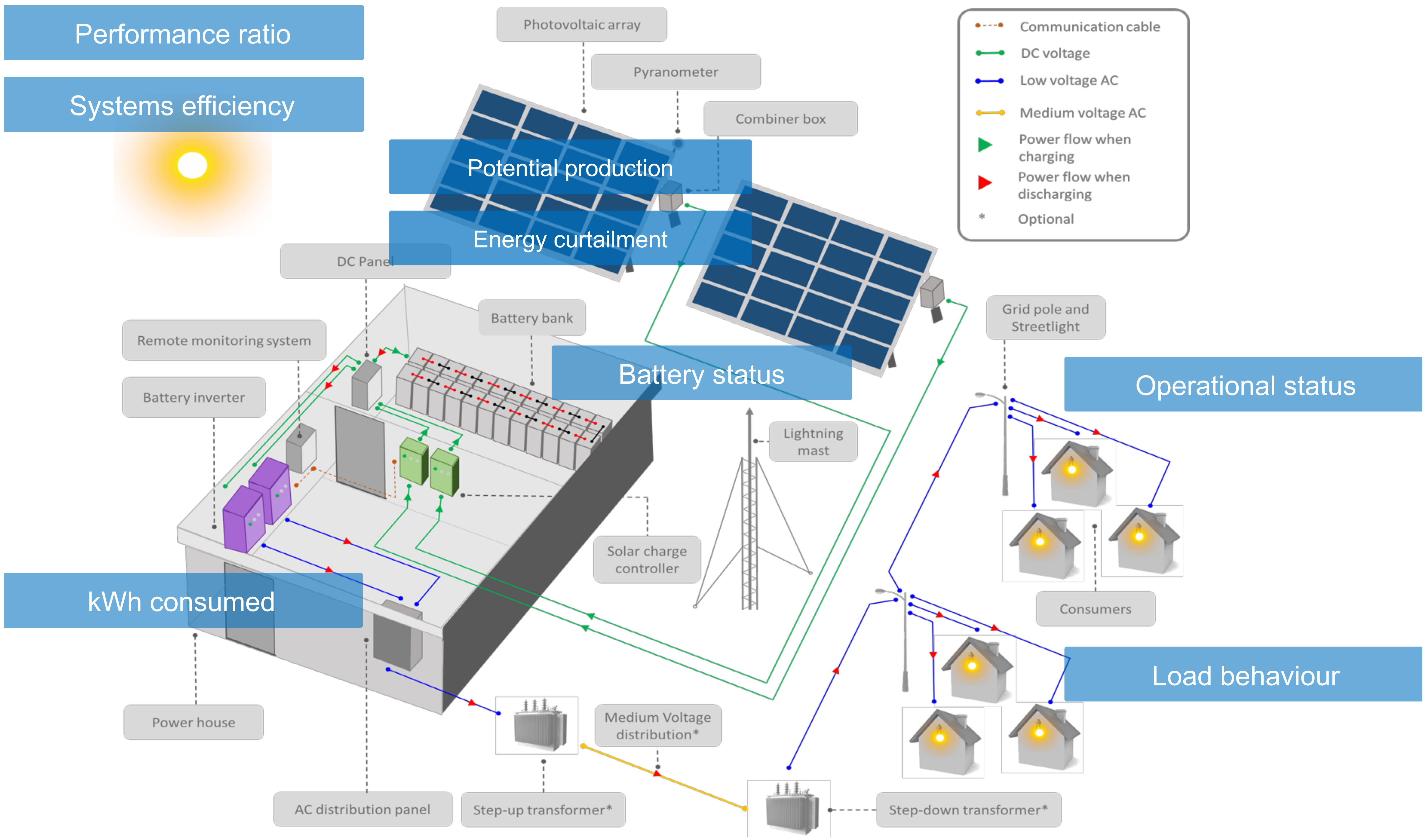

Figure 10 Visualisation of applied digitalisation in mini-grids (EnDev, 2020)

3.4.3 Add-on Products & Service

Because SHS retailers are now able to remotely deactivate products, and customers are paying with mobile money, some of the retailers are starting to use deployed SHS as a type of "collateral" for the purchase of new products or services. When payment for the new products or services is not made in time, the SHS retailer simply switches off the solar system, effectively leaving the customer in the dark until payment has been effected. Analysing and monitoring the data from SHS customers allows the companies to determine who the best repaying customers are and what additional products or services they could be marketed to. Products and services sold include mobile phones, LPG cooking stoves, microfinance loans, insurances and others.

This trend of additional products and services is accelerating across companies and markets, eventually leading to a situation in which some of the SHS companies could become rural product distributors and service providers in their own right. The focus of these companies will then not be on the provision of energy per se, but rather the establishment and growth of a significant rural customer base that can act as off-takers for a large variety of products and services. The SHS companies will effectively become an interface between remote rural customers and broader national markets.

Some nano-grid and mini-grid companies have also partnered with appliance suppliers (e.g. mobile phones, electric appliances) to bring their products to communities covered by nano- and mini-grids to enable customers to access high quality appliances, in some cases with a financing model to enable affordability and faster acquisition.

3.4.4 Battery innovation

The vast majority of SHS companies has already made the switch from lead-acid to lithium-ion batteries. Conversely, the majority of mini-grids and some nano-grids are still installed with lead-acid batteries, considering their relatively lower up-front costs. Nevertheless, the dropping costs as well as physical and chemical properties of li-ion battery banks, especially in terms of higher depths-of-discharge, longer cycle-lives and lower maintenance requirements, are enabling the technology to gradually become the new standard for application in nano- and mini-grids. Lithium-ion battery costs have been falling more than 8% year on year for the last eight years,[33] making them increasingly attractive to nano- and mini-grid developers.

In addition to first-hand lithium-ion batteries, the growing global electric vehicles market is opening up the opportunity for recycling these batteries and utilisation of second-hand lithium-ion batteries by nano- and mini-grid developers, but also SHS and picoPV companies. It should however be considered that second-hand batteries have high energy densities which contribute to lower runaway temperatures (battery banks should be kept under 45°C during charging to avoid thermal runway). In contrast, lithium-ion-phosphate batteries have much higher thermal runaway temperatures (180–250°C) and thus pose a clear advantage in this regard. For an integrated, sustainable development, the entire recycling chain has to be supported in parallel in order to set up political directives, technical standards, collection and recycling structures.

33 https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/

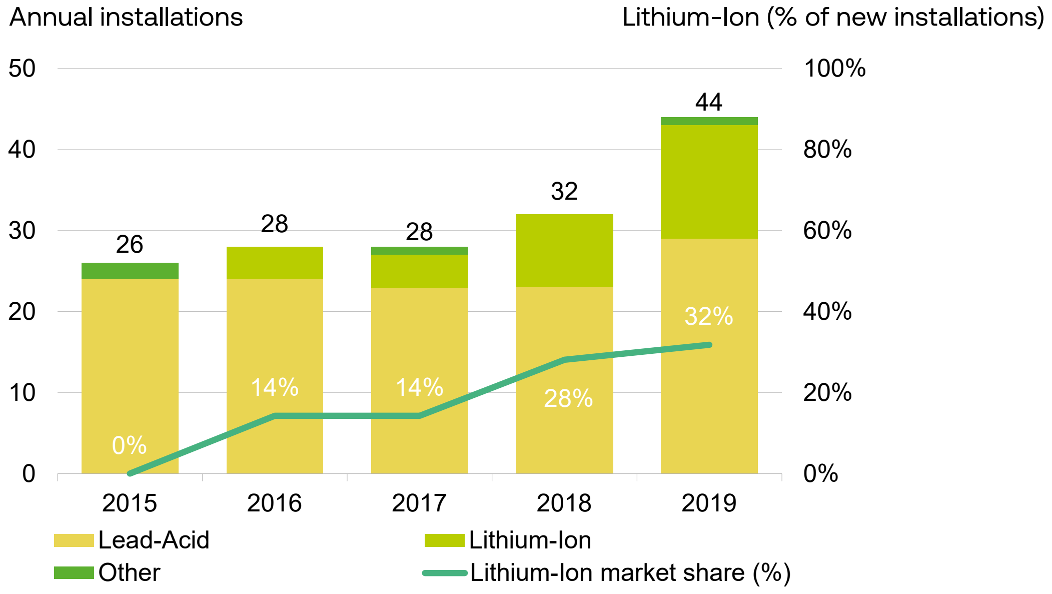

Figure 11. Annual installations of lead-acid and lithium-ion batteries in mini-grids (MGP, 2020)

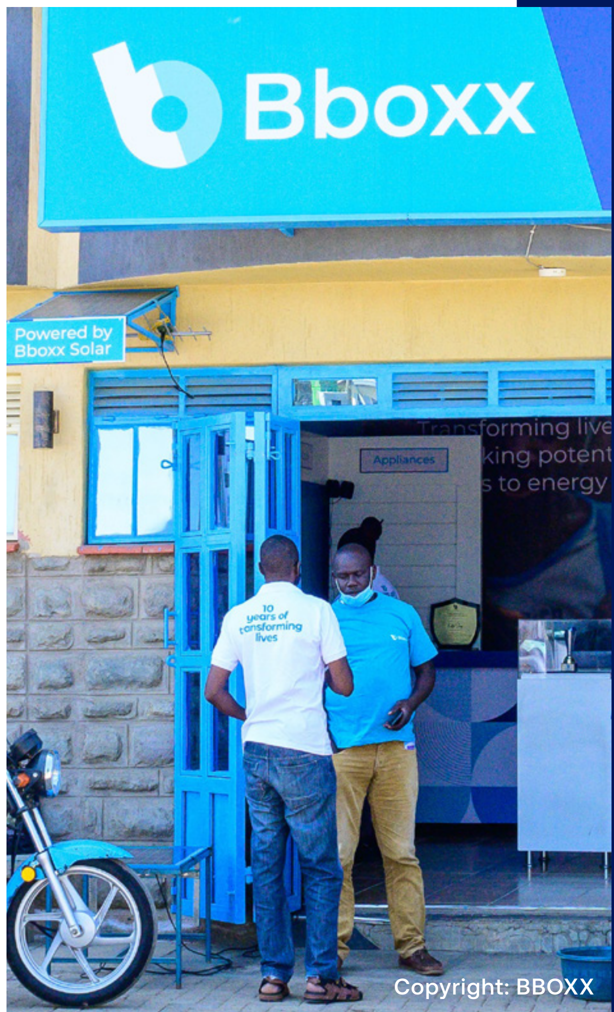

Figure 12. BBOXX store in Katito, Kenia

Case Study: BBOXX – Fee for Service

BBOXX, a UK-based self-declared 'next generation utility' that manufactures and distributes solar home systems to rural areas in Sub-Saharan Africa and parts of Asia, has in the past attempted to sell solar systems to customers on a 'fee for service' basis. Customers would pay a monthly fee for an unlimited amount of time for having a solar home system installed and operated within their home. Bboxx strongly believes in a service culture, however has improved their model by providing a set of options to customers ranging from ownership, pay for repairs, and fee for service. The options are designed to provide the customer's choice and flexibility to continued after sales and service.

Nowadays, BBOXX is starting to utilise the credit history from solar systems to assess the credit worthiness of customers to provide additional upgrades. The products include electronic goods such as televisions, premium TV bundles and phones which can be powered by Bboxx solar systems, but also cook stoves in line with Bboxx's new clean cooking service offer. Credit control is managed by the ability to remotely turn off the solar systems that customers already have. Further, BBOXX is providing water pumps, and seeking to extend its value-added services to include insurances and microfinance products, and tied to the sale of solar home systems. The company is utilising its own platform called 'PULSE' to monitor and manage customer contracts and relationships.

3.4.5 Rural industrialisation

Although the agriculture sector in Sub-Saharan Africa (excl. South Africa) accounts for one quarter of the region's GDP and employs the majority of the continent's working population, it does not sufficiently tap the available renewable energy potential. Most farming is conducted at the subsistence level, and access to electricity for farm operations or crop processing is inadequate and costly in most African countries. Water scarcity is an additional constraint to raising agricultural production in Africa. Only 6% of Africa's land is irrigated, compared to 37% in Asia and 14% in Latin America, making it the world's region with the lowest proportion of land under irrigation.[34]

Recent approaches have used mini-grids as a strategic tool to establish and actively promote rural industries based on locally available resources, in turn significantly advancing the development of the community in which the mini-grid is present.

One of these innovative business models, known as the KeyMaker Model, is based on the general idea that the mini-grid developer acts not only as a provider of electricity, but as a company that can purchase goods from the rural community, process these goods using electricity from a mini-grid and finally trade the processed goods to urban trade hubs. By opening up this revenue stream, mini-grids are becoming increasingly commercially viable, while additional value and cashflows to the local communities are realised and the quality of products, which previously had to be transported before being processed, can be improved.

Taking rural industrialisation as the main driver to position new mini-grids also opens up the opportunity to deploy mini-grids in more remote communities, which may not be attractive in terms of population numbers or density, but are nonetheless attractive from a resource point of view. This model makes it interesting for companies which were traditionally industrial players to enter the mini-grid space. Pilots of this concept are taking place in Uganda through a partnership between INENSUS and the rural agro-processor Gourmet Gardens. Industrial players could also set-up value addition processes in mini-grid villages which would increase demand for the mini-grids and benefit the processing companies which perform first-level processing/ decentralised processing. Communities can also decide for themselves which added value they want for their products before they are procured. Milk coolers in mini-grid villages for example, enable farmers to collect and store the milk to a volume which can later be better transported in bulk to milk processing factories. In some cases, mini-grid developers have partnered with appliance and service providers to provide these services in the communities. Internet service providers for example can make use of the mini-grid facility to power internet services and mobile towers accessed by the communities. Furthermore, technologies like electric motorcycles have been tested by some mini-grid developers, such as MAX Nigeria with Rubitec in Nigeria, where the batteries are charged on the mini-grid providing additional demand and revenues for the mini-grid developer while saving costs of diesel for the motorcycle users for transportation. Electric cooking, which has been piloted by CLASP and the mini-grid developer PowerGen in Tanzania,[35] has the potential to increase demand for households in mini-grid villages and contribute to climate mitigation and time savings when users switch from charcoal and fuelwood use for cooking.

34 United Nations Environment Programme, 2017: Atlas of Africa Energy Resources

35 https://www.clasp.ngo/updates/accelerating-the-uptake-of-electric-pressure-cookers-on-mini-grids-in-tanzania/

Case Study: JUMEME - Rural industrialisation through mini-grids in Tanzania

The combination of the processing of local resources together with the provision of mini-grid electricity has already been successfully tested in Ukara Island, Lake Victoria, Tanzania. A mini-grid developer called JUMEME is freezing Tilapia caught in the lake to trade this fish to wholesale off-takers in the country's economic hub Dar Es Salaam.

This provides local fishermen and their families with a stable and reliable source of income, and JUMEME a secondary source of revenue beyond electricity. Since the processing business has been established, the revenue from this business stream has been larger than that from electricity sales. The company is now rolling out fish farming around the lake following its successful pilot in Ukara Island.

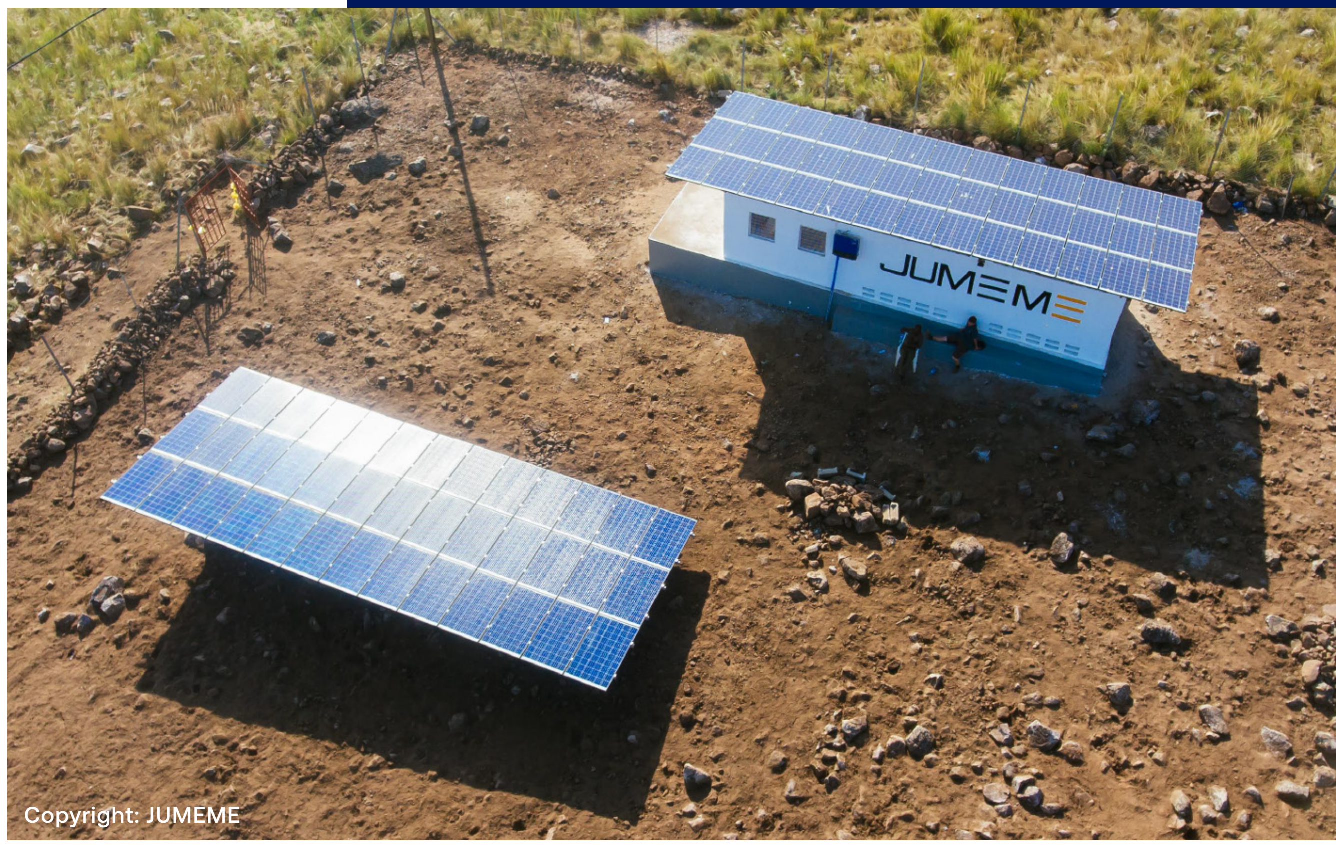

Figure 13. Some impressions from JUMEME's operations in Tanzania

3.4.6 Integrated electricity supply solutions

One of the future trends in the off-grid space is for private companies to start from a demand-based perspective, very similar to what the EnDev country team is already doing in Mali. Instead of considering their company as a pure SHS retailer or a pure nano- or mini-grid developer, these companies deploy integrated holistic solutions to cover the entire energy demand of rural communities.

In the centre of a community, a mini-grid will supply power to commercial customers/main productive users, to social institutions and close-by residential premises. The perimeter of the community, to which extending a mini-grid connection would not be financially sensible, will be supplied with SHS/ nano-grids.

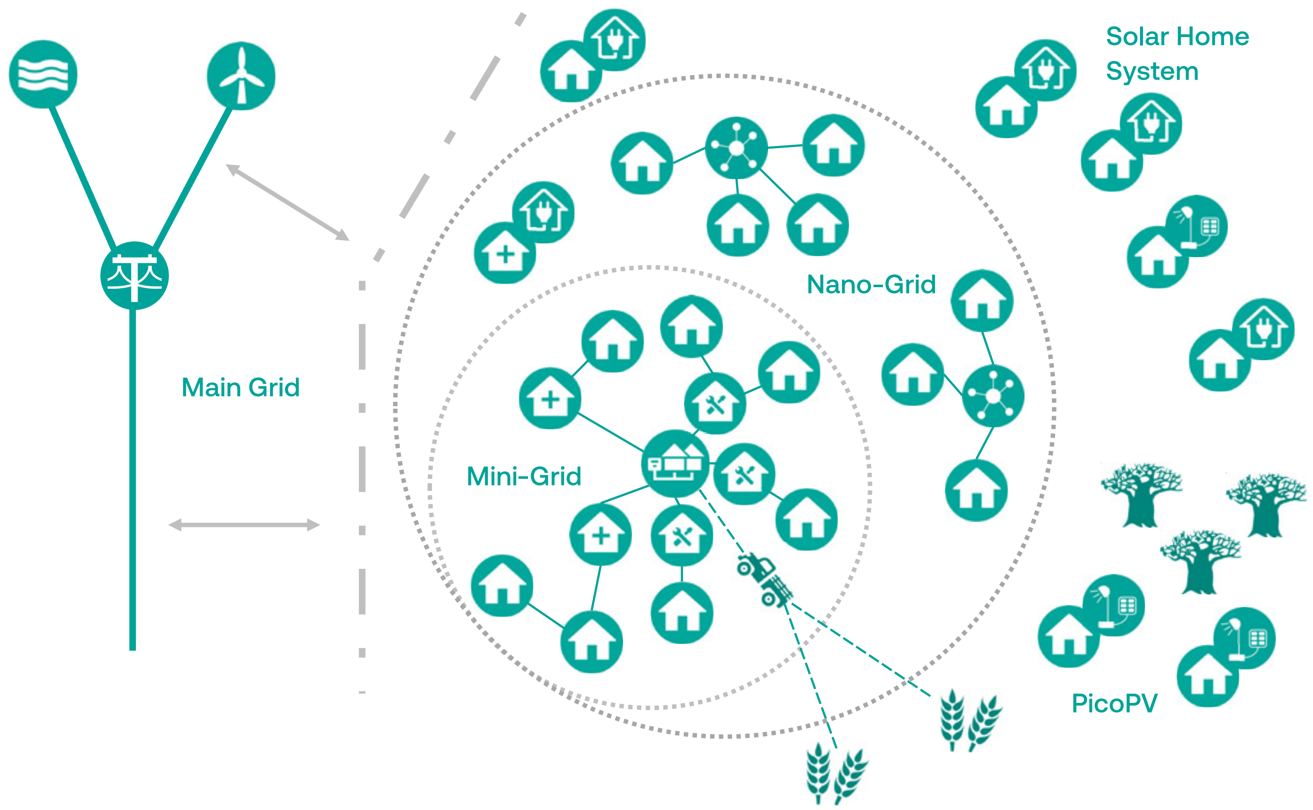

Figure 14. A range of customers in off-grid areas may be served by a single company through various technologies, or different companies in partnership

Figure 15. Winch Energy solar mini-grid

Case Study: Winch Energy – An integrated approach to electricity delivery

The mini-grid developer Winch Energy has developed a new integrated approach towards electricity access in cooperation with Mobile Power (MoPo). The companies have partnered to deliver options for electrification to customers in villages in Sierra Leone and Uganda. Winch Energy supplies the customers with higher income levels with electricity through mini-grids, and additionally supplies electricity to a battery 'hub' operated by Mobile Power and financed by Winch Energy.

Mobile Power's battery hub can recharge up to 300 small distributable batteries at a time, which are rented out for a period of 24 hours at a time to customers against a one-time rental fee. Customers may use the batteries for lighting, charging mobile phones, usage of fans and radios. The Winch MoPo partnership has so far been trialled in two villages in Sierra Leone and will also be deployed in the north of Uganda. It aims to help Winch Energy to smoothen its load profile and is increasing the commercial viability of its mini-grids.

3.4.7 Carbon credits

The increased scale and maturity of off-grid companies will eventually allow them to have a significant measurable positive impact on climate mitigation.

Carbon credits aim to account for the positive environmental impact of climate change mitigation and adaptation projects in monetary terms. A carbon credit represents one ton of carbon dioxide equivalent (tCO2) from the atmosphere that has either been captured or avoided by a given project. For off-grid electrification companies relying on clean technologies, the utilisation of polluting fossil fuels such as kerosene, diesel and charcoal is either mitigated or reduced. These companies earn the right to account for CO2 avoided by issuing carbon credits, which can serve them as a source of additional finance. An example of such a company is Namene Solar, a private company that has started financing solar lights in Zambia and Namibia by carbon credits and offsetting carbon emissions.[36]

Once fully implemented, the schemes in Zambia and Namibia are expected to generate 41,000 and 50,000 carbon credits[37] each annually.[38] Other organizations, such as South Pole, act as interfaces between carbon credit issuing companies and companies wishing to support carbon off-setting projects via the purchase of such carbon credits.

In the off-grid electrification sector, most active players are for now too small for their achieved impact to have reached the sufficient scale that justifies the transaction costs of issuing such carbon credits.

36 https://www.sun-connect-news.org/press/details/news///press-release-solar-for-every-off-grid-home-in-namibia-with-namene-solar-carbon-credit-scheme/

37 Internal communication with Namene Solar.

38 A carbon credit (also known as Verified Emission Reductions (VER)) is equivalent to 1 ton of CO_2.

Over the next decade, it is expected that off-grid companies will scale significantly, through organic growth, mergers and acquisitions, eventually leading to a situation in which the largest internationally active companies can become traders of carbon credits. Other promising pilot projects that can support the up-take of this trend are digital platforms that capture real-time data from remote solar energy systems and clean cooking solutions using blockchain technology and translate these into carbon-equivalent environmental values that can be marketed. This is the case for the DDIG concept (*Distributed Digital Impact Gains*) developed in partnership by Bboxx, South Pole, IBM and Shell Foundation, the aim of which is to be a public good that substantially reduces transaction costs for off-grid active players.[39]

39 https://shellfoundation.org/opinion/digitizing-unlocking-climate-finance-for-the-off-grid-sector/.

Current Trend

<table>
<tr><th>picoPV</th><th>SHS</th><th>Nano-grids</th><th>Mini-grids</th><th>Detail</th></tr>
<tr><td></td><td colspan="3">Productive use of energy</td><td>Wider inclusion of small-scale Productive Use into SHS opens competition between SHS and traditional small-scale mini-grids. Additionally mini-grids are increasingly fostering productive use.</td></tr>
<tr><td colspan="4">Digitalisation</td><td>Completion of the digitalisation processes incl. Artificial Intelligence (AI) and blockchain features simplifying off-grid company management, making project development and operations more efficient, transparent and reducing fixed cost.</td></tr>
<tr><td></td><td>Add-on Products & Services</td><td></td><td></td><td>Solar home system companies are bundling more and more diverse products & services on the back of technology that can enforce payments by switching off the solar system’s electricity output.</td></tr>
<tr><td></td><td></td><td colspan="2">Battery innovation</td><td>Technology switches from lead-acid to Li-Ion batteries for mini-grids. Second Life batteries may come into play and open some interesting investment opportunities within the hardware supply market.</td></tr>
<tr><td></td><td></td><td></td><td>Rural industrialisation</td><td>Mini-grid operators have the opportunity to actively shape rural industrialisation by processing agricultural goods in rural communities, trading these goods to national and international markets.</td></tr>
<tr><td></td><td colspan="3">Integrated mini-grid and SHS solutions</td><td>Single companies will operate mini-grids and SHS in parallel to cover complete communities through integration of mini-grid companies with SHS companies to gain efficiency and effectively address demand.</td></tr>
<tr><td colspan="4">Carbon credits</td><td>The reductions in CO_2 realised through the provision of renewable energy will be capitalised on by project developers and retailers of solar systems, once the ecosystem has reached sufficient scale.</td></tr>
</table>

Future Trend

Figure 16 Identified key market trends across the different off-grid energy sectors

Powerhouse of a solar DC mini-grid in Rwanda

Case Study: Developing a new, internationally recognized market instrument called D-RECs

South Pole is leading a multi-stakeholder coalition (Shell Foundation, UNDP, IFC, EnDev) to design and develop an internationally recognized market instrument for the certification of distributed renewable energy in collaboration with sector experts. The development of D-RECs will enable service providers to procure renewable energy certificates for corporate clients from distributed small-scale, off-grid renewable energy projects in a set of pilot countries (and later in other developing countries). The outcome is intended to be a new product for corporate clients to achieve RE commitments, develop new sources of revenue and improved unit economics for RE project developers, making projects more bankable for future investment and improving the economics of existing Results Based Financing programs. Consequently, the deployment of distributed renewables in the pilot countries and other developing countries is intended to be accelerated.

4

Sustainability in off-grid projects: Learning and innovation

Since its inception in 2005, EnDev has reached over 20m people through its energy access programs for electricity and clean cooking. EnDev's intention is to contribute sustainably to the provision of reliable, climate-friendly and affordable off-grid electricity access in beneficiary countries. This section provides an insight into the major factors to be considered when designing sustainable off-grid projects.

4.1 Definition of sustainability

"Sustainability" is a widely and dispersedly used definition that can take on different meanings depending on the application and organisation measuring it. In its simplest definition, in line with the IEA's definition of energy access, "sustainability" entails that beneficiaries of off-grid programs have **access to long-lasting reliable and affordable electricity.** In accord with UNFCCC's definition of "sustainability", a sustainable off-grid market would ensure that present electrification needs are met without compromising the capacities of future generations to meet theirs, ensuring the balance between economic growth, environmental care and social welfare. For EnDev, "sustainability" comprises a balance of financial, institutional, ecological, technological and social dimensions.

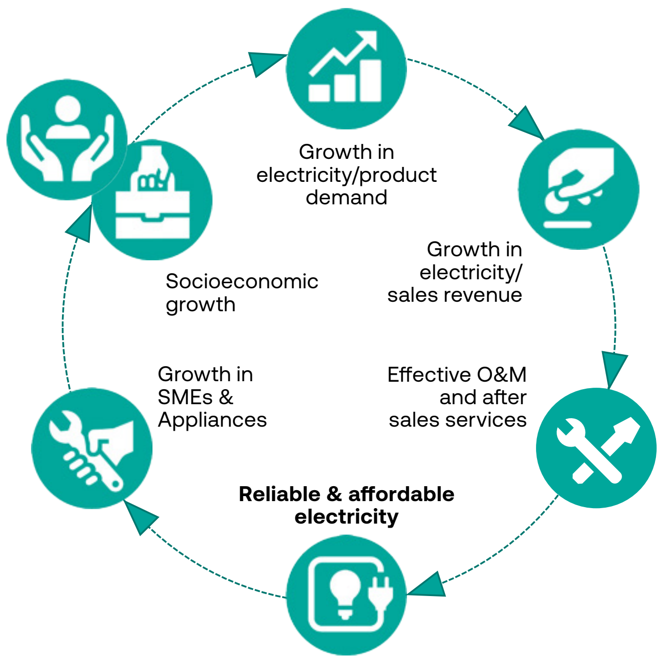

Figure 18. Virtuous cycle of electricity provision[40]

The term "reliable" implies that the electricity access is reasonably meeting the demand without being cut off unexpectedly, or frequently. In the context of sustainability, a reliable power supply would further have to be guaranteed in the long-term (measurable in years), which in turn necessitates the provider of electricity to be able to provide electricity in a commercially viable manner.

The term "affordable" implies that the electricity access can be afforded by the beneficiary. For households, the definition of what is truly "affordable" can vary by country and region, and even within countries. Providing affordable electricity can imply that subsidies ought to be put in place during the project development, construction, commissioning and even early operational phases in order to reduce initial investment costs and/or early ongoing operational costs for electricity providers (especially those related to the intensive early efforts of providing training to customers in electricity usage and setting up company processes). Such subsidies may be passed on to end consumers by enabling lower (nano- or mini-grid) tariffs or PAYGo-fees (in the case of SHS and some nano-grids), until the company's customer base is consolidated and the positive impact of a more dynamic local economy triggered by electricity access translates into increased local incomes.

For productive users, the definition of "affordable" implies that electricity is provided at a level equivalent to or cheaper than an alternative supply, which in the case of off-grid areas may involve the reliance on (fossil based) diesel generators in hybrid systems for a transitional period. Beyond the reliance on subsidies, **scale** in the number of systems deployed is regarded as an additional factor contributing to achieve affordability, provided it enables off-grid companies to reduce their per unit overhead costs.

Based on a paper developed by the University of Santiago de Chile and the Leuphana University Lüneburg, the provision of reliable and affordable electricity in itself sets off a virtuous cycle that ultimately leads back towards reliable and affordable electricity (see Figure 18).

Through the provision of reliable, renewable and affordable electricity, local SMEs may capitalise on additional opportunities for growth, increasing appliance usage and productive use. This results in the socio-economic growth of the community and a resulting growth in electricity and/or off-grid product demand, therefore increasing the electricity/sales revenue by electricity providers. The additional revenue generated can be invested by electricity providers into the provision of effective O&M and after-sales services, resulting in an increasingly reliable and affordable provision of electricity.

40 Based on graphic from https://ukdiss.com/examples/sustainability-of-off-grid-community-energy-projects.php

4.1.1 Sustainability indicators

In the bigger picture, sustainability is first and foremost a function of the extent to which the market for the required energy service delivery has developed. A mature market implies a viable business case in an adequate enabling environment, good availability of technology, good technical support, etc.. This would entail most ingredients for a sustainable further uptake of the energy service delivery.

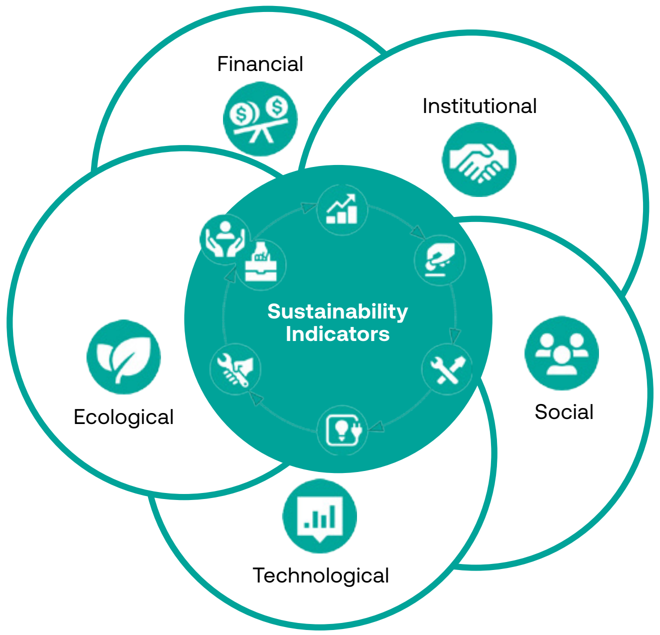

Figure 19. Overview of indicators impacting sustainability and the virtuous cycle

On the other hand, a market that has not yet fully developed, implies there are still hurdles on the demand- or supply side or in the enabling environment that may jeopardise market development and thus sustainability. However, a well-developed market does not by definition imply that ecological aspects of off-grid projects are taken care of.

EnDev's sustainability derives from five different perspectives:

1. **Financial**: Is there eventually a viable business case in the absence of the project, or sustained alternative funding if not?
2. **Institutional**: is there a properly developed enabling environment with supportive institutions as needed?
3. **Social** – is the project's output well appreciated and does it not in any way lead to inequality or social tension otherwise?
4. **Technological** – is technology for replacement and repair as well as the technological know-how for proper repair and maintenance available as required?
5. **Ecological** – does the project activity do no ecological harm? In particular, is there proper handling of E-waste for electrification projects?

The full list of questions to be considered under each of the sustainability indicators is presented in Annex A.1. It should be noted that a consideration of the sustainability indicators directly impacts the virtuous cycle resulting in reliable and affordable electricity.

4.2 Key challenges/barriers

Naturally, in the real world, the virtuous cycle for electricity access presented in Figure 18 may not always materialize automatically. Challenges and barriers exist that can hinder off-grid system providers (such as PicoPV and SHS) and electricity providers (mini-/nano-grid developers and operators) from providing reliable and affordable electricity, and/or block the virtuous cycle at important junctures. Oftentimes, these challenges and barriers are not just single "road blocks", but rather various speed bumps and obstacles interacting with each other that off-grid market players need to navigate simultaneously. In the words of one of the interviewees and particularly related to mini-grid deployment, **"there are no individual problems, there are causal, complex (inter-)relations that are hindering the development in rural electrification**".

The challenges can be categorized according to the developed sustainability indicators, though it should be realized that these are all interacting.

4.2.1 Financial challenges

Financial challenges can be relevant to both entire sectors and/or more project/implementation-level challenges.

On a sector-level, it was noted by the Ethiopian interviewees that local companies are facing difficulties in accessing foreign currency. To access foreign currency, local companies need to place a special request to the central bank. The time between application and final disbursal of foreign currencies can take months or in some cases even a year. This inability to access foreign currency, and/or foreign investment prevents companies to import high quality products and/or components into the country. This in turn results in companies resorting to either cheaper/lower quality products and/or locally produced products, if available, which can be more expensive. Ultimately, the customer will pay the price, either as higher cost or reduced quality of product/electricity.

In the mini-grid sector, the key economic challenge that any project needs to tackle is the tariff level to be applied. This has been confirmed as a key challenge across four of the five interviewed markets. A decision on mini-grid tariffs is inherently complex because it contains political, economic and cultural aspects. Mini-grid tariffs need to be politically acceptable, financially viable for project developers, affordable and acceptable to end users who do not have a very high purchasing power, and a justifiable balance needs to be struck between the tariffs charged by mini-grids vs. national grids (which are as a norm significantly subsidized, as outlined in Figure 21). By regulating/setting mini-grid tariffs, governments are indirectly making a decision on justifiable subsidies that ought to be paid to mini-grid developers.[41] Therefore, a debate on mini-grid tariffs and subsidies ought to precede the rollout of mini-grid programs by governments.

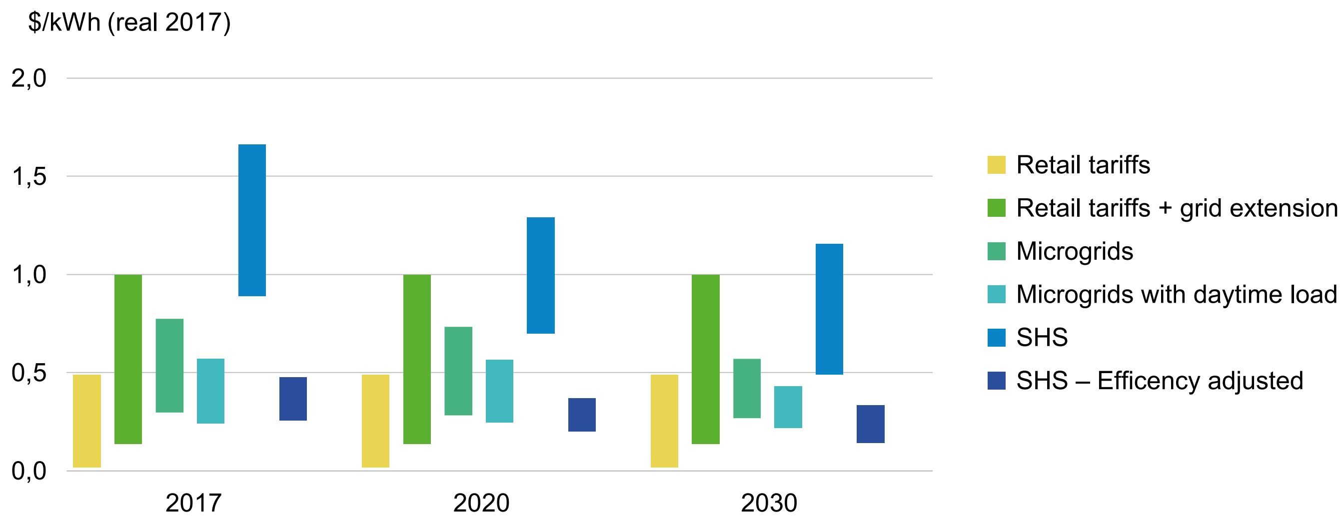

Figure 20. Level of mini-grid tariffs in comparison to national retail tariffs (MGP, 2020)

41 https://www.unido.org/news/unido-and-partners-publish-new-mini-grid-policy-development-guide

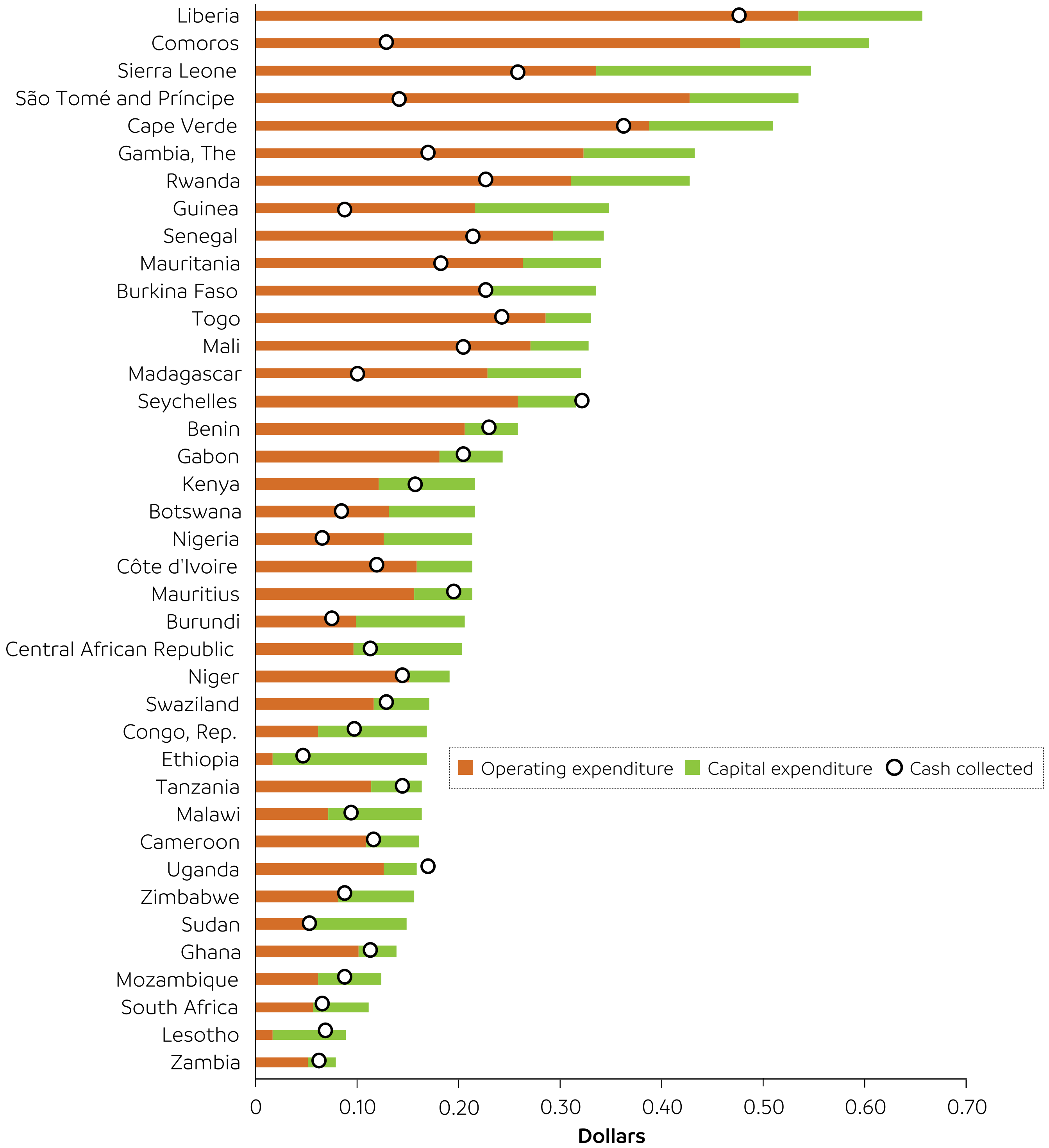

Figure 21. Comparison of utility electric supply costs with cash collected in 2014 U.S. dollars per kWh.
Source: Trimble et al., 2016[42]

42 http://documents1.worldbank.org/curated/en/293531475067040608/pdf/108555-Revised-PUBLIC-Making-power-affordable-for-Africa-and-viable-for-its-utilities-Oct-2016.pdf

4.2.2 Institutional challenges

Beyond the challenge of mini-grid tariffs, other decisions in off-grid projects can also be highly politically driven. Institutional challenges commence with electrification planning. In some countries, governments are only slowly acknowledging the important role that off-grid technologies will play in delivering universal access to electricity. Other countries are only just preparing nation-wide electrification plans. In Mali and Senegal, a clear overall direction/strategy for rural electrification planning is yet to be developed, and a changing political landscape is making planning even more complicated. In some cases, inappropriate planning has resulted in situations in which off-grid systems are built just next to or under grid extensions. The lack of appropriate regulations (or regulatory clarity) can thus undermine the efforts of finance development providers to support off-grid projects. The financial risk of an off-grid project that prevails beyond the completion of the donor's intervention is often ignored in favour of the arrival of the national grid.

With the previously outlined demand-based/push-approach to electrification, an *ex-ante* decision on the most appropriate technology to be deployed as part of a specific program could be contradictory, considering that technologies should only be selected when the specific demand has been evaluated. By assigning financing to particular technologies only, donors are actively determining how rural areas will be electrified. Significant funding has therefore gone into main grid extensions. Until 2019, only 1.2% of all finance for access to electricity went into off-grid projects.[43] With ambitious mitigation obligations from the Paris Agreement, donors are pushing towards the deployment of 100% renewable-based projects, which at the same time might be more capital-intensive than hybrid mini-grid projects, and ultimately impacting end user tariffs.

When it comes to regulation for off-grid technologies, the recent years have seen significant progress, with off-grid-specific regulations having been developed in many countries, and solar products often receiving import duty and VAT exemptions. However, the establishment and application of regulations can differ. In Senegal, only one out of five companies that has applied for a license to operate mini-grids has received one, effectively meaning that the other companies are operating in limbo and do not have any protection from grid interconnection. In the DRC, highly bureaucratic processes differ between regions and high levels of corruption make the realisation of projects time-consuming and difficult to realise.

43 https://www.seforall.org/news/research-shows-world-at-a-tipping-point-to-meet-global-energy-goals-by-2030

4.2.3 Technological challenges

While technology in off-grid systems is fairly advanced, some technical issues in the implementation of off-grid projects remain.

In the DRC, logistical and security challenges make it difficult for companies to access rural areas, posing significant limitations on the locations in which rural electrification through private sector initiatives is viable. Generally speaking, projects in rural areas do carry comparatively higher O&M costs, considering that access and logistics to these rural areas can be challenging. An additional challenge is the case of equipment damage, as spare/replacement parts are often not locally available and have to be imported.

A key challenge with both economic as well as technical implications is that in some programs, project developers are well-incentivised to be installing off-grid systems, but do not receive any incentive for adequately operating and maintaining the systems. In this regard, the principle of results-based financing commonly applied for power generation assets (i.e. number of connected customers) could be extended to measure a number of connected customers that regularly consume the system's electricity. This can be assessed by monitoring monthly pre-payment credit refills in the case of mini-grids to assess customer satisfaction for a well-operated and maintained system. Within the SHS space, SNV adjusted its RBF scheme in Cambodia to also create incentives for improved after sales service and maintenance of the marketed systems.[44]

Keeping the focus on subsidizing system installation can lead to a situation where developers focus too much on generating sufficient revenue from the installation, neglecting operation and maintenance. In Mali and Senegal, many of the mini-grids are non-operational, partly due to a lack of incentives for a proper O&M leading to unsatisfied customers. This can even end up in customers reverting back to private diesel gensets, particularly in areas where the price of diesel is affordable and easily accessible.

For SHS, nano- and mini-grids, some existing installations have not been sized adequately for demand. This can easily be resolved through adequate demand assessments in the planning process. Demand levels ought to be benchmarked with similar projects that are already operational in the country and by utilising suitable software to design the projects. In Senegal for example, batteries for SHS had been purposely oversized by EnDev so that they would still provide sufficient electricity during cloudy days. During the operation of these systems however the comparatively smaller PV panels were unable to recharge the batteries, keeping them operating at a low state of charge, and deteriorating much faster than expected.

Nevertheless, these lessons learnt contribute to the learning curve in the off-grid electrification sector.

44 https://snv.org/update/results-based-financing-grid-solar-energy-access-cambodia

4.2.4 Social challenges

COVID-19 has been the most important challenge over the last year, incapacitating project developers to adequately install and maintain systems. Travel restrictions, social distancing rules has resulted in a situation in where already existing projects are becoming non-operational, and SHS are sold but cannot be installed.

A recurrent challenge faced by many off-grid actors is the lack of qualified labour in remote rural areas to take-on the field tasks of system O&M. Also, qualified employees once qualified, migrate to urban clusters, effectively voiding the training efforts. In some countries, local private developers and operators simply do not have the capacity yet to sustainably develop and operate off-grid projects. Furthermore, the lower purchasing power of remote households often prevents the system providers/operators from generating sufficient cash flows to let the company grow.

Another social challenge is the fact that it is difficult to change consumer habits. Getting customers hooked to electricity requires deployed systems to perform smoothly from early on, especially when supply alternatives are available (such as diesel generators). In some cultural contexts, and when innovations, such as electric stoves, are promoted, beneficiaries may argue to prefer the taste of food from traditional cooking approaches.[45] In combination with a lack of awareness of negative health impacts of indoor pollution, this may lead to no/little demand for such products, or even switching back to traditional methods.

In cases where off-grid technologies provide access electricity for clean water pumping, the investment in an off-grid system will benefit women and children disproportionately as they save time for walking long distances for water-fetching, whereas the investment decision rather falls on the men. For off-grid market actors it remains a challenging task to convince households of the benefits from switching to clean renewable energy to off-set the costs in the long-run as they face increased up-front costs.

45 https://www.sciencedirect.com/science/article/pii/S2214629619304700

4.2.5 Ecological challenges

The ecological challenges of sustainability comprise the ecologic impact that a project has on its direct environment as well as the results of these damages. On the other hand, the impact of climate change can influence the sustainability of the project.

In off-grid electrification systems, e-waste generation (in particular of battery banks) is already prevalent, and expected to increase as the deployment of these systems increases. It is thus fundamental to identify, institutionalize and enforce circular economy principles in the off-grid electrification industry. Some (informal) collectors and recycling chains exist for lead-acid batteries across SSA that recover parts of the raw materials, however, this is often done at the expense of recyclers' health and the surrounding environment, mostly due to lead leakages.

Thus, for ecological challenges to be fundamentally tackled and circular economy practices to be internalized across the value chain, adequate regulatory frameworks and programs together with the willingness to enforce these must be in place. Beyond the performance of sound environmental and social impact assessments (specially for larger mini-grid systems), promising examples include the Sustainable Recycling Initiative[46] in Ghana which supports the building of capacity for sound management of e-waste, and the Lead Acid Batteries Road Map Development Program launched by Ethiopia's Environment, Forest and Climate Change Commission (EFCCC).[47] These programs pave the way for similar initiatives to be triggered in other countries in SSA.

A project that implies a negative environmental impact on its surroundings eventually affects the host community, both in the quality of the natural resources available as well as the health and well-being of its population. Both these factors ultimately undermine the potential for the community as a whole to thrive and develop, which in turn affects the community's ability to move up the energy ladder (and thus the economic sustainability of the off-grid project).

Finally, climatic factors beyond the control of the project itself, such as increasingly unpredictable and strong tropical rains, hail and floods can damage the deployed systems to the point they have to be partially or fully replaced.

46 https://www.sustainable-recycling.org/ghanaian-minister-for-the-environment-announces-two-key-initiatives-for-sustainable-use-of-natural-resources/

47 https://www.press.et/english/?p=10165#

DRC

Sustainability indicator: Financial

- Difficult logistics
- Presence of MFIs and other financial services Providers very limited
- Limited availability of other payment solutions

Sustainability indicator: Institutional

- High corruption
- Bureaucratic and opaque procedures

Sustainability indicator: Social

- Security issues
- High dependency of the population on humanitarian aid

Sustainability indicator: Technological

- Post sales and maintenance services are quite limited because of the low accessibility of most of the off grid areas

Sustainability indicator: Ecological

- E-waste not fully tackled by suppliers

Ethiopia

Sustainability indicator: Financial

- Mini-grid tariffs challenging as v. low tariff ($0.07/ kWh) for first kWh per week for households
- Limited access to FOREX for importers
- Financial institutions not yet ready to co-finance and insure hardware
- Inflation rate is high, thus interest rate is high

Sustainability indicator: Institutional

- Institutional framework for mini-grids not yet in place (under implementation currently)
- Directive for mini-grids in place, however not tested and considered incomplete
- The Cooperative proclamation does not allow to sell electricity to 3rd party. Therefore it is impossible for a cooperative to supply/sell electricity to a company and/or a government institution.
- Tariff setting is not flexible as first kWh/week according to the directive is sold at a very low cost.
- There is no cross subsidisation with the national grid (rural areas pay a much higher price for electricity than urban areas)
- There is no clear transparent mapping and plan for mini-grids making sustainable investment in mini-grids risky

Sustainability indicator: Social

- Capacities of local organisations for installation and O&M lacking.
- Operators in communities are not trained, and trained technicians leaving to urban hubs.
- Lack of understanding that a cooperative is also a business and should be managed to an extent with business principles.
- Difficult to explain to customers that high degree of energy efficiency (LED lights etc.) is a must to keep tariffs and electricity bills at a minimum
- There is still a gap in the understanding of end beneficiaries why cost-reflective electricity tariffs are necessary for the provision of mini-grids; Operators not having the full understanding of what happens if they charge low tariffs can have huge consequences on the installations and electricity supply, potentially jeopardizing sustainability

Sustainability indicator: Technological

- Low quality picoPV and SHS products without certification on market
- Combability between technology providers is not always in place
- All bits and parts must be imported

Sustainability indicator: Ecological

- All mini-grid projects require an Environmental and Social Impact assessment. This is good. However, this is not followed up closely in all instances.
- Battery recycling still need to be implemented.

Mali

Sustainability indicator: Financial

- 60+ different mini-grid operators who initially install with a margin on installation; not incentivised to be financially sustainable and no focus on operation
- Cost effectiveness of mini-grids not evident for most realisations thus far

Sustainability indicator: Institutional

- No clear overall direction/ enabling environment in place by government; Very donor-focused development; Changing political landscape
- Mini-grid tariff for 100kW+ mini-grids decided by committee; no real regulation in place; low tariffs preferred over viable business plans
- Electrification is necessary in local communes that lack financial and technical capacity to develop
- In 2017 multiple mini-grids transferred to national utility without proper cost compensation

Sustainability indicator: Social

- Low purchasing power
- Security not guaranteed in the north of the country

Sustainability indicator: Technological

- Technology is ‘fixed’ once in place while demand generally increases
- Abundant low quality solar installations (individual systems) leading to lack of confidence

Sustainability indicator: Ecological

- New systems are installed next to old (defect) ones instead of improving quality system/repaid resulting in abundant future waste
- Waste management lacking and E-Waste PV hardly addressed

Senegal

Sustainability indicator: Financial

- Current mini-grid tariffs are reflecting true costs; However, harmonisation exercise has not yet been extended to mini grids, causing frustration and mistrust by customers; In some cases, households reduce payments or stop paying their electricity bills
- High O&M due to remote communities
- Unsigned operating licenses (see below) impedes access to finance and thus investments into installations by operators

Sustainability indicator: Institutional

- Unsigned operating licenses/ contracts (only 1 of 6 operators with license) mean no compensation on grid arrival
- Lack of coordination between grid extension and mini-grids leading to systems built next to each other (similar to Mali)

Sustainability indicator: Social

- Low purchasing power of consumers (low capacity for productive use of energy is unable to increase users' ability to pay through economic development)
- Difficulties enforcing electricity payments / retrieving equipment in case of non-payment especially regarding SHS (no remote access)
- Confusion on fee-for-service approach with emerging awareness of PayGo products
- Consumers tampering with installations (e.g. circumventing power limiters or charge regulators, connecting HH to solar street lights, etc.)
- COVID-19 had huge impact as could not move between regions, impacting even minor maintenance
- Incomplete implementation of tariff harmonization by government causing confusion and mistrust by rural clients (who believe they are cheated by the operators)

Sustainability indicator: Technological

- Energy wastage due to flat rate tariff
- Fast energy need evolution / number of connected households exceeding capacity leads to overloading and premature degradation of equipment (especially batteries)
- SHS had oversized batteries vs. Panels
- Unavailable spare parts on local market and lack of knowledge transfer on handling and maintenance
- Use of equipment with regular maintenance needs (lead-acid batteries)
- Lack of upkeep and maintenance of equipment in general (choice of local caretaker not based on technical aptitude)
- Lack of incentive to use gensets led to gensets not being used
- Elevated ambient temperatures unfavourable to the operating conditions of the equipment, in particular the batteries

Sustainability indicator: Ecological

- E-waste not yet tackled

Uganda

Sustainability indicator: Financial

- Long-term sustainability in question if donors leave
- PUE financing for users is also a challenge
- Project development process takes very long with Gov until the projects are installed

Sustainability indicator: Institutional

- Government understands 'electrification' to be grid extension mostly, though slowly changing mindset
- Government wants to have mini-grid tariff below $0.30/kWh, not necessarily cost-reflective
- Electrification planning currently is not reflecting least-cost analysis and potential (though GOU has committed to revise the masterplan in 2020).
- Caping tariffs in mini-grid projects to lower figures which require subsidies to reach
- Few mini-grid projects so far hence little experience in the sector

Sustainability indicator: Social

- Low purchasing power of customers, high distribution costs due to poor infrastructure and remoteness of customers
- Land acquisition for the MG generation plant sites takes long and needs approval by long government processes
- Little awareness about the potential for MG electricity

Sustainability indicator: Technological

- Quality standards/ awareness about quality standards
- More efforts needed to ensure repairs and after-sale services for SHS and MGs are in place for all companies

Sustainability indicator: Ecological

- E-waste not yet fully tackled

4.3 Lessons learnt and innovation

Based on the challenges and lessons learnt from EnDev countries in the implementation of rural electrification projects, access to electricity needs to be tackled from a holistic perspective, not considering economic, political, institutional, ecological, technical and capacity considerations in isolation, but aiming to understand, relate to and apply multi-faceted and integrated solutions.

“Blanket approaches” that are standardised and prescriptive across regions often fail to reach the desired sustained outcomes, as it is important to consider country-specific contexts, challenges and situations. Approaches that have worked in one country may not necessarily work in another country, considering different conditions. For off-grid projects to be successful, both supply-side conditions such as local capacities, framework conditions, financing, and geographical constraints as well as demand-side conditions such as social, cultural and environmental aspects need to be considered when developing a project approach.

To give one example, nano- and mini-grid tariffs that may be well-accepted and workable in one country are not necessarily comparable to another country, where the implementation model, customer willingness to pay, socio-cultural norms, economic conditions and subsidy levels can differ significantly.

Country-level innovations that are considering lessons learnt from other countries can however lead to success, as long as it is clear that the best practices from other countries may need to be adjusted to suit local conditions.

Some promising innovations and lessons learnt that may improve the sustainability of off-grid solar projects from the EnDev countries are highlighted on page 66 et seq. Here we have highlighted some of the most important lessons relating to each of the sustainability indicators:

4.3.1 Financial lessons learnt

From the outset, (pilot) projects ought to be **designed for scale**, ensuring replicability and commercial viability (even pilot projects!) in the mid- or long-term, which enable their sustained operations particularly when the time comes for equipment replacement needs and donor finance may highly likely no longer be available (e.g. lead acid battery banks and other electronic components in mini-grids must be replaced after 10-15 years while mini-grid projects are designed to operate at least 20 years). The projects must by then have generated enough cashflows to finance such expenditures that ensure project continuity. Further, accessing debt to cover future financial needs necessarily requires for a project to be commercially viable and the implementing company to have a financially sound profile. Pilot projects cannot be said to be commercially viable when the pilot itself is designed at such a small scale that financial sustainability within the pilot cannot be achieved. For nano-grids and mini-grids, this means that projects for implementation in clusters of villages should be preferred to projects in single villages. For picoPV and SHS, pilot projects need to be of a sufficient scale to justify the administrative costs incurred by companies.

Private investments should be promoted and encouraged. Public funds and grants will continue to be limited and may run out eventually.

Despite a steady growth of the off-grid market, the move up the energy ladder is only happening slowly for the majority of customers, and mostly attributable to changes in income unrelated to electricity access, unless productive use has been incorporated. Prior to forcing customers to adopt solutions at tiers which are too high for their demand or ability to pay, projects should be designed sustainably for **sufficient scale within individual tiers**.

For nano- and mini-grids in particular, it is important that local economic considerations in terms of **ability and willingness to pay are accurately reflected in demand assessments**. Overall budgets for electricity expenditure in rural households do not differ much between countries, therefore international benchmarks can be evaluated to determine demand. The final demand is dependent on the tariff applied, therefore price elasticity needs to be taken into account. The tariff for productive users needs to be competitive when compared to local alternative solutions.

4.3.2 Institutional lessons learnt

Off-grid projects need to adhere to the broader policy framework in which they operate, and the local economy considered as a key driver to commercial viability. Measures to directly enhance the local economy, such as **rural industrialisation**, can be considered. EnDev off-grid programs can be designed either by including program activities aimed at stimulating a more conducive **enabling environment**, or in partnership with other programs that are influencing these.

For off-grid projects to be successful, **local stakeholders** should not be viewed merely as beneficiaries, but as active contributors.

The EnDev Senegal country team is considering **information sharing and knowledge dissemination** an integral part to successful project design. Peer exchange and learning can occur at a local level within the communities, or on a project level.

For mini-grid developers, the most important risk related to the longevity of the project is the **risk of project termination** through interconnection with the main-grid. Off-grid energy regulations need to be designed to minimise negative impacts following such a termination and ensure sufficient financial compensations to developers whose project returns can be hijacked by the above interconnection to the grid. The mere likelihood of such a scenario may undermine developers eagerness (and the appetite of investors backing them) to install mini/nano-grid systems in other parts of the targeted countries where the national grid may not arrive. Such a scenario thus can negatively impact not the recipient community of the encroached mini-/nano-grid (since they would be supplied national-grid electricity) as much as other communities so far remaining unelectrified and beyond the reach of the national grid. Mini-/nano-grid developers themselves can also consider implementing semi-mobile containers to house generation assets to at least partially mitigate this risk.

Case Study: UNDP Yemen – Women empowerment in mini-grids

A UNDP Yemen project, in partnership with the Sustainable Development Foundation (SDF) and supported by the European Union, has developed an innovative mini-grid project focusing on women empowerment. Against the background of a disaster-torn country, and the lowest-ranked country globally on the World Economic Forum's Gender Index, the UNDP Yemen project selected a group of educated women in the community of Hajjah to install and operate a local solar mini-grid with a capacity of 63kWp. The women received a capital grant towards the mini-grid and were trained for 20 days prior to components for the mini-grid being bought and installed.

The project is unique in its approach, considering that women in rural communities of Yemen are typically marginalised, and gender roles are fixed. Under the project, some resistance towards the project from local men in particular had to be overcome. However, following the successful installation of the mini-grid, the project is now delivering reliable access to electricity to 72 customers and the community is recognising the women group as leaders in the field of energy. The UNDP Yemen project is currently mobilising resources to further spread this type of initiative to other parts of the country.

Figure 22. 63kWp mini-grid deployed in Hajjah, Yemen

4.3.3 Social lessons learnt

Beyond consideration of women and girls as beneficiaries, measures should be put in place that foster **female entrepreneurship, empowering them to turn into installers and system operators**. In Senegal, 50 women groups are being trained to distribute SHS to end customers. By considering female entrepreneurs, an increased balance will also be achieved in terms of the ultimate beneficiaries of off-grid projects. This is backed by a recent study by Ashden: access to solar energy gives women flexibility in spending time on alternative (productive) activities other than household chores in the early morning and evening.[48]

Gender-conscious targets can raise awareness among the project implementers of the importance of gender aspects to project delivery, creating conscious positive biases towards delivering gender-sensitive projects.

Off-grid projects do not merely impact local beneficiaries. The broader impact of a project beyond the local community in, among others, its capability to stimulate and encourage neighbouring populations to organize themselves and potentially find new windows of opportunities for the implementation of similar projects should be considered. Further, fostering project acceptance and a good reputation across neighbouring communities can facilitate the scale-up phase for a given company to increase its portfolio or encourage communities to run the system, e.g. in a "Community Based Operator Model".

Alternatively, where the newly obtained access to electricity enables the community to now have access to potable water and other services stemming from commercial and productive use, electricity can indirectly benefit neighbouring community members who now have easier access to these services than before. Thus, **information and awareness campaigns should be** carried out not only for the sake of project acceptance by the recipient community but also indirectly neighbouring communities.

Mini-grid projects should be designed from the outset with the local economy as the driving force behind the project, for which a minimum level of existing economic activity is required for such a capital-intensive project. By considering a **rural industrialisation** approach, local farmers and families are immediately contributing to and benefitting from projects by acting as suppliers of raw natural resources and eventually labour. It is hereby important that instead of forcing a particular approach or process onto the local community, already established value chains are utilised, and adapted to the local needs. When productive use of energy is to be fostered, it is easier to coach and enhance existing businesses than trying to establish new businesses from scratch.[49] Based on the virtuous cycle theory, as the overall income level of the community raises, new businesses will organically develop as the beneficiaries themselves take the chance and use existing electricity access to initiate new economic-value generating activities. Provided the community is endowed with accessible routes, a more dynamic local economy in the community can eventually lead to its interconnection with existing trading links as its product and service offering increases.

Despite highly skilled staff potentially leaving rural areas to more urban hubs, it is nonetheless important that **local technicians** are identified and adequately trained on basic operations and maintenance tasks, allowing overall maintenance of projects to be more efficient and cost-effective. In Senegal, mini-grids will now be maintained through a combination of remote monitoring and local technicians (the latter can be called upon in case of system issues). Such a combination is particularly efficient, considering that the remote monitoring equipment ultimately saves time and money on operations, and the interaction with trained local technicians reduces the need to access remote sites. Local technicians are carefully selected and trained based on standard operating procedures (SOP). Regular trainings and peer-to-peer learning enable continuous learning over time.

48 https://ashden.org/downloads/Insights-from-Tanzania_Gender-and-Energy.pdf

49 Refer also to EnDev Lessons learnt from Indonesia

Figure 23. Delivery of solar systems to customers by Bidhaa Sasa staff in Kenya

Case Study: Bidhaa Sasa – A gender-driven approach to solar product distribution

Bidhaa Sasa (Swahili for Products now), a Kenya-based rural product distribution company that sells picoPV and SHS products, has a very clear commitment towards gender equity, all the way from the company's CEO to its on-ground staff. Recruitment, staff contracts and company procedures all consider gender sensitivity as a core attribute. The gender-driven approach is further translated into Bidhaa Sasa's customers. Data on product and service provision is sex-disaggregated, resulting in tailored marketing and messages to meet the needs of women and men.

Sales staff promote their products by scheduling demonstrations in potential customer homes as well as nearby locations (churches, schools). The majority of Bidhaa Sasa's sales staff is female, and sales are made towards groups of a minimum of five customers at a time. A 'group leader', who is responsible for communication with Bidhaa Sasa, is nominated by the clients in the group, with the entire group bearing the risk of payment default. According to Bidhaa Sasa, this model has been very successful, with the company having sold products to more than 90,000 customers over only six years, and 73% of the company's clientele being women. Women have also been evaluated to pay back loans more reliably than men, with only 53% of all payment defaulters being female.

4.3.4 Technological lessons learnt

Having O&M in mind from the outset as well as engaging and formalizing contracts with relevant actors from the project early phase ensures that the project is delivering reliable and affordable electricity over the entire duration of the project. When designing off-grid projects, it is important not only to fund the systems or components themselves; it is important to consider how the systems will be installed, operated and maintained. O&M should be properly considered in business modelling, i.e., profit margins should not just be based on the installation. Innovative approaches such as **digitalisation and machine learning applications,** data on consumer behaviour and local weather patterns can gradually enable the mini-grid operator **to optimize the system's performance.**

Importantly and in accord with a demand-side approach to electrification, the **technology deployed should fit the demographic, socio-economic and cultural characteristics of the local context** and not the other way around. Systems need to be sized appropriately and with potential demand increases in mind.

When deploying technology to rural areas, it is **important to consider how this technology will be effectively utilised by beneficiaries**. There is no need to deploy technology making use of high-speed internet when the area only has 2G networks. Similarly, the repairability of systems should be key. For example, batteries should be easily replaceable using local spare parts. Good quality batteries with identical composition should be locally available.

For mini-grids, it should be noted that the choice of generation technology results in consequences beyond technical considerations. The implementation of 100% renewable (solar) systems means that projects will need to be oversized, increasing the overall CAPEX deployed. Unless diesel is easily accessible and affordable (and thus cheap to procure on-site), the increase in CAPEX will also increase the consumer tariff, unless subsidies cover the difference in investment. While for instance the application of time-of-use tariffs and stimulation of productive use of electricity can influence a village's load curve to a certain extent, accurately dimensioning the project utilising state-of-the-art software and accurate demand assessments is particularly important to ensure that generation assets are not under- or over-utilised. Designing systems to allow for modular increases in size can be one of the ways to ensure generation assets meet demand even following demand growth.

Case Study: Fee for Service for Social Institutions (SI)

The Grüne Bürgerenergie (GBE) Bénin has developed a fee for service concept for off-grid technologies deployed in social institutions.

Generally, social institutions would purchase off-grid systems with only a short pre-defined maintenance period by the installers, followed by a hand-over to the management of the institution.

Once handed over, the new owners of the systems however would not have enough resources and capacity to invest into the continued maintenance of the systems. Therefore, the operation of these systems often halted after the first need for equipment replacement or after a warranty period.

The GBE has now come up with a concept whereby social institutions no longer pay for the purchase of the system, but for its long-term rental and maintenance (fee for service).

GBE further supports the implementation of this solution by providing RBF incentives, remote monitoring and technical assistance

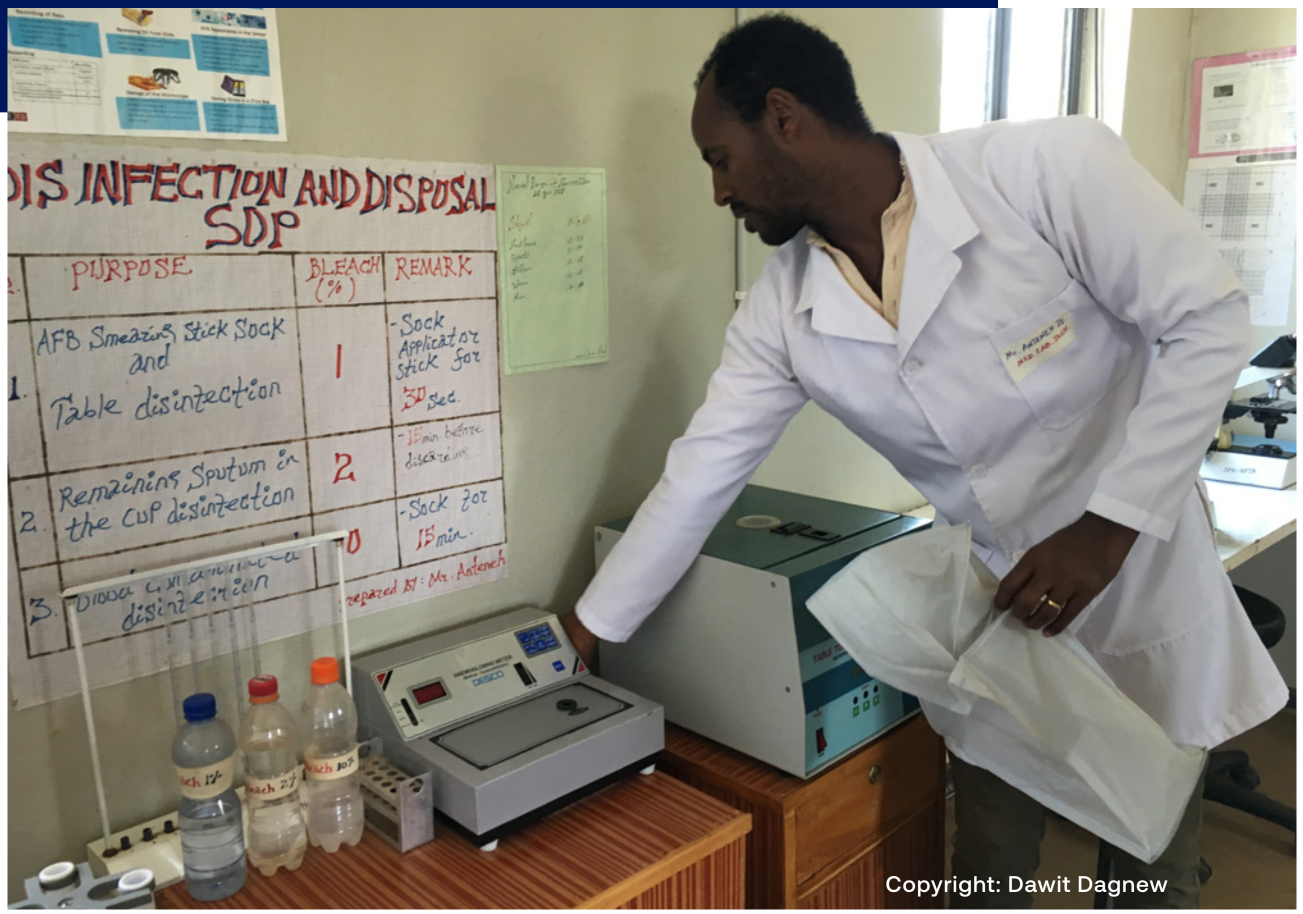

Figure 24. An off-grid health Center powerd by solar PV in Jimma, Ethiopia

4.3.5 Ecological lessons learnt

For projects to not only result in immediate access to electricity, but in long-lasting positive impacts, implications of the project implementation towards the **entire lifecycle of the project** need to be considered from the start. This re-enforces the importance of performing solid environmental and social impact assessments during the early project development phases, the outcomes of which can, where applicable, be reflected on the final design of the system.

The increased distribution of off-grid systems, in particular picoPV and SHS, will evidently result in an increase in **e-waste** following the decommissioning of these systems. Currently, the majority of markets do not have systems and processes in place to tackle this issue and question the sustainability. When developing an off-grid program for picoPV and SHS, a component that increases the capacity for dealing with e-waste/circular economy must be included. In Nigeria, the Extended Producer Responsibility Programme (EPR)[50] is an important governmental initiative that mandates component manufacturers, importers and distributors to take-back their end-of-life products from the environment.[51] As a donor, dedicating part of the efforts to develop a strategy that ensures such programmes can be sustainable by mapping the value chain and supporting the establishment of collection points and recycling would imply a coherent step in tackling the ecologic challenges of off-grid electrification projects.

The EnDev Mali country team is applying the **"reduce", "repair", "recycle"** strategy to its projects. With this, they are ensuring that projects are only implemented if1) a real need is addressed and projects do not duplicate other efforts (reduce), 2) all projects consider how systems will ultimately be operated and maintained (repair) and 3) the design takes into account end-of-life and recycling considerations at an early stage (recycle).

50 https://www.un.org/ecosoc/sites/www.un.org.ecosoc/files/files/en/2018doc/3_%20Anukam.pdf

51 https://guardian.ng/business-services/nigerias-ewaste-regulation-covers-producer-responsibility/

DRC

Sustainability indicator: Financial

- Important to facilitate agreements between financial services providers (FSPs) and renewable energy products suppliers

Sustainability indicator: Institutional

- May be easier to conduct private business than work as international organisation as more layers of bureaucracy involved

Sustainability indicator: Social

- Important that the private sector leads the interaction with the client to avoid that the presence of the NGO creates expectations of receiving free assets

Sustainability indicator: Technological

- Focus on providers that can guarantee post sale services and maintenance

Sustainability indicator: Ecological

- EIAs for mini-grids required

Ethiopia

Sustainability indicator: Financial

- Focus on PUE demand and high energy efficiency to counter tariff issues
- Identification of MFIs and access to loans for investment in PUE
- The financial sector (insurance and banks) not yet ready to tap into the mini-grid market. Due diligence needed before insurance companies will insure 3rd party O&M and banks will lend funds

Sustainability indicator: Institutional

- Focus on provision to rural areas (LNOB)

Sustainability indicator: Social

- Aim to reach energy justice and support gender balance by using a high degree of energy efficiency. This lowers the need for OPEX and CAPEX and reduces tariffs making electricity cheaper and more accessible to more people. This will also increase sustainability.

Sustainability indicator: Technological

- Diesel mini-grids not viable due to O&M requirement/ theft, , cost and supply of diesel, logistics, environmental consequences if there is a leakag
- Micro-hydro challenging due to limited number of sites, meaning the price/MHP is high compared to PV, thus the MHP sector might not be economic sustainable

Sustainability indicator: Ecological

- Development of roadmap for battery recycling
- Focus on Lithium-Ion batteries because of life time, reduced costs and more sustainability (lower tariffs and less pollution – if recycled correctly)

Mali

Sustainability indicator: Financial

- Off-grid markets are only developing slowly, need to keep in mind for scaling
- Need to tackle electricity access from integrated/ holistic perspective
- Need to consider installation, operations and service for solar, not just supply of material
- Assure service at proximity to reduce (important) transport costs

Sustainability indicator: Institutional

- Possible to arrive at agreement for cost effective pricing of mini-grids, based on business plan and implicating beneficiaries (local communes)
- Few private parties include sharing of benefits with local communes in mini-grid development enhancing financial capacities (and allowing technical capacities to grow)

Sustainability indicator: Social

- Improve access with Pay-As-You-Go and lease/ purchase
- Specific interventions required to enhance (the feeling of) security, still keeping focus on future market development

Sustainability indicator: Technological

- SHS and picoPV should be repairable ('no iPhones in rural areas')
- Purely solar mini-grids would result in tariffs which are too high; least-cost and max RE for clients results in hybrid

Sustainability indicator: Ecological

- Starting e-waste for SHS and picoPV (this is a problem)
- Focus on „reduce", „repair", „recycle"
- Solar lanterns for LNOB areas

Senegal

Sustainability indicator: Financial

- Remotely managing systems with contact to local caretaker may reduce cost and improve efficiency
- Targeted promotion of PUE
- Remote pre-paid payment systems may reduce cost and effort of money collection and increase payment discipline

Sustainability indicator: Institutional

- Information sharing may result in integration of lessons learnt into further mini-grids
- Institutional capacity building (training and deployment of assisting tools to monitor off-grid electrification)
- Need for introduction and use of a joint planning tool for all relevant stakeholders that invest into rural electrification

Sustainability indicator: Social

- Planning to select 50 women groups to distribute SHS
- Inclusion of gender-conscious targets
- Formalisation of local mini-grid caretaker with performance-based remuneration may help to enforce proper use of installations
- Special consideration of cost recovery of electrification of social infrastructure (development of income-generating activities, community fund, etc.)

Sustainability indicator: Technological

- Usage of semi-mobile containers for mini-grids
- Use of durable, low-maintenance equipment available on the local market
- Fee-for-service system not commercially viable when fees are collected manually (integration of remote fee collection)
- Inclusion of remote system and consumption monitoring and control (e.g. prepaid smart-meters, smart charge controllers) may reduce O&M costs, energy wastage, and cases of non-payment
- Deploying (digital) tools to support village-based maintenance
- Including technical and operational capacity building of operators and local mini-grid caretakers
- Dimensioning of systems (batteries vs. panels) key to sustainability
- Piloting Li-Ion batteries and active cooling of power stations
- Integration of user awareness raising activities on energy efficiency measures, establishing links to local suppliers of EE equipment

Sustainability indicator: Ecological

- Conducting study on establishment of solar e-waste sector and batteries and feed results into the stakeholder groups under the Ministry in charge of energy

Uganda

Sustainability indicator: Financial

- Rural industrialisation an interesting concept for mini-grids
- Community-run mini-grids difficult due to lack of capacity/ resources; Private sector is incentivised to operate system well considering revenue upon good operation
- GIZ Pro Mini-Grids project has 2 lots of 15 mini-grids and 25 mini-grids per operator. Upcoming projects like Get.Access also target lots of 29 mini-grids. The GCF proposal looks at lots of 50-100 sites per operator/tender.
- Subsidies are paid for part of the CAPEX (currently 65%) and rest of investments from developer is got through tariffs on energy sales. Future projects like GCF with bigger lots aim for 50% CAPEX subsidies.
- Mini-grid developers partner with appliance suppliers to provide electric appliances (mobile phones, etc.) and services (internet services, etc.)
- Government project ownership with REA financing distribution grid and part of connection costs in the Pro Mini-Grid tender.
- End-user financing is critical for SHS & PUE appliances and needs to be tackled both internally (i.e. PAYG) but also by financial intermediaries (i.e. solar loans)

Sustainability indicator: Institutional

- Climate change an underlying driver
- Mini-grid tender is run by the government (REA) instead of GIZ to ensure government ownership of the instrument
- Contracts are signed by the mini-grid developer with governmental agencies (Ministry of Energy, Electrification Agency and Regulator)
- Private investors e.g. NeOT, FMO, Sun Funder are involved in financing the project
- Contracts with developer are signed with Government also including measures of early termination as well as grid arrival cases

Sustainability indicator: Social

- Training technicians key to sustainable operation
- Uganda is one of the Energia pilot countries (focus on gender)

Sustainability indicator: Technological

- Developers use modular systems to manage future scale and lowering CAPEX costs per kW with set equipment
- Energy kiosk model offering energy services as well as products can help to provide market-based access even to refugees & host communities which are otherwise hard to reach

Sustainability indicator: Ecological

- Integrated e-waste policy/management of companies as added advantage in the tender process for RBFs to encourage best practices from the sector
- Pro Mini-Grids tender was 100% RE and no diesel generation allowed. Demand-side management was promoted.


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5 Recommendations

To create a lasting impact on the delivery of sustainable off-grid projects, the findings of this guide can be applied by EnDev practitioners and the wider off-grid sector. By planning from the perspective of the virtuous cycle for affordable and reliable electricity; by leveraging on the identified key market trends and by internalizing key learnings and best-practices of the five sustainability dimensions across the project life-cycle, the goal of universal access to electricity can be realised while ensuring a harmonization between socio-economic and environmental considerations.

Recommendations

5.1 Planning from the perspective of the virtuous cycle for long-lasting universal electricity access

When designing off-grid projects, the virtuous cycle resulting in reliable & affordable electricity should be applied. By ensuring that all sustainability indicators have been carefully considered, projects are designed with sustainability in mind.

In addition to the five sustainability indicators, the incorporation and **consideration of key market trends** identified in the picoPV, SHS, nano- and mini-grid sector can directly enhance the virtuous cycle. Figure 25 on page 75 is displaying how three of the key market trends directly impact the cycle.

Productive use interventions directly increase the number of commercial appliances in the village, indirectly leading to socio-economic growth, growth in electricity demand and revenue. In addition, the revenues for productive use equipment are a direct positive contribution towards the off-grid project operator's revenue stream.

Digitalisation approaches help to make O&M more effective and can contribute directly to the provision of reliable and affordable electricity, for example when machine learning is utilised to optimise the utilisation of diesel gensets in solar hybrid mini-grids.

Of all market trends, the consideration of **rural industrialisation** directly impacts most of the points in the cycle. Through close collaboration with the local community, the rural industrialisation approach directly contributes to a growth in local SMEs. Because mini-grid developers or industrial processors channel cashflows from urban trade hubs into the local community, the local economy is positively impacted. The local processing equipment effectively becomes an off-taker of electricity, leading to a growth in demand from the mini-grid. In the case where the mini-grid developer is the operator of the rural industrialisation business, the mini-grid developer realises additional revenues through the sale of processed goods. Because mini-grid developers make use of the same resources for the provision of electricity as for the processing of goods, O&M resources are used more effectively.

When realising access to electricity, it is important that this access is not only achieved at a particular point in time, but in a sustainable manner. There is no need for a beneficiary to have received access to electricity, when that electricity access is intermittent, with insufficient power to supply demand, or terminated after a few months or years following a lack in maintaining power supply and distribution.

The question of "how do we reach universal electrification within the next decade?" therefore automatically implies the question on "how do we ensure that electricity access is long-lasting and sustainable?". By applying the virtuous cycle for reliable and affordable electricity access, and considering all points of this cycle to be of equal importance, sustainable electricity access can be realised.

The setbacks realised through the ongoing pandemic should be viewed as an opportunity to design electricity access not just for within this decade, but for decades to come. Rather than striving purely for universal access, we should strive to reach a tipping point beyond which universal electrification is inevitable. At such a tipping point, market forces driven by innovations, efficiency gains and reductions of prices in technology, combined with enabling environments will enable the off-grid sector to actively deliver sustainable electricity access .

The question of when this tipping point will be achieved is thus an important and complex one for development practitioners. One of the requirements for the off-grid electrification market is to prove its long-term commercial viability. This implies **leaving the market opening phase and entering the scale phase**. A market can be seen to have reached **scale** when major players begin to emerge, and sufficiently trust the potential of the market to generate long-term profits so as to buy up competitors and start forming larger groups.[52] At this point, the market can be understood to be sufficiently dynamic, and eventually reach full market penetration (which in the context of off-grid electrification would imply universal access to electricity).

Instead of defining the tipping point from which universal electricity access will be inevitable in terms of the percentage of electrified population (which does not necessarily give insights on the economic sustainability of such market), it may make sense to use the point at which full acquisitions by the most successful and consolidated players of their competitors start to take place. Until present and as outlined in a recent World Bank's report, examples of strategic acquisitions and other mergers and acquisitions in the sector remain isolated.[53] Once these gain momentum (and regardless whether this process is led by traditional large energy companies or industrial players with an interest in the rich natural resources of remote rural areas), it can be understood that the market will have proven its potential for commercial viability, thus making universal electrification a matter of time.

52 https://hbr.org/2002/12/the-consolidation-curve#

53 https://sun-connect-news.org/fileadmin/DATEIEN/Dateien/New/gogla_2020_mar_off-grid-solar-market-trends-report-2020.pdf

Recommendations

5. 2 Internalizing key considerations from the five sustainability factors across the project's life-cycle

In alliance with the dynamics that are being triggered by the identified key market trends and leveraging on these, setting the focus on the following considerations stemming from the five sustainability factors may significantly contribute to make the most of deployed resources, time and efforts, in a context when all of these are scarce and time is pressing to timely achieve SDG7's affordable and clean energy access for all goal.

When aiming for the **financial sustainability** of the off-grid electrification sector, it might make sense to think in sector-coupling or "nexus" terms beyond merely energy access. This implies leveraging on the natural synergies that exist between the energy and natural resource processing industries as means to decentralized rural industrialization approaches. This in turn can facilitate attracting private capital that no longer needs to solely come from the traditional energy and finance industries, but can stimulate the interest of well-consolidated **national industrial players** (i.e. agro-processors).

Attracting interest of additional players can further contribute in fast-tracking the journey to scalability, one of the pre-conditions for market consolidation. Additionally, applying result-based financing principles to effective operational practices can stimulate the long-term planning approach of developers beyond securing grants to finance up-front capital investments.

From the perspective of **institutional sustainability**, donors could support conducive rural industrialization frameworks that are well harmonized with the growing number of rural electrification and mini-grid directives being put into place across several countries in SSA. Additionally, conducive mini-grid frameworks that mitigate early-termination and grid encroachment risks must be further developed for a consolidated mini-grid market to develop. Furthermore, for environmental considerations to be internalized by all, public and private actors, regulations need to be put in place that mandate active stakeholders to account for these. Finally, and given the persistent challenges faced by off-grid practitioners, the importance of information sharing and knowledge dissemination cannot be underestimated.

Considerations of **technological sustainability** necessarily imply gradually shifting from a supply-based/pull approach to electrification to one that is demand-based and in harmony with the targeted local context. As increasing amounts of data, experience and tools are available, this transition is but natural to ensure deployed resources are used optimally and impact is maximized. Further, while 100% renewable energy systems are in closer alignment to climatic considerations, it is important to assess in which contexts this may be a barrier to electrifying populations which, at a lower overall cost, could be electrified by relying in hybridised solar-diesel systems, at least for a transitional period.

Among **social considerations**, recently published research verifying the **strong price-elastic consumer behaviour** of the lowest income groups in rural populations should be kept in mind. This suggests that low-income households have a fixed budget for energy-related expenditures and thus increasing tariffs or fees for service will not lead to higher revenues, but rather to decreased consumption. Rather, the focus should be set on **stimulated productive use of electricity**, prioritizing those businesses already existing in the community. Aligned with this rationale and specially for capital-intensive mini-grid projects, focus should be on communities that have a minimum given level of economic dynamism. Finally, **gender empowerment considerations** should be a core part of project conceptualization efforts, not only as beneficiaries of electricity access but as well as active actors in the journey to universal electrification. Recent research proves that women tend to be more effective and consistent sellers of solar products than men. This is attributed to an inclination to "listen well, convey trust and honesty in their dealings with others".[54]

Finally, the sustainability of the off-grid electrification sector can only be ensured in the long-term if **ecologic considerations** become a core part of the project conceptualization and implementation phases. In close alignment with institutional factors, the undertaking of sound environmental and social impact assessments must be normalized and the focus on developing chains of e-waste collection points and recycling that enable the materialization of circular economy principles in remote rural areas ought to be enforced.

54 https://nextbillion.net/off-grid-solar-women-sales-agents/

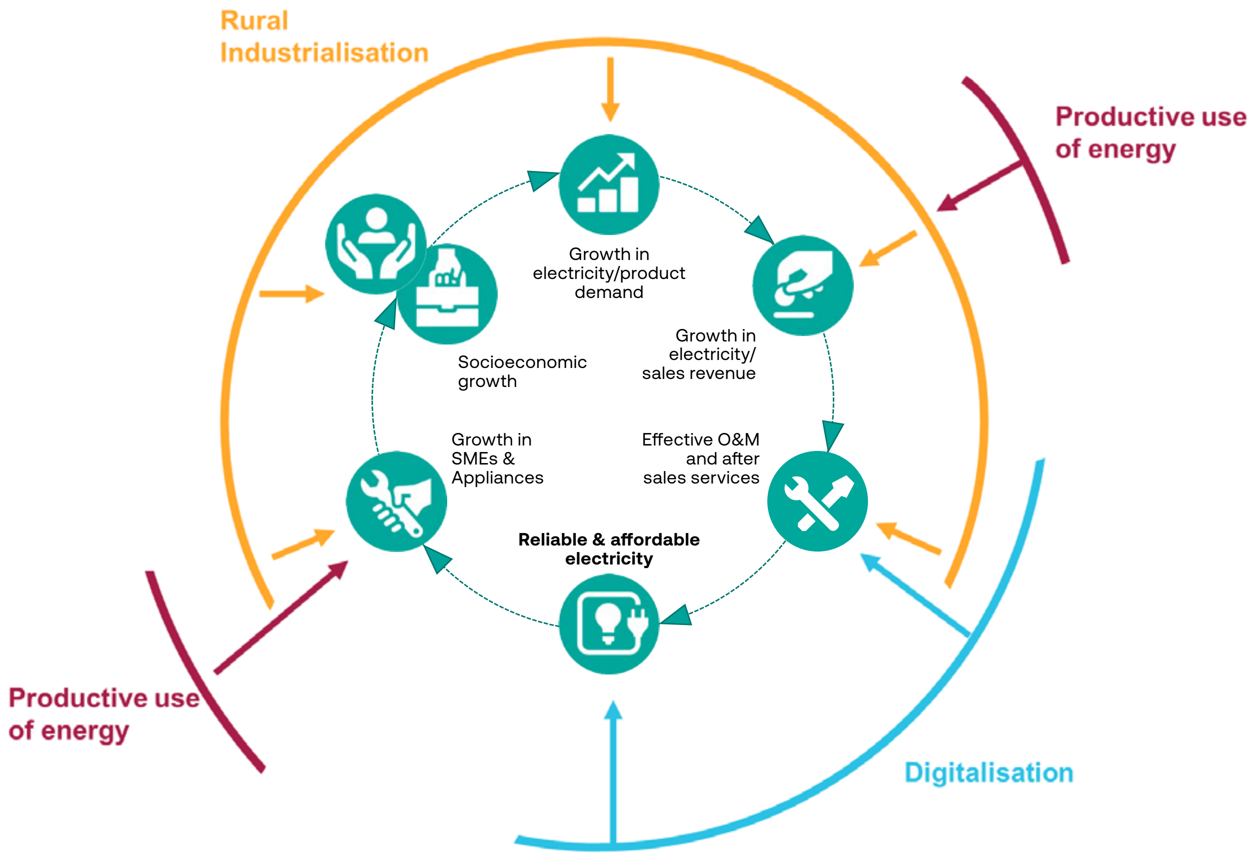

Figure 25 Impact of a consideration of key market trends on the virtuous cycle of sustainable electricity access

Annex

A.1 Table with full set of sustainability indicators

Indicator	Detail
1. Financial	• Can the project as implemented be successfully rolled out on a larger scale? • Have initiatives been considered to increase the local purchasing power (e.g. through a rural industrialisation approach)? • Does the project consider a realistic willingness and ability to pay for electricity, and realistic demand levels? • Has a realistic financial model for the project been developed that objectively showcases the commercial viability of the project? • Is private financing leveraged to the maximum during the project set-up
2. Institutional	• Have relevant public and private institutions/stakeholders been considered in the implementation of the project? • Are local entities/individuals capacitated and do they feel empowered and have ownership over the project? • Have lessons learnt from the project been compiled for transfer to other projects? Does the project consider knowledge dissemination to share lessons learnt? • Is the licensing and tariff scheme upon which the project is based firmly anchored in policy and regulation? • Is the project and deployed business model well-aligned with local policy on rural electrification? • Did the project foster learning & knowledge on the part of the operational entity? • Were embedded experts considered as part of the project implementation and did they transfer knowledge? • Does the project target not only energy companies but also involves related organisations e.g. agricultural organisations/local cooperatives?
3. Social	• Have women and girls as beneficiaries of energy access in terms of better health, reduced drudgery and improved information and education been considered, and impacts measured? • Does the operation of the off-grid projects consider women and girls as operators and/or entrepreneurs? • Have users been adequately trained on the utilisation of technology, and does a clear understanding exist with respect to consequences of default on payment? • Does a feasible plan exist for how projects will be sustainably operated once put in place and have roles and responsibilities been clearly defined? • Is the initiative considering risks in subsequent operation and has addressed mitigative measures to address these? E.g. COVID-19, political risks, demand risks • Is a clear need of the local community being addressed? • Does the project consider marginalized groups?

Indicator	Detail
4. Technological	• Does the project take a modular approach with increases in demand resulting in the deployment of additional energy capacity? • Does the project allow for interconnection to the national grid (in case of a mini-grid)? • Is it possible to remotely monitor the project through utilisation of digital tools? • Have machine learning/artificial intelligence been considered to optimise operation procedures? • Has the technology deployed been chosen based on the demand? • Have high quality components been utilised? • Is the installation of components of a high quality? • Are the components compatible with one another? • Has the project been adequately sized for the demand?
5. Ecological	• Has it been considered what happens to projects and their components at the end of the project lifecycle? • Does the project consider and meet social, economic and low carbon goals? • Were environmental and social impact assessments carried out and an environmental and social management plan put in place?

A.2 Interview questions for practitioners

The following set of interview questions was developed to guide the conversations with practitioners interviewed for the purposes of compiling this guide.

Rural electrification programs

- *This project looks at picoPV, SHS, nano-grids and mini-grids. Please briefly explain the technological focus of EnDev interventions for rural electrification in your country, and the reasoning for this focus.*
- *Has there been or will there be an evolution in this focus from one technology to another over time, and if yes, why?*
- *What type of electrification (by Tier and subsequently technology) is required where, and how can EnDev provide that?*
- *What are the key challenges / barriers faced while ensuring the sustainability of picoPV/SHS/nano-grid/mini-grid projects?*
- *How to overcome these challenges ?*
- *How are you linking or intending to link EnDev's priorities (e.g. climate change, e-waste, gender, LNOB) to the implementation of off-grid projects?*

Currently implemented mini-grids

- How many mini-grids are currently implemented in your country (best estimate)?
- What is the state of on-grid connection? How many mini-grids are somehow (in-)directly connected?
- How many of these mini-grids were implemented through support by EnDev?
- Could you please outline the most prevalent technologies (e.g. Solar/Solar Hybrid/Micro-Hydro) and sizes of the mini-grids implemented?
- How many of the mini-grids implemented (by EnDev) are still operational today?
- For those mini-grids that are not operational, what is the cause of failure and (how) are they intended to be re-activated/better serviced, also by EnDev?
- What kind of mechanisms are in place for repair, operations & maintenance?

Planned mini-grids

- What level of importance do mini-grids have in the country's overall electrification agenda?
- Does the country have a mini-grid specific regulation in place and what are the cornerstones of this (e.g. tariffs, grid arrival)?
- Through which delivery model are mini-grids intended to be implemented (e.g. ESCO, Private with Capex Grant, Split Asset Model etc.)?
- How many mini-grids do you know of that are planned to be implemented (by EnDev), how are these to be funded and what technology are they using?
- What additionality do planned EnDev mini-grids provide that are not covered through other programs?
- For mini-grids to be implemented by EnDev, how does the implementation incorporate past lessons learnt?
- For mini-grids to be implemented by EnDev, how will you ensure operational sustainability and scale?
- What are the recommended activities or approaches for a sustainable development of mini-grids (i.e. financial, economic, social, environmental, and institutional aspects)?

Any other comments

A.3 List of contributors

This guide has been developed with the insights and contributions from the following persons. We are thankful for their contributions through reviews of the guide text as well as interviews. Without their support, the development of this guide would have not been possible.

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