Malawi Rural Energy Development

Minigrid and stand-alone electrification

Policy and regulations

Case studies with energy demand, system design and feasibility analysis

ASCENDIS

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CONTENTS

LIST OF BOXES

ABBREVIATIONS AND ACRONYMS

ACRE	Access to Clean and Renewable Energy
ASCENT	Accelerating Sustainable and Clean Energy Access Transformation
ATP	ability to pay
AWP	Annual Work Plan
B2B	business-to-business
BDT	Bangladesh Taka
CAPEX	capital expenditures
CEM	Community Energy Malawi
CO	Country Office
CSO	civil society organisation
DEO	District Energy Officer
DPC	Direct Project Costs
DSS	demand-side subsidies
dvpt.	Development
EaaS	Energy as a Service
EAP	Electricity Access Project
EASE	Energy Access and Social Enterprise
EE	energy-efficient
EnDev	Energising Development
ESCOM	Electricity Supply Corporation of Malawi. Ltd.
ESMF	Environmental and Social Management Framework
FAC	Financial Advisory Committee
FCDO	Foreign, Commonwealth and Development Office (UK)
FSS	Financing Support Scheme
GDP	gross domestic product
GCF	Green Climate Fund
GEF	Global Environment Facility
GETF	Green Economic Transition Facility
GIS	Geographic Information System
GIZ	Gesellschaft für Technische Zusammenarbeit GmbH
GWh	gigawatt-hour (billion watt-hours)
HACT	Harmonized Approach to Cash Transfers
ha	hectare
HE	high-efficiency
IACADES	Increasing Access to Clean and Affordable Decentralised Energy Services in Vulnerable Areas of Malawi
IDCOL	Infrastructure Development Company Ltd. (Bangladesh)
IRRF	Integrated Results and Reporting Framework
KfW	Kreditanstalt für Wiederafbau
km	kilometre
kW	kilowatt
kWh	kilowatt-hour
LCOE	levelized cos of energy
LED	light-emitting diode
LPAC	Local Project Appraisal Committee
LPG	liquified petroleum gas
MAREP	Malawi Rural Electrification Program
MBS	Malawi Bureau of Standards
MCHF	Modern Cooking for Healthy Forests
MEGA	Mulanje Electricity Generation Agency
MERA	Malawi Energy Regulatory Authority
MFI	microfinance institution

MG	mini-grid
MITC	Malawi Investment and Trade Centre
MNB	Malawi National Bank
MoA	Ministry of Agriculture
MoE	Ministry of Energy
MoLG,U&C	Ministry of Local Government, Unity and Culture
MREPG	Malawi Renewable Energy Partnership Group
MSME	micro, small and medium-sized enterprise
MW	megawatt (million Watt)
MWh	megawatt-hour
MWK	Malawi Kwacha
NIM	National Implementation Modality
NGO	non-governmental organisation
NPC	National Project Coordinator
NSO	National Statistical Office
OGELS	Off-Grid Energy Loan Support (scheme)
OGMDF	Off-grid Market Development Fund
OPEX	operating expenditures
PAYG	pay as you go
PM	Project Manager
POPP	Programme and Operations Policies and Procedures
PPP	public-private partnership
PSP	portable solar product
PUE	productive use of energy
PV	photovoltaic
QAMF	Quality Assurance and Monitoring Framework
RBF	results-based financing
RE	renewable energy
REIAMA	Renewable Energy Industries Association of Malawi
RP	Responsible Party
RR	Resident Representative
RURED	Rural Renewable Energy for Development
SACCO	Savings and Credit Cooperative
SAS	stand-alone solar
SBAA	Standard Basic Assistance Agreement,
SDG	Sustainable Development Goal
SHS	solar home system
SMEDI	Small and Medium Enterprises Development Institute
SUE	social use of energy
TAC	Technical Advisory Committee
UNCDF	United Nations Capital Development Fund
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
USD	United States dollar
W	Watt
WB	World Bank
WTP	willingness to pay
ZCF	Zambia Cooperative Federation

1. BACKGROUND INFORMATION ON ENERGY AND ELECTRIFICATION

1.1 Energy supply and demand; rural energy planning

Because Malawi has no known natural gas reserves, nor the ability to refine petroleum fuels, it must import all petroleum fuel sources. These include petrol (gasoline), diesel, paraffin (kerosene), and heavy fuel oil, which are used for a range of energy services from transportation (about 85% of final demand for fossil fuels), in the industry for direct use, to running generators. The National Oil Company of Malawi maintains the country's fuel reserves.

Malawi is quite unique with about three-quarters of its electric energy generated coming from hydropower (1692 GWh in 2021, out of a total of 2,335 GWh Installed capacity was 442 MW in 2022[1], of which he estimated installed capacity of hydropower was 290 MW[2], solar and wind power is 81 MW and bagasse-based 18 MW[3]. Currently, none of Malawi's hydropower plants have dams, which would allow for holding water reservoirs to ensure consistent power supply when water levels in the river are low. Diesel power plants (with a total capacity reaching 53 MW) supplement hydropower plants during daily peak periods. Most plants are owned by the utility EGENCO (445 MW, mostly hydro, incl. the Kapichira facility) and IPPs (independent power producers, 91 MW of which mostly 80 MW solar). Auto producers, (35 MW) are businesses who produce electricity largely for their own needs but their main economic activity is not the production of electricity. Examples of auto producers include sugar mills (18 MW).

The installed capacity will not be sufficient yo meet power demand (estimated at 380 MW in 2017) and available capacity is at times much less than installed capacity due to frequent infrastructure and equipment breakdowns and fluctuating river levels limiting water flow that lead to frequent load shedding and power outages[4]. To close the gap between supply and demand there is an opportunity for Malawi to integrate into regional power-sharing agreements such as the Southern Africa Power Pool (SAPP) and the East African. Power Pool (EAPP). In 2019, the World Bank approved funding to link the power grids of Malawi and Mozambique. In addition, the government is currently exploring the potential for hydroelectric power generation on the South Rukuru and Bua Rivers to complement power generated on the Shire River[5]. Committed generation projects may increase capacity by 50% by 2030 but may fall short of all customers that will be added to new on-grid connections[6].

Household energy demand is driven by cooking and lighting needs. Malawi has one of the lowest rates of household electricity access in the world, with only about 17% of the total population having access to electricity. About 560,220 households are connected to the power grid, some 200,000 households are served by stand-alone applications, while about 2,500-6000 households may be connected to hydro and solar minigrids[7]. Access to clean sources of energy for lighting has increased significantly in the past two decades as households shift away from kerosene use towards battery or solar-powered torches (flashlights), and small, but growing amounts of electricity from the national grid or home solar systems.

The government launched the Malawi Rural Electrification Program (MAREP) in the early 1980s, the Malawi Rural Electrification Program. The approach of MAREP is to electrify trading centres and marketplaces in a phased manner. So far, the government under MAREP has electrified over a thousand trading centres across the country.

1 IRENA

2 EGENCO's capacity (316 MW) is largely generated by four hydropower plants: Nkula power station, located on the Shire River (installed capacity of 135 MW); the Tedzani power station, also on the Shire River (capacity of 121 MW); and the Wovwe power station on the Wovwe River (capacity of 4 MW). The figure does not include the he Kapichira power station located at Kapichira Falls (installed capacity of 128 MW, about 25% of the country's installed capacity), which was damaged catastrophically after tropical storm Ana struck the dam in January 2022. World Bank will lend to restore the plant's cap[acity to 135 MW.

3 See *Digest of Malawi Energy Statistics* (2022), Ministry of Energy

4 A number of industrial enterprises have installed diesel generators to serve as a backup for the energy services that are reliant on the national grid for electricity. In addition, many small business owners have purchased portable diesel generators as back-up for grid electricity, or as a standalone power source.

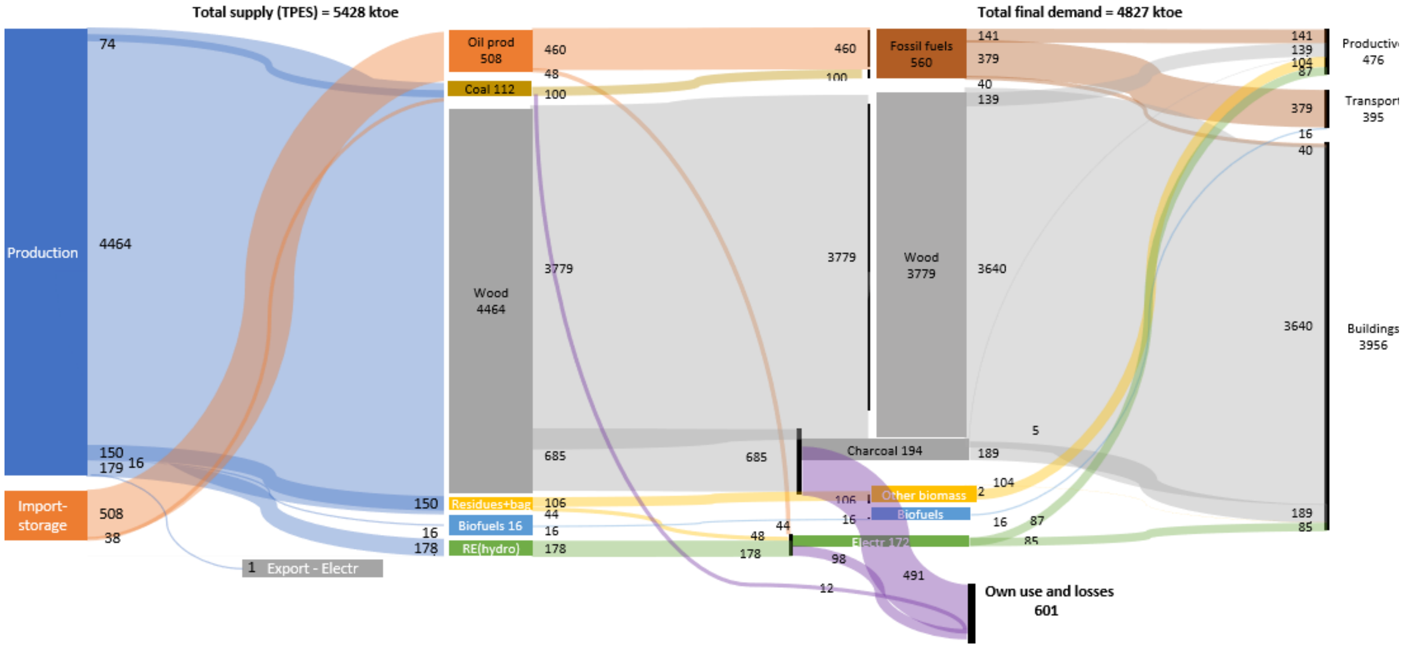
5 EPPSA (2022)

6 *Malawi Sustainable Energy Investment Study* (2019), Ministry of Natural Resources, Energy and Mining (MNREM)

7 Own estimate,. Basedc on ESCOM data, table and

Note: This section has been made available by J. van den Akker as part of additional analyss and can be accessed at www.ascendis.nl

Box 1 Energy supply and consumption in Malawi, 2021



Source: own elaboration, based on data complied from AU-AFREC database (2021 data)

All infrastructure under MAREP belongs to the Government of Malawi but it is managed by the utility ESCOM in terms of maintenance, operations and new connections. MAREP operates under the Rural Electrification Act of 2004 which has also established the Rural Electrification Fund (REF). By 2022, about 500 rural centres had been electrified[8]. Currently, MAREP is in its 9th phase, with completion expected in 2025[9].

Biomass is the source of about 85% of the primary energy supply (see Box 1). Two domestic companies produce bio-ethanol and biodiesel from sugarcane and another from Jatropha curcas providing 4% of total transport energy. The main form of biomass used for energy are woodfuels. Some 97% of Malawi's population (90.3% urban; 99.7% rural) use biomass solid fuels (e.g., firewood, charcoal) for cooking, according to the Malawi Integrated Household Survey 2017. Alternatives are very limited in urban areas; about 70% of urban households predominantly use charcoal, and around 20% firewood). Alternatives to woodfuels are non-existent in rural areas (80% predominantly use wood; 20% charcoal).

Charcoal production is typically produced in traditional earthen kilns, which are used throughout Malawi. The energy conversion efficiency of this type of kiln is inefficient, with an efficiency ratio of little more than 20%. Almost half of the charcoal comes from government-owned forest reserves and 39% is produced on customary land. According to Globalforestwatch data, Malawi experienced a net loss of 222,000 hectares (ha) of forest cover between 2000 and 2020 (equivalent to a decrease of 15%)[10]. The main cause is clearing for agriculture. The effect of charcoal production on deforestation is not that easy to determine; historically, charcoal production in Malawi prioritizes the selective harvesting of preferred tree species, with a preference for denser wood with higher calorific value, and longer and cleaner burn. But more recently charcoal production in Malawi utilizes clear-cutting of areas in addition, as the preferred trees get scarcer. In any case, both practices undermine forest biodiversity.

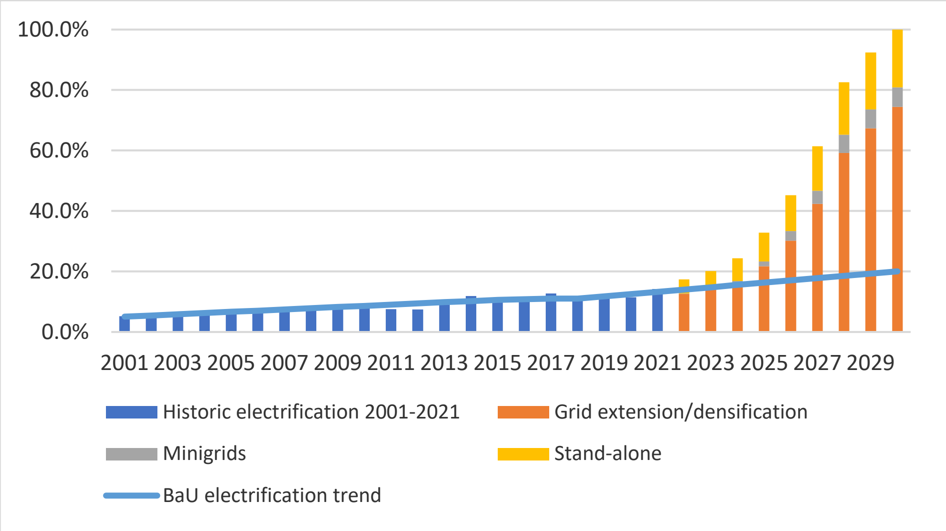
Urbanization will play a large role in increasing demand for household energy in Malawi. This increase in urban population will affect the already high, unmet demand for energy. On average, annual electricity demand is projected

8 *Stand Alone Solar (SAS) Market Update* (2021), TetraTech International Development

9 https://eppsa.cpc.unc.edu, *Energy Access in Malawi* (2022)

10 Loss was 264 kilohectares and gain 42 kilohectares, Total forest area was about 2,540 kilohectares (of which 240 kilohectares characterized as distrurbed). Two regions are responsible for half of the tree cover loss (Nkhata Bay; 83.2 kha; and Mzimba, 32.4 kha

Box 2 Historic electrification and planned 2023-2030 to achieve '100% energy access'



Source: complied from data.worldbank.org and Malawi Integrated Energy Plan

to grow 5% percent per year over the next decade. An increasingly urban population will also alter the portfolio of biomass fuels used for household energy purposes, increasing the country's reliance on charcoal, more commonly used than fuelwood in urban settings. LPG is imported as an alternative to wood-based fuels in homes but its usage is very limited due to high costs, perceived lack of safety, and the absence of a distribution network.

On current trends, Malawi will only reach around 20% electrification in 2030 and fail to reach the 'universal access to electricity' targets for serving the population (see Box 2). The 2022 Electrification Report of the Malawi Integrated Energy Plan maps out the pathway and its investment cost to achieve universal access to electric power by 2030 using on-grid and off-grid solutions. To increase access from today's population (4.5 million households) to universal access by 2030 (with a total population of 5.5 million households), 42% of new consumers will need to be connected via grid expansion and 22% will be connected via densification; off-grid electrification would account for 26% of the electrification plan, of which 7% represent mini-grid expansion and 19% via standalone solar solutions. Very significant investments would be needed during 2023-2030 in both grid and off-grid electrification technologies to achieve universal access to electric energy; about USD 3.4 to 4.5 billion (of which about USD 0.5 billion for minigrids).

The Malawi Sustainable Investment Study (2019) presents different scenarios, in which 30% of households will have on-grid access by 2030, and off-grid solutions will provide 70%. Estimated investments needed are about USD 2.37 billion for on-grid (of which USD 1400 million for generation, USD 350 million for transmission, USD 500 million for distribution and USD 70 million for DSM measures) and USD 140 million for off-grid solutions. In order to meet the fast-growing energy demand, EGENCO has ambitions to increase generation capacity to 521.5 MW by 2024; and 1256.5 MW by 2029[11], implying a 250% increase to reach the goal of 30% on-grid access.

Health facilities and schools are two energy-dependent predominantly public sector institutions critical for the health and future of Malawi. Recent studies indicate that about 70% of healthcare facilities depend on the electrical grid as their primary source of energy, however, only 20-50% of these reportedly receive a consistent, uninterrupted supply[12]. The Government of Malawi and donor organizations are increasing investment in solar electrification of healthcare facilities to support refrigeration and lighting. Solar backup systems are a promising option to provide reliable energy at healthcare facilities throughout the country. Off-grid systems (solar, diesel generator backup) provide power to about 20-22% of health facilities. Electricity access also plays an important role in school settings by improving the educational services offered, improving administrative processes, and extending the possibility for new services such as evening classes, computer courses, and access to the Internet and social media. Reportedly, only 10% of primary schools and 52% of lower secondary schools in Malawi had access to electricity[13]. In the Malawi IEP, 7123 schools will be provided

[11] And 1,631 MW by 2034. *Malawi Sustainable Energy Investment Study* (2019), *Energy Sector Position Paper* (JICA Malawi office, 2022). The proposed energy generation in the grid is 55% hydro (now 76%), solar (20%), wind (10%), biomass (1%) and interc onnections (14%).

[12] Ibid.

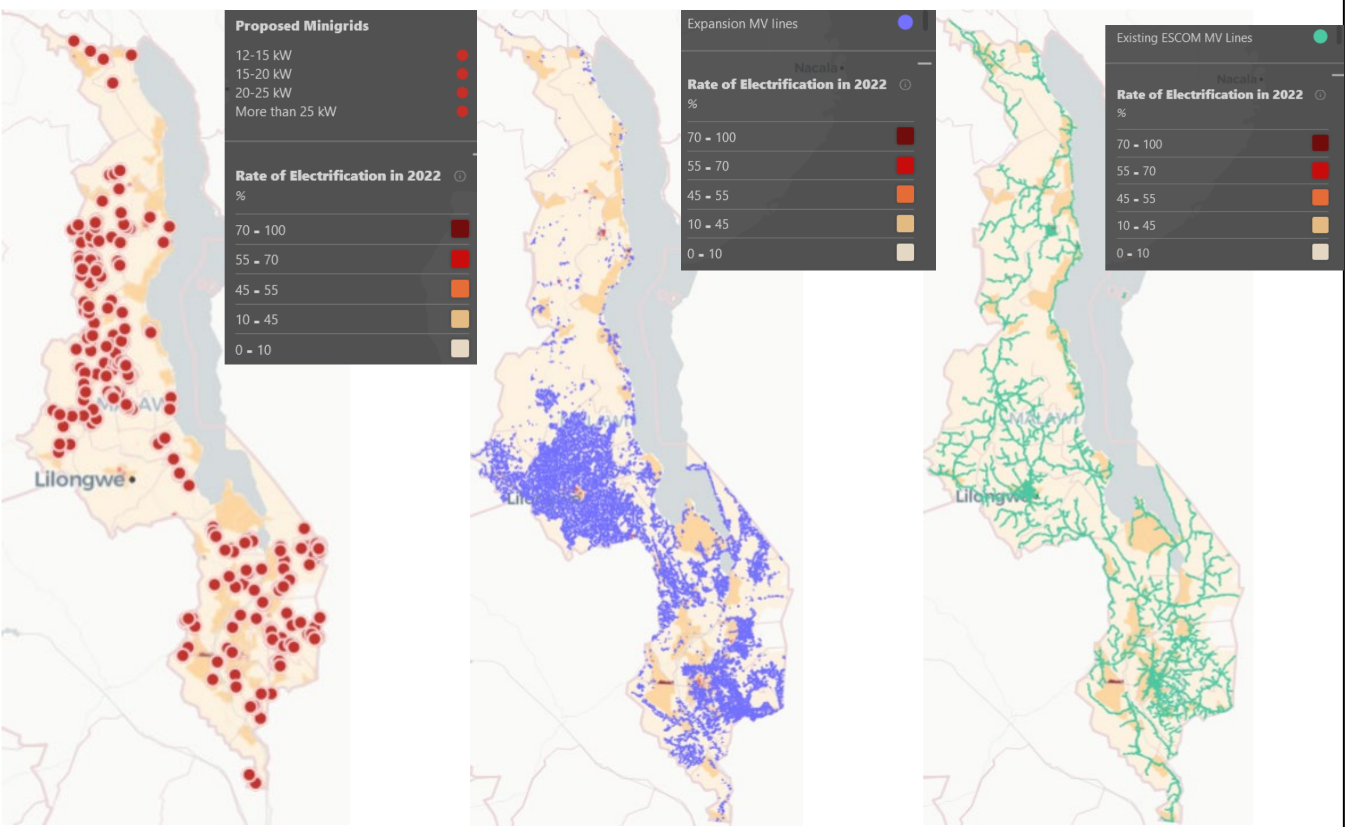
[13] Ibid., based on UNESCO data (2012)

with electricity by 2030 (of which 3,039 with minigrid or solar PV) and 1058 health facilities (of which 106 with minigrid or solar PV).

Combining Geographical Information System (GIS) data such as population density, solar resources, and distance to maintenance centres with estimated demand and load profiles can inform spatial planning of microgrids, locating and sizing systems and optimising maintenance logistics of operating multiple sites. The geospatial mapping developed by the World Bank/ESMAP has produced a least-cost electrification plan for Malawi that informed the Malawi Integrated Energy Plan-Electrification. The tool is powered by extensive geospatial analytics and modelling and provides actionable intelligence for the private sector and government stakeholders to plan the expansion of least-cost access to electricity, access to clean cooking, health-facility electrification and medical cold-chain energy assessment. The tool can be accessed at https://malawi.sdg7energyplanning.org/dashboard/mwi-iep (see Box 3)

While most government focus has been on extending the grid, the energy sector framework is gradually being expanded to minigrids and SAS. The Minigrid Regulatory framework (see Box 15) aims to reduce risks for minigrid developments, encouraging greater participation from private sector players in accelerating market development. There are mandated import duty exemptions for critical energy equipment for construction (cranes, lorries, tractors, etc.); electricity generation (fuses, transformers, electricity supply meters, solar PV panels, etc.); solar lamps, and chargers. While Malawi has adopted policy and regulatory measures to address some of the key risks and issues but needs to communicate with investors to dispel perceived risks. For example, there is a need to enforce consistent and expedited customs procedures for energy project equipment and maintain and share a database of component trends, OEMs and retailers. The duty and surtax waiver on the importation of renewable energy technology equipment helps to reduce capital costs, which enhances the affordability of some mini-grid components which can lead to lower tariffs for customers. However, the tax waiver on the importation of renewable energy technologies is not always reflected in the retail prices, and not all components (cabling and wires for example) are immediately classified as renewable energy. Despite these regulatory provisions, delays in importing products, licensing fees and the de facto lengthy time required to process a business license deter expansion of the renewable energy sector. Currently, appropriate standards are in place but enforcement is problematic, resulting in a proliferation of cheap substandard products in the off-grid solar market. Malawi faces difficulty in controlling the supply of counterfeit goods imported through uncharted routes. This makes it difficult for end-users to distinguish between products and make trade-offs between quality, value, and price.

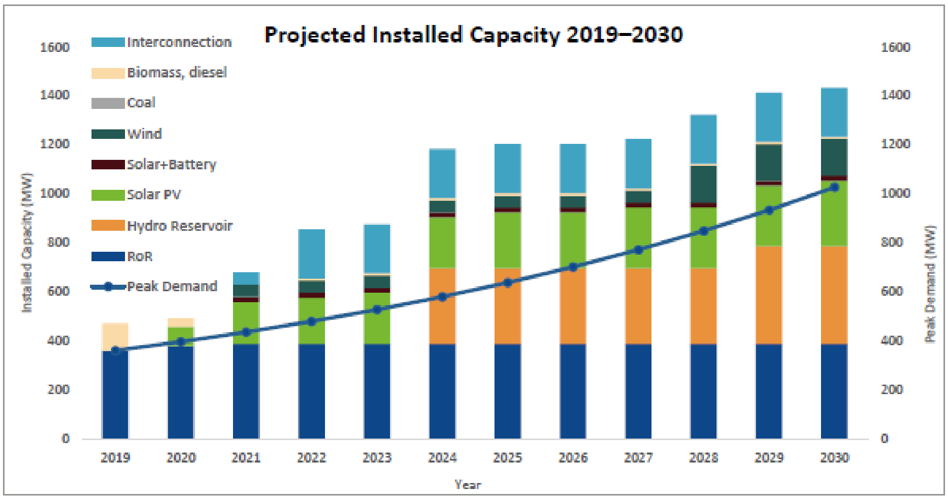
Box 3 Images from Malawi's energy geospatial planning tool



Box 4 Electrification: Integrated Energy Plan (2022) and Sustainable Investment Study (2019)

The SE4All-supported Sustainable Investment Study (2019)mentions that continuation of current electrification trends, Malawi would only reach around 20% electrification in 2030. Combining grid strengthening (expansion and densification) with an increased pace of rural electrification, Malawi could reach the goal of nearly 30% on-grid energy access by 2030.

This implies that about 70% of the population would be provided by off-grid systems, mainly stand-alone systems (SAS) ,and minigrids. To be able to serve existing and newly grid-connected households, will require substantial expansion and diversification in generation capacity to reach about 1400 MW, as well as in expansion of its transmission and distribution lines. In the Investment Study, minigrids play a minor role, expected to provide 18,000 connections by 2030.



Sustainable Investment Study

Investment needs, 2019-2030	[million USD]
Committed funding 2019	150
Requiremnte to reach 100% access:	
Generation expansion	1,400
Transmission and distribution	850
Minigrids	10
Stand-alone RE systems	130
Demand-side management	70
Capital investment	**2,610**
Sources of financing, 2019-2030	
Donor and first-loss capital	350
Concessional/subordinate capital	1,000
Market-based financing	1,150
Beneficiaries	110
Total financing	**2,610**

The recent IEP-Electrification (2022) report provides even more ambitious investment figures for the period 2023-2030 needed to reach universal electricity access and a more pronounced role for minigrids. Today's population (4.435 million households, about 4.6 people per household; 20,410,000 people)) increases to about 5.42 million in 2030 (4.42 people per household). Grid connections comprise 64% of the projected new consumer growth, with minigrids providing 7% and stand-alone systems 26%.

Investments needs are about USD 3,977 million over the period 2023-2030 (ranging between USD 3.42 and 4.53 billion, depending on cost assumptions of main grid extension). This amount translates into about USD 497 million on average annually.

IEP -electrification connections and investment figures

	Connections in 2022	Connection to be added annually (IEP, 2022)									Cumulative connections	Investment 2022-2030 [million USD]
		2023	2024	2025	2026	2027	2028	2029	2030	Total		
Grid densification	560,220	60,159	96,254	120,317	144,381	180,476	240,634	240,634	120,317	1,203,172	4,033,295	574.43
Grid extension		12,450	24,900	163,137	301,374	466,114	680,655	266,260	355,013	2,269,903		2,548
Minigrids	6,000	8,521	17,061	45,992	74,923	67,182	93,564	17,945	17,926	343,114	349,114	491.37
Stand-alone systems	207,667	62,300	83,067	103,834	124,600	155,750	155,750	103,834	41,533	830,668	1,038,335	362.38
Total	*773,887*	*143,430*	*221,282*	*433,280*	*645,278*	*869,522*	*1,170,603*	*628,673*	*534,789*	*4,646,857*		
Cumulative total	**773,887**	**917,317**	**1,138,599**	**1,571,879**	**2,217,157**	**3,086,679**	**4,257,282**	**4,885,955**	**5,420,744**		**5,420,744**	**3,977**

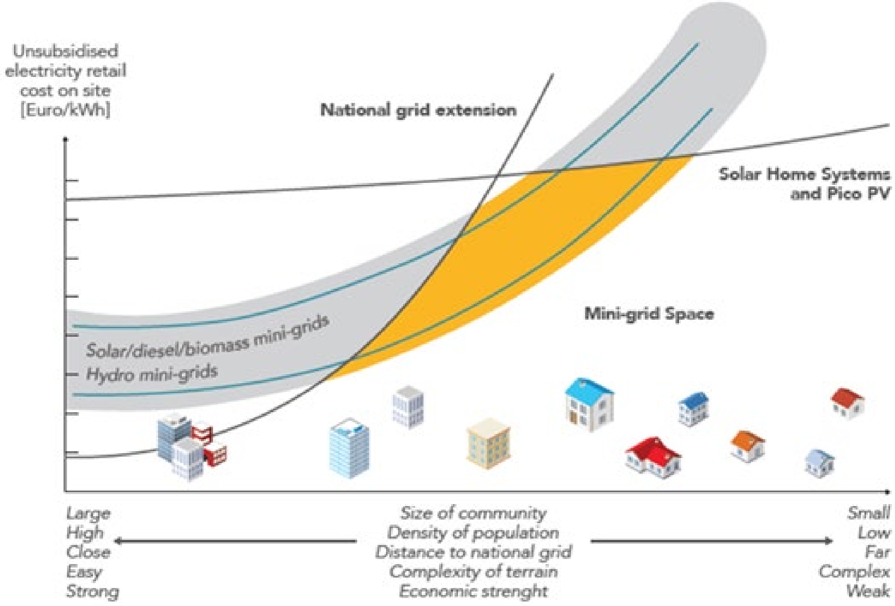
Solar home systems and minigrids can meet power needs in areas that grid extension has not reached, and help increase demand to achieve better economics when the main grid does arrive. In terms of niche areas, minigrids play a role where the costs of grid extension are over USD 1300 per connection and costs of minigrids below USD 2000 per connection. If costs are higher, stand-alone (PV) systems provide Tier-1 and Tier-2 level electricity supply.

The calculations assume that 1688 minigrids would be installed over 2023-2030 at an average of 207 customers (mostly households) per minigrids. The average cost per minigrid is about USD 291,000, and the cost per household is USD 1,407. Of the total MG investment needs of USD 491.37 billion, it is assumed that government and development partners finance 40%, end-users (connection fees), 1% and the private sector, 59%.

In addition to the households, there will be 7,123 schools in 2030 to be all electricity-connected (44% presently grid-connected, 3122 in total) to be electrified (of which 961 by grid expansion, 617 by minigrids and 2,422 served by SHS). Similarly, 1,058 health facilities (of which, 82% are presently grid-connected, 869 facilities) are to be electrified (of which 83 by grid expansion, 53 by minigrids, and 53 by solar home systems).

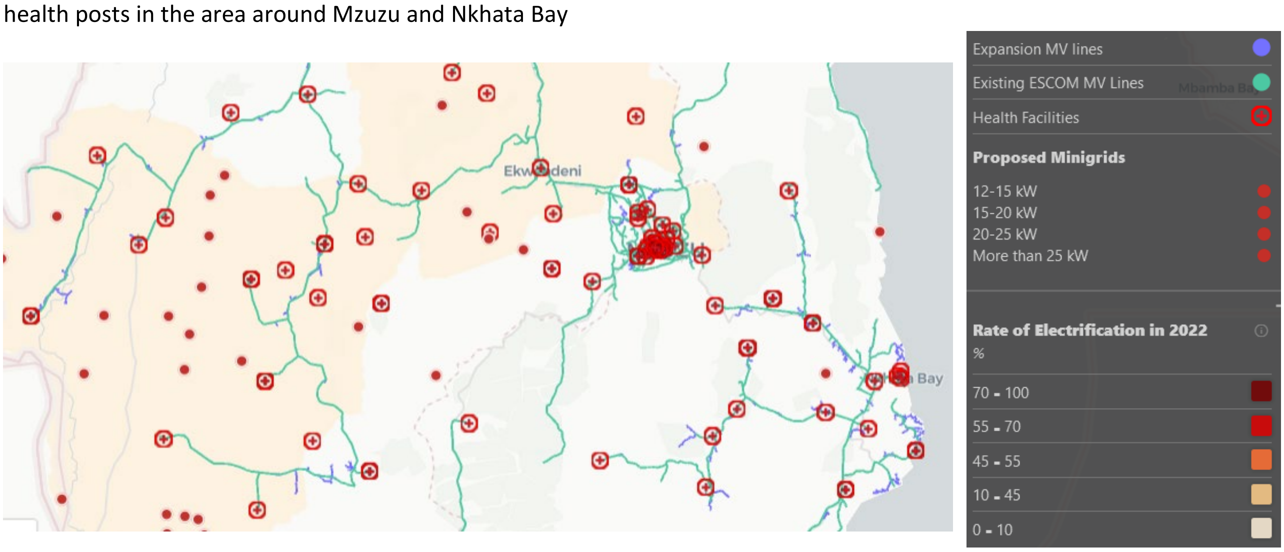
Box 5 Opportunities for grid extension, mini-grids and small RE systems

To increase the electrification rate, Malawi will rely on three main electrification strategies: the extension of the main power grid (by ESCOM) or the development of decentralized systems, that is, the delivery of solar home systems (often delivered by the private sector or NGOs); and minigrids (delivered by the private sector, NGOs in private-public partnership (PPP) with government agencies). Expanding the electricity grid into all rural areas in Malawi will be costly, and in the end perhaps not the most economically viable option. Mini-grids and SHS are the most relevant for areas that are located far from the main grid (or are sparsely populated) and have lower levels of consumption and the ability to pay



Mini-grids form a small-scale source of electricity generation (5 kW to a MW) that serve a localized group of customers (e.g., 100-1000 households) via a distribution grid that can operate in isolation from a national electricity transmission network (or are sometimes or later connected to the main grid). Mini-grids are typically the most economical option for households in dense settlements far from the current grid. Those consumers should then be distant from the main grid (e.g., over 10-20 km), fairly close to each other (e.g., < 150 m or density > 50 customers/km²) and with sufficient load demand (>200 kWh/year). The systems can be powered by diesel or by renewable sources of energy (solar, hydro, wind, biomass), diesel or in a hybrid configuration Smaller mini-grids (e.g. < 50 kW) are sometimes referred to as 'micro-grids'. *Stand-alone systems*, often pico solar or solar home systems, are isolated power systems that usually supply one rural customer (household, community infrastructure, battery charging station, multifunctional platforms and solar kiosk, water pumping station) without distribution and range in size up to 0.5-10 kW.

Geospatial analysis helps government agencies to determine how least-cost universal access can be achieved with grid extension and densification as well as minigrid and off-grid solutions. The figure generated by the Malawi geospatial tool helps to locate potential minigrid sites in view of existing and planned ESCOM medium-voltage (MV) lines and the location of health posts in the area around Mzuzu and Nkhata Bay

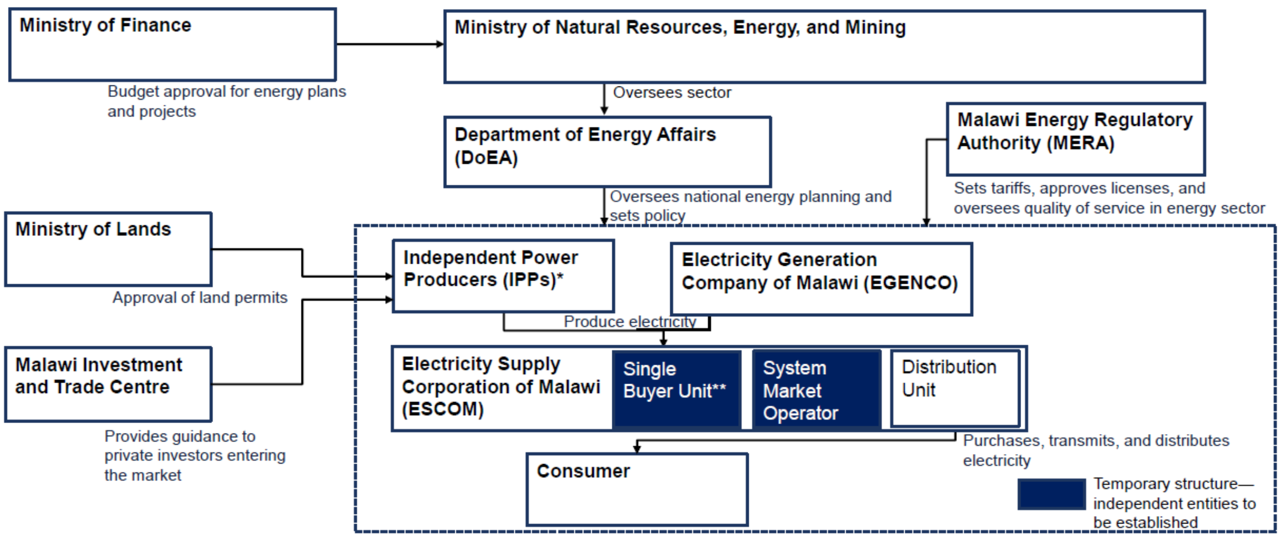


1.2 Relevant energy sector institutions and stakeholders

Energy is regarded as a critical input resource for economic growth and development and is key to poverty alleviation. The provision of sustainable and reliable energy is expected to catalyse industrialization and modernization of the Malawian economy by supporting the rapid growth of the productive sectors such as agriculture, manufacturing, mining and the service sector. Increasing the supply of and access to reliable, affordable energy is at the core of Malawi's development goals

The 2018-updated National Energy Policy recognizes the role that off-grid and minigrid systems can play in reducing or closing the electricity supply deficit in the country The Government of Malawi has implemented comprehensive power sector reforms including unbundling of the national utility company and opening the market for independent power producer (IPP) participation. In 2003 Malawi approved the Power Sector Reform Strategy to foster private sector involvement. In 2017, ESCOM was unbundled to act solely as a dispatcher (and in the interim as single buyer), and EGENCO was formed to handle generation. By opening up the market, it is expected that private sector players will contribute to increasing the country's energy generation.

Box 6 Eneegy sector institutional setup



Source: Malawi Sustainable Energy Investment Study (2022)

1.3 Clean cooking

Currently, about 87% of rural households use 3-stone fire or basic firewood or charcoal stoves and 12-133% an improved (firewood) stove (electric cooking less than 1%). In urban areas, 10% of households use basic firewood stoves, 50% basic charcoal stoves, 20% predominantly use an improved charcoal stove, 2% LPG, 3% use e-cooking(hot plate or induction), and 10% a mix of improved charcoal stoves and e-cooking, The Malawi SDG7 Energy Compact sets targets for clean energy cooking, in which rural households will use only improved wood (40%) or charcoal (60%) stoves, while urban households use improved charcoal stoves (30%), e-cooking (15%) or a mix of the two methods (42%) or shift to other fuels (LPG, pellets, ethanol; 3%). The Clean Cooking Report of the Malawi IEP (2022) assumes that all woodfuel-based cooking could be eliminated by taking advantage of achieving 100% electricity access. In the IEP scenario, 90% of urban households would cook electrically (10% LPG) and 70% of rural households (with the remainder using pellets, biogas or ethanol as fuel). There is also a significant financial challenge to reaching 100% clean cooking access due to the low durability of improved cookstoves available in Malawi today.

Box 7 Institutions and stakeholders related to off-grid energy

Entity	Description
Ministry of Energy (MoE)	MOE was established in 1992 as the Department of Energy Affairs (DEA) and is responsible for energy sector policy-making; renewable energy and rural electrification planning and implementation. DOE sets targets for rural electrification and renewable energy and facilitates the achievement of targets through appropriate policy and incentives. The DOE also coordinates the Malawi Rural Electrification Programme (MAREP) and also guides the rural electrification and renewable energy development plans of ESCOM
Utilities and IPPs	Malawi's power utility ESCOM (established in 1957) was unbundled in 2017 creating EGENCO (100% government-owned, power generation company) and the government-owned national transmission and distribution network (retaining the name ESCOM). The policy calls for private sector involvement in the electricity sector and, in concurrence with the Electricity Act, prompted the restructuring of the sector, including the unbundling of the vertically integrated national power utility and establishment of the Single Buyer and System and Market Operator to enable private sector participation in the market. These independent entities still need to be established. The IPP Aggreko has been providing diesel power (78 MW, mainly as a stop-gap measure to provide peak power. Salima Solar PV and Golomoti Solar PV Battery have together 85 MW, while two IPPs provide hydro (11.3 MW). https://africa-energy-portal.org/aep/country/malawi
Local Government	The Ministry of Local Government, Unity and Culture (MoLG) oversees the local government system, composed of 28 Districts, 4 Cities and 4 Municipalities. Local Government bodies at the sub-national level are also responsible for the electrification of the local areas and villages in coordination with MAREP and DOE. In each of the districts, the District Executive Committee (DEC) headed by the District Commissioner (DC) is supposed to coordinate the electrification activities but in practice has a limited role. Below the District level, the Area Development Committee (ADC) headed by the traditional authority, and the Village Development Committee (VDC), play a role in local rural electrification.
Malawi Energy Regulatory Authority (MERA)	MERA is responsible for implementing the electricity regulatory framework and approves licences for the generation, transmission and distribution of electricity. MERA also approves the electricity tariffs across the country based on tariff proposals by ESCOM. MERA also develops regulations to encourage private sector participation in the electricity sector and to facilitate the deployment of renewable electricity;
Other government	Important decision-making institutions include the National Resources and Climate Change Committee (NRPC) Parliamentary committee responsible for oversight of energy affairs; and the Office of the President
MREPG Malawi Renewable Energy Partnership Group	The (MREPG) was established through the Renewable Energy Strategy for Malawi and comprises representation from development partners, government, NGOs, academic and research institutions and the private sector to coordinate the activities and share information among stakeholders to minimise duplication of efforts.
Education and research institutions	have also played a role in training and capacity building for clean energy and rural electrification and testing and quality control, as well as for research, advisory and consulting services to clean energy and electrification initiatives. The Technical, Entrepreneurial and Vocational Education and Training (TEVET) Authority developed a solar PV apprenticeship programme in January 2019 offering foundation, intermediate and advanced certificates. Mzuzu University offers bachelor's degree programmes in renewable energy and the Malawi Polytechnic offers bachelor's degree in energy engineering. The Malawi Industrial Research and Technology Development Centre (MIRTDC) has technology development and assessment capabilities in solar and hydro energy technologies
Associations	The Renewable Energy Industry Association of Malawi (REIAMA) represents the private industry and RE businesses (about 80% of its 75 members encompass solar companies and the rest are engineers). The Cooperation Network for Renewable Energy (CONREMA) represents more interests for NGOs. The Solar Trade Association supports, organises and champions the solar companies present in Malawi
Small and Medium Enterprises Development Institute (SMEDI)	SMEDI is a parastatal organization under the Ministry of Industry specializing in the capacity building, training, research and support of SMEs. Business support is focused on generating employment, strengthening value chains, and developing markets to bring about inclusive growth and improved living conditions for MSMEs in Malawi. Services include, among others (i) business training and coordination as well as (ii) business information and dissemination. SMEDI operates a "One Stop Information Centre" for start-ups and established MSMEs. It also facilitates linkages between MSMEs and financial institutions.
Minigrid developers	A number of NGOs (or social enterprises) run minigrids, such as MEGA (Mulanje Electricity Generation Agency, Community Energy Malawi (CEM), and Self-Help Africa (SHA, formerly known as United Purpose).
Solar companies	There are several companies that sell and market stand-alone solar-powered consumer products and PUE equipment, such as Team Planet, Powered by Nature, Kumudzi Kuwale, Solar Works, Zuwa Energy, Kuwala Energy, Blue Zone/Grundfos, RECAPO and PowerAid.
Banks and financial institutions	B Malawi has nine commercial banks, eight insurance companies, two development finance institutions (DFIs), and a growing microfinance sector. Financial institutions have not yet played any significant role in financing rural electrification through project financing or enterprise financing, Some banks offer loans for solar home systems. Banks, organized in the Bankers Association of Malawi, have expressed interest in offering loan products as well as managing a revolving fund for renewable energy financing for solar financing

The Compact scenario shows a USD 108.8 million investment is needed to reach 2030 '100% clean cooking' targets, comprised of USD 52.7 million for new customers and USD 56.1 million for improved cookstove customers that need their device replaced due to degradation and failure at the expected end of life. The Malawi Sustainable Investment Plan mentions an amount of USD 510 million needed to increase sustainable biomass availability, increase stove efficiency and for new technologies and infrastructure.

Box 8 Clean cooking: Integrated Energy Plan (2022) and SDG7 Energy Compact

Households eligible for e-cooking usage, based on electricity access are projected to increase from an estimated 92,000 today (2022) to 522,000 in 2030, according to the SDG7 Energy Compact. This represents 15% of urban households using only e-cooking and 42% of urban households that use a mix of improved charcoal and e-cooking solutions. Meeting the Compact 2030 goals will require considerable strategic planning and centralized policy incentives as well as mobilization of private sector actors to enhance multiple modalities of improved and modern cooking technologies. This will include additional fuel sources and the expansion of e-cooking, LPG, and biofuels within the country. Some consumers will own one stove, while others will stack with multiple stoves (e.g. electric and charcoal cooking). The Compact scenarios still expect significant biomass utilization in 2030 with an estimated 88% of households continuing to use firewood, charcoal, or briquette/pellet fuel. In the scenario about USD 108.8 million investment is needed to reach 2030 Compact targets, comprising USD 52.7 million for new cooking technologies and USD 56.1 million in replacement costs for improved cookstove customers that need their device replaced due to degradation and failure at the expected end of life.

For the IEP an additional scenario was developed which matches the 10% LPG goal (in urban areas) of the Compact but assumes that fuelwood and charcoal use for cooking would disappear. The underlying thought is that if universal electricity access can be achieved for households, potentially 73% of households could be served with e-cooking.

	Number of hiusehokds 2022		Energy Compact 2030		IEP-Cooking 2030	
Rural areas						
Firewood (3-stove/basic)	2,390,272	67%				
Charcoal	713,514	20%				
Firewood (improved)	463,784	13%	1,880,440	40%		
Charcoal (improved)			2,820,659	60%		
LPG						
E-cooking (hot plate/induction)					3,275,564	70%
Improved charcoal & e-cooking						
Other (pellets, bioethanol, biogas)					1,425,535	30%
Total HH	*3,567,570*		*4,701,099*		*4,701,099*	
Urban areas						
Firewood (3-stove/basic)	86,743	10%				
Charcoal	433,715	50%				
Firewood (improved)						
Charcoal (improved)	173,486	20%	283,691	30%		
LPG	17,349	2%	94,564	10%	94,563	10%
E-cooking (hot plate/induction)	26,023	3%	141,846	15%	851,074	90%
Improved charcoal & e-cooking	86,743	10%	397,168	42%		
Other (pellets, bioethanol, biogas)			28,368	3%		
Total HH	*867,430*		*945,637*		*945,637*	
Urban+rural HH	**4,435,000**		**5,646,736**		**5,646,736**	

The Sustainable Energy Investment Study (2019) provides another set of 2030 targets with a more advancing uptake of efficient woodstoves and uptake of biogas, electric, ethanol and LPG cooking. The Study estimates that about USD 166 million would be needed over 2019-2030 to cover the CAPEX cost of these new technologies to households. Rural communities will need some subvention to be able yo afford cooking fuel expenditures as they transition to non-biomass technologies (USD 58.6 million).

	SDG Energy Compact	SE Invest. Study 2019	IEP-Cooking 2,022
Advanced woodstoves	1,880,440	2,200,000	
Improved charcoal stoves	3,104,350	300,000	
LPG	94,564	893,000	94,563
Electric	141,846	477,000	4,126,638
Electric and impr charcoal	397,168		
Other (ethanol, bio, pellets)	28,368	894,000	*1,425,535*
Traditional methods (wood)	0	882,736	
Total number of households	**5,646,736**	**5,646,736**	**5,646,736**

t and landscape restoration instruments can help optimize biomass supply. The Study mentions a) natural forest management vatershed protection (USD 195.6 million), conservation agriculture (USD 13.4 million), farmer-managed natural regeneration (USD million), and community plantations and woodlots (USD 80.3 million).

Box 9 Cost-benefit assessment of traditional and cleaner, biomass and alternative cooking methods

This text box estimates the investment (purchase) and annual (operating and maintaining, O&M) costs of various stoves and fuels as applicable to urban and rural households in Malawi. It also presents the cost of charcoal production from various kiln types, as well as the use of wood for use as fuel or as a source of charcoal production from woodlots.

Purchase and annual (O&M) cost of cooking device	Purchase (USD)	O&M (USD/yr)	Life (yrs)	Efficiency	Use per household per year
Open fire	0	0	n/a	14%	1985 kg
Brick oven	10	0	2	30%	926 kg
Chitetezo wood mbaula	2.1		2	25%	1112 kg
Uganda rocket Lorena stove	5		4	31%	893 kg
Kenya jiko - charcoal	6	0	2	25%	612 kg
Envirofit SmartSaver - charcoal	29	2.95	3	34%	450 kg
Jikokoa - charcoal	40	4	2	43.5%	352 kg
Alternative fuels					
Kenya jiko - briquette	6	0	2	25%	851 kg
Envirofit - briquettes	40		3	34%	626 kg
Green Impact biogas stove	84	8.4	3	43.5%	477 m3
LPG	92	9.2	6	56%	336 L
Ethanol	76	8.4	6	51%	422 kg
Electricity					
Hot plate	20	0	2	70%	1853 kWh
High-pressure cooker (EPC)	110	0	6		889 kWh

Three stones holding a cooking pot over an open wood fire is the most common cooking method in rural Malawi but also used in urban areas. The Chitetezo mbaula is a low-cost, all-ceramic woodstove made by informal sector artisans in Malawi, and is the most common improved woodstove in the country. The Kenya ceramic *jiko* is currently the most common charcoal stove in Lilongwe with informal sector production and distribution channels. Developed in the 1980s in Kenya it was introduced in Malawi early 1990s. When the lining wears out, usually a new stove is bought. The Uganda Rocket Lorena stove is not available in Malawi.

The Environ SmartSaver and jikokoa are relatively high-cost, high-capacity, imported metal stoves (imported from Kenya). LPG stoves consist of a metal cooking ring and burner over or linked to a six-kg LPG cylinder, sold in Malawi for example, by 265 Energy. The price of the cylinder of LPG is not included, but the relatively high price is often a barrier to switching to LPG in urban areas (in rural areas the lack of distribution facilities is the issue). Green Impact Technologies (GIT) converts biodegradable waste from markets into biogas, which is stored and distributed in refillable 1 m^3 biogas bags to local households, restaurants and businesses. The bags come with an imported metal cooking ring. Single-burner hotplates can hold one cooking pot at 1000 W at full capacity (or lower level for slower cooking). Hot plates have an energy efficiency of about 70%, depending if the pot covers the whole of the plate or not. Rice cookers have an efficiency of around 90%. An electric pressure cooker (EPC) uses about 48% of the energy used in hot-plate cooking (the higher pressure in an EPC means the food cooks at a higher temperature and therefore more quickly, requiring less fuel).

The table on the left gives estimates of the prices of woodfuels and alternative fuels. The price of charcoal (in urban areas, Lilongwe) is an average of the price of a wholesale 50 kg sack (USD 0.22/kg) and those of daily purchases of a typical household (USD 0.42/kg). The cost of production is about 20% of the retail price, or about USD 0.085/kg (see the table right). Prices throughout Malawi can vary widely depending on the enforcement of prohibition and transport costs. The price of wood is USD 0.34 in one kg bundles. In rural areas, wood sold near collection/production sites or roadside is about 9-18% of the eventual retail price in Lilongwe.

Fuel prices	Urban (Lilongwe)	Rural (local)		Net heating value
Fuelwood	0.340	0.046	USD/kg	16.8 MJ/kg
- Woodlots	0.390	0.095		
Charcoal	0.385	0.135	USD/kg	30.5 MJ/kg
- Eff prod+ Plant+EE	0.637	0.387		
Briquettes	0.420		USD/kg	21.9 MJ/kg
Biogas	0.880		USD/m3	22.5 MJ/m3
LPG	1.340		USD/L	24.8 MJ/L
Ethanol	1.250		USD/kg	21.9 MJ/kg
Electricity	0.090		USD/kWh	3.6 kWh/MJ
Solar minigrid (min)	0.430		USD/kWh	
Solar minigrid (max)	0.950		USD/kWh	

Most charcoal in Malawi is produced in earth mound kilns. Artisans rebuild the earth mound for each carbonization cycle, stacking wood covered with a layer of grass or leaves and sealed with soil. Labourers rebuild the earth mound for each carbonization cycle. Brick kilns are built from brick, mud, or clay in a half-spherical shape. These kilns are permanent installations and have long lifespans. Steel drum kilns are small, portable, and come in various designs. They require smaller pieces of wood. They have a faster production cycle than brick kilns or earth mound kilns. The carbonization (conversion) efficiency of a kiln is the weight of the charcoal produced as a percentage of the weight of the input wood. Brick and steel drum kilns usually have higher efficiency.

Charcoal kilns	Conversion Efficiency	Life (yrs)	Cycles per year	Wood input (kg/cycle)	Charcoal produced (kg/cycle)	Charcoal (kg/yr)	Investm. cost (USD)	O&M per cycle (USD)	Total (annualised inv.+wood+O&M) cost: Free wood USD/yr	Free wood USD/kg	Woodlots USD/yr	Woodlots USD/kg
Earth mound (trad.)	19.50%	0.06	18	4,769	930	16,740	0	78.77	1,418	0.085	5,667	0.339
Brick kiln	31%	10	31	13,613	4,220	130,820	1000	43.49	1,504	0.011	22,394	0.171
Steel drum	29%	3	97	61	18	1,702	40	5.65	564	0.331	854	0.502

Source: Own calculatiions, based on data from *Cost-benefit analysis of charcoal and wood use for household cooking and demand- and supply-side initiatives for forest conservation, CEADIR;* USAID (2021), *Smallholder willingness to pay for imporved cookstoves in Dedza,* in: "American Journal of Rural Development, 2017, Vol. 5, No. 3, 73-80, by Mc.Nulty, et.al.; *Prospects of expanding ethanol as a residential fuel,* USAID (2021)

Box (cont'd) Cost-benefit assessment of traditional and cleaner, biomass and alternative cooking methods

Commercial woodlots and plantations of hardwood trees can help meet the demand for biomass fuels without increasing deforestation or forest degradation if harvesting rates are limited to the maximum sustained yield and stands are replanted as needed. The table on the left gives an estimate of the costs produced of fuelwood on a small woodlot. The figures are indicative only and are not meant to reflect average plantation cost but to illustrate the impact on fuelwood and charcoal prices if the wood would be sustainably produced.

Wood lot costs and sales price		
Nursery and establishment	520	USD /ha
Annual O&M	180	USD/ha
Yield	5.72	ton dry matter/ha
Density	0.52	ton/m3
Year	21	yrs
Annualised investm.+O&M cost	236	USD/ha
Sales (production) price	283	USD/ha
	0.050	USD/kg

The table below gives the total annual cost (sum of investment, annualises over lifetime at 9% discount rate), plus maintenance (O&M cost) and fuel cost) Urban households have to purchase firewood and lifecycle costs (with initial investment discounted at 9% over its useful life) and three-stone cooking would be the most expensive. The cheapest option, maybe surprisingly, is electric cooking, with cooking on charcoal on efficient stoves coming second (however, noting that charcoal prices can vary widely, as some households will buy in bulk and others in smaller quantities). For comparison and sensitivity analysis, the reader is referred to USAID (2021). LPG and biogas are expensive options.

Over 93% of rural households use free (collected wood). With firewood free and time spent in collecting not a major issue, few rural households would want to switch to purchased fuel. According to a survey carried out a Dedza, respondents on average were willing to pay up to USD 7-9 for an efficient stove (motivated by risks of fines in illegal wood collection in forest reserves, time spent on fuelwood collection, smoke-related ailments)However, women who cook outdoors with woodfuels are typically less concerned about smoke from stoves because their exposures are much lower than those of women who cook indoors. Cooking on electricity in minigrids will be expensive. The use of high-pressure cookers may reduce the energy needs in comparison with a simple hotplate but energy costs would still be high and may only be acceptable for the top 10% or so of rural customers.

Annualised cost o cooking methods	**Annual fuel cost (USD)**					**Total (annualised equipment + O&M+fuel), USD/yr**				
	Collected wood	*Locally bought*	*Woodlot (at site)*	*Urban area Bought*	*Produced more sust.*	*Collected wood*	*Locally bought*	*Woodlot (at site)*	*Urban area Bought*	*Produced more sust.*
Open fire	0	91	189	675	773	0.0	91	189	675	773
Brick oven	0	43	88	315	361	5.7	48	94	321	366
Chitetezo wood mbaula	0	51	106	378	433	1.2	52	107	379	434
Uganda rocket Lorena stove		41	85	304	348	1.5	43	87	305	349
Kenya jiko - charcoal		83	237	236	237		86	240	239	240
Envirofit SmartSaver - charcoal		61	174	173	174		75	189	188	189
Jikokoa - charcoal		47	18	135	136		74	45	162	163
Alternative fuels										
Kenya jiko - briquette				357					361	
Envirofit - briquettes				263					279	
Green Impact biogas stove				420					461	
LPG				450					480	
Ethanol				528					553	
Electricity		**MG (min)**	**MG (max)**	**Grid**			**MG (min)**	**MG (max)**	**Grid**	
Hot plate		797		167			808		178	
High-pressure cooker (EPC)		382		80			407		105	

It should be noted that the comparisons assume that all meals are cooked with one method. It is more likely that households will stack various cooking technologies. Cultural preferences for cooking certain foods with charcoal or wood will remain. Households that can afford to use faster-cooking stoves may use them for certain meals or occasions when they are pressed for time or have guests while other methods may be better for meals that require slow-cooking. In urban areas, although electric cooking is financially attractive as it may require changes in cultural preference for cooking with charcoal or wood. Since fuelwood and charcoal will continue to be widely used in urban areas of Malawi for the foreseeable future, there is a good economic rationale for promoting more efficient stoves for these fuels, while also rural households may be more willing to pay as access to firewood become more restricted or collecting more time-consuming,

Adoption of kilns with a higher carbonization efficiency will be difficult as long as wood for charcoal production is underpriced or can be collected for free. Relatively little has been done to promote more efficient charcoal kilns in Malawi. One low-cost alternative that deserves further attention is the Casamance kiln, an improved earth mound kiln with a chimney and better air circulation to improve the carbonization efficiency and quality of the charcoal.

Source (cont'd): *Market assessment for modern cooking in Malawi,* Conference paper, Coley, et.al. University of Strathclyude (2020), *Economic evaluation of improved househokd cooling stove dissemination in Uganda,* (GTZ, 2007), *Woodlot Technical Specidfication,* Trees of Hope, Clinton Development Initiatuve, Malawi (2011), *Woodfuel integrated supply/demand overview mapping, Malawi* (USAID, 2019)

Modern Cooking for Healthy Forests (MCHF) is a five-year activity funded by the United States Agency for International Development (USAID) and the United Kingdom Foreign, Commonwealth & Development Office (FCDO). The Malawi Clean Cooking Fund is a USD 1.1 million dollar performance-based grant fund (PBG) designed to increase the supply of, and demand for alternative cooking energies and fuel-efficient cooking technologies in Malawi, as well as the supply of sustainable wood fuels from well-managed forest resources. The Malawi Clean Cooking Fund is structured to support and improve the adoption of market-based improved cookstove and sustainable fuel supply chain solutions in urban Malawi (Window 1), and the delivery and adoption of fuel-efficient cooking technologies in select rural areas (Window 2). The objective of Window 2 (USD 50,000-150,000) is to deliver cost-effective solutions, within a 2-km buffer of all selected Forest Reserves within a specific landscape, that increase household adoption of efficient firewood cookstoves.

GIZ has been supporting the EnDev programme in Malawi with a component on improving cookstoves. As part of its results-based financing programme, EnDec has supported women's and other production groups in Malawi (women make up 80% of all workers employed by local ICS producers). EnDev provided incentives for each produced cookstove, called the Chitetezo Mbaula, which means 'protective stove'. Made from clay, these locally-produced stoves are practical and can be moved around easily. EnDev Malawi aims to enhance a financially sustainable market for improved cookstoves, focusing on urban and peri-urban areas.

Box 10 EnDev Demand-Side Subsidies (DSS)

EnDev's Energy Access through Demand-Side Subsidies component (2022-2025) seeks to develop and pilot Demand Side Subsidy (DSS) mechanisms to facilitate access to modern energy services for vulnerable populations who are currently unable to access commercial off-grid solar and cooking markets. The programme has a EUR 4.9 million budget, financed by the Directorate-General for International Cooperation (DGIS) of the Netherlands. off-grid solar products and cookstoves remain unaffordable for a significant share of the population, especially the poorest and most vulnerable. Through its demand-side subsidy schemes, EnDev Malawi aims to directly enable up to 200.000 people to have access to modern energy services (and indirectly, through scaling up and replication).

Beneficiaries will be selected based on clearly defined eligibility criteria (e.g. household poverty levels, area of residence; as defined by Unified Beneficiary Registry) to ensure as many intended beneficiaries (the 10% poorest households) receive the subsidy while minimizing leakage of benefits to unintended beneficiaries. The value of subsidies should be pegged to the difference between the cost of the off-grid/EE stive product and the target group's ATP (ability to pay, see e.g. Box 25). This level shall be monitored and adjusted as needed. Similar EnDEv DSS activities have been launched in Liberia, Niger and Uganda.

1.4 Stand-alone solar (SAS) application

Over the past years, the SAS market in Malawi has nearly quadrupled in size and seen solar companies changing business models through customer and product diversification. Statisticcs are difficult to get but some 70,000 pico-solar and SHS were sold in 2019 up from 55,000 in 2018[14]. An increase in the number of off-grid productive use of energy (PUE) products in the market, including solar irrigation pumps, millers, incubators, cooling units and cold storage.

Programmes such as USAID's KickStarter, GIZ's EnDEv and WB's EAP have helped to influence sales. Such programmes are often geared as well toward providing incentives for products with agricultural productive uses (for example irrigation, drying and cooling) with potentially more beneficial terms for the promotion of these technologies. While there is a lot of interest in productive use, the following factors still need to be addressed: enhanced access to micro-credit; facilitation of business development services and training; support for the upgrading of infrastructure and offering of after-sales service. More established companies, such as Team Planet, Powered by Nature, Kumudzi Kuwale, Solar Works, Zuwa Energy, Kuwala Energy, Blue Zone/Grundfos, RECAPO and PowerAid have diversified the products and services they provide to include PUE equipment. More recently, Zuwa Energy has piloted PUE systems in clinics through PAYG and plans to scale up to schools.

For SAS, the main regulatory provisions are a) mandatory licensing by MERA of energy businesses as well as the importation, sale, installation and maintenance of solar products, b) quality standards certification by MBS, and c) zero-

[14] GOGLA (2020)

rating of solar products and components from import duty and excise duty, although the 16.5% VAT remains. Despite these regulations, many lower-quality SHSs and solar products are sold without warranty or any means of redress. The sale of low-quality products weakens the demand for all similar products, and the lower price of such products skews the perspective of the value of solar products.

As the market grows, some solar companies have begun changing their approaches through customer and product diversification, and how they reach customers. Importers like Kumudzi Kuwale and Zuwa Energy establish partnerships with retailers and promote franchise models. Other companies sell through agents who then use targeted marketing techniques including school teachers, associations, petrol stations, community groups, agricultural stores, Malawi Posts Corporation (MPC), bus companies and last-mile entrepreneurs.

In general following distribution models can be distinguished:

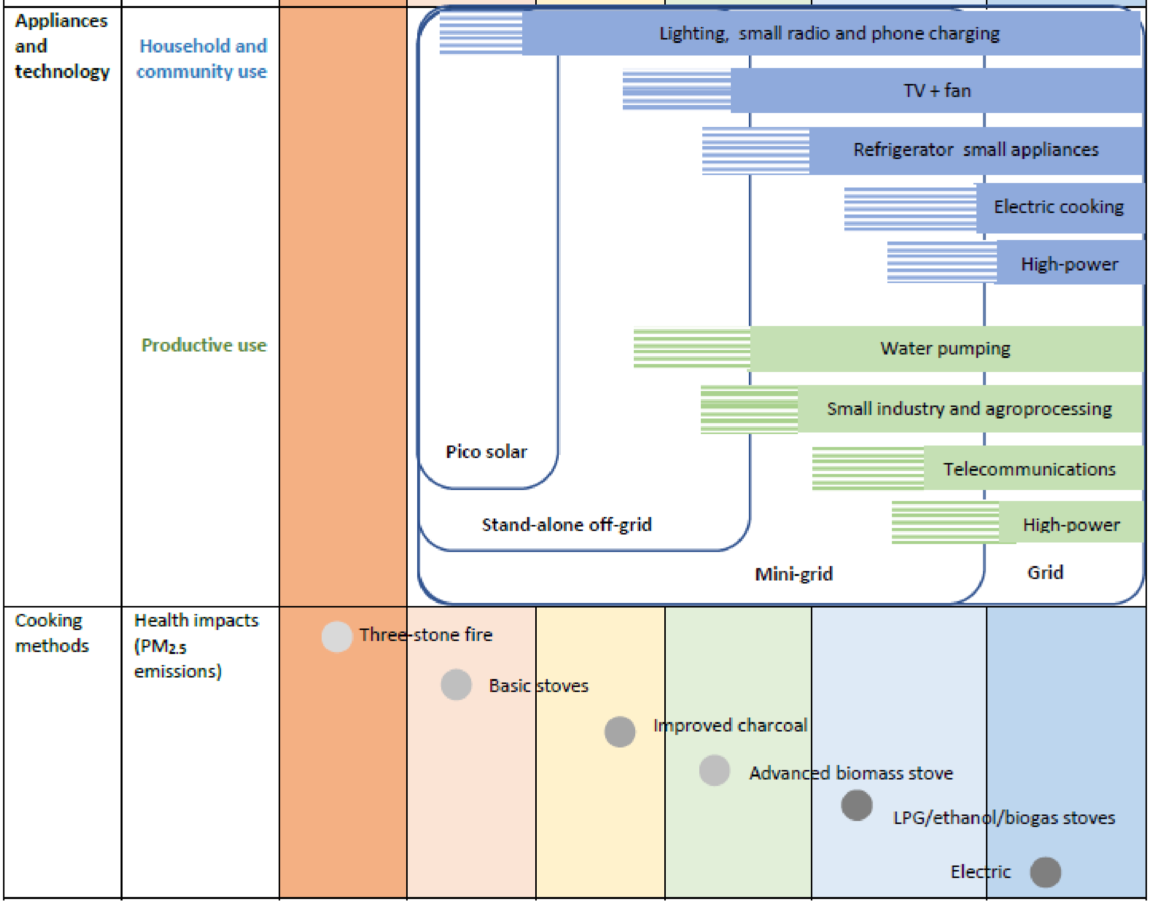
- *Proprietary channels* - Products move through a proprietary distribution channel from manufacturer to in-house storage/assembling facilities to a salaried/contracted salesforce, which delivers them to customers directly;
- *Distributor-dealer* - The solar company sells through established networks of generalist or specialist distributors, leveraging the traditional consumer durables supply chain. Products are often retailed in a basket of consumer durables. A distribution hierarchy of at least two levels (distributor and dealer/retailer) is maintained'
- *Rent-leasing* - The solar company franchises local agents (microentrepreneurs) who set up solar charging kiosks. The micro-entrepreneurs either (1) rent products to consumers on an hourly/daily basis or (2) sell systems without a power source, offering a fixed fee for charging
- *Micro-franchise* - The company offers franchising packages (such as financing, training, marketing support etc.) to microentrepreneurs who wish to become formalized retailers of exclusive company products.
- *Institutional partnerships* – The solar company may partner with an institution (e.g., NGO, MFI, rural bank, cooperative) with links to a large potential customer base) to market its products to its customer base/members and/or to leverage its assembling & aftersales support services

In the *franchise-dealership* models, solar energy enterprises often provide credit to dealers and/or franchises to allow them to sell to clients on an instalment basis. This particular model is common for relatively inexpensive products (usually those that cost under USD 50, such as small portable solar products). In the *partnership arrangements*, the financial institution (FI), provides credit to an end-user and manages the monitoring and repayment processes, while the energy company provides the energy product, installation, service and maintenance. The energy enterprise may also enter into a partnership arrangement with an "apex institution" that manages a network of local FIs (e.g. a union of credit cooperatives, credit unions, or other village-based FIs). The apex institution lends money to the local finance providers, who lend to an end-user and manage the monitoring and repayment processes. The energy enterprise provides the product, installation, service and maintenance. Alternatively, a third party is paid by the finance provider and the energy enterprise as a *broker* to market energy products and assess customers' suitability for financing. They bring viable customers forward to buy energy products. The broker may also be involved with loan payment collection, after-sales service, and technical upkeep. In a *one-stop-shop model*, the same organization provides the products and finance. This happens when a finance provider decides to offer energy products, or when an energy enterprise decides to offer finance.

Pay-as-you-go (PAYGO) are increasing uses in higher-cost solar products and also as a payment means in minigrid systems (see next paragraph). PAYGO is a financing platform for off-grid energy systems with high up-front capital costs. An IT system underlies the platform, allowing automated payments and system monitoring/activation. Various payment platforms can be used. In a pre-paid credit agent-based model (off-network), the agent gives a unique code (after payment). Online systems require full connections (mobile money, M2M) or intermittent connections (e..g. using airtime as prepaid credit, or USSD (unstructured supplementary device data), in which payment processing is performed by sending a text message to the energy service provider. As PAYGO facilitates payment in instalments, these can boost the ability to pay (ATP).

Box 11 Energy demand tiers

		Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Electricity	Power	< 3 W	≥ 3 W	≥ 50 W	≥ 200 W	≥ 200 W	≥ 2000 W
	Energy/ day	< 12 Wh	≥ 12 Wh	≥ 200 Wh	≥ 1 kWh	≥ 3.4 kWh	8.2 kWh
	Minimum availability		≥ 2 hrs	≥ 4 hrs	50% of working hrs	75% of working hrs	95% of working hrs
	Minimum availability		Day: 4 hrs Night: 1 hr	Day: 4 h Night: 2 hr	Day: 8 hrs Night: 3 hr	Day: 16 hr Night: 4 hr	Day: 23 hr Night: 4 hr



Taken from *Just Energy Transitions in Africa (2022),* J.H.A. van den Akker, www.ascendis.nl

A WB study has attempted to estimate the SAS market based on willingness and ability to pay (see Box 25). Taking into consideration the number of off-grid households (3.7 million) and their ability to pay for different sizes of products, there is a potential USD 265 million market. Of the off-grid population, 24% could afford pico and solar home system (SHS) with multiple lights and phone charging, 9% could afford SHS (>10W) with multiple lights and other basic appliances, and only 1% could afford Tier 2 SHS (>50W) equipped with TV and other appliances[15].

Many solar companies are providing consumer financing through a pay-as-you-go (PAYG) model, allowing instalment payments for up to 36 months (with only 20% up-front payment), in order to make products more affordable and to expand their customer base across market segments. This makes access to adequate finance critical.

Recently, two projects have been aiming to support the development of the off-grid lighting market in Malawi:

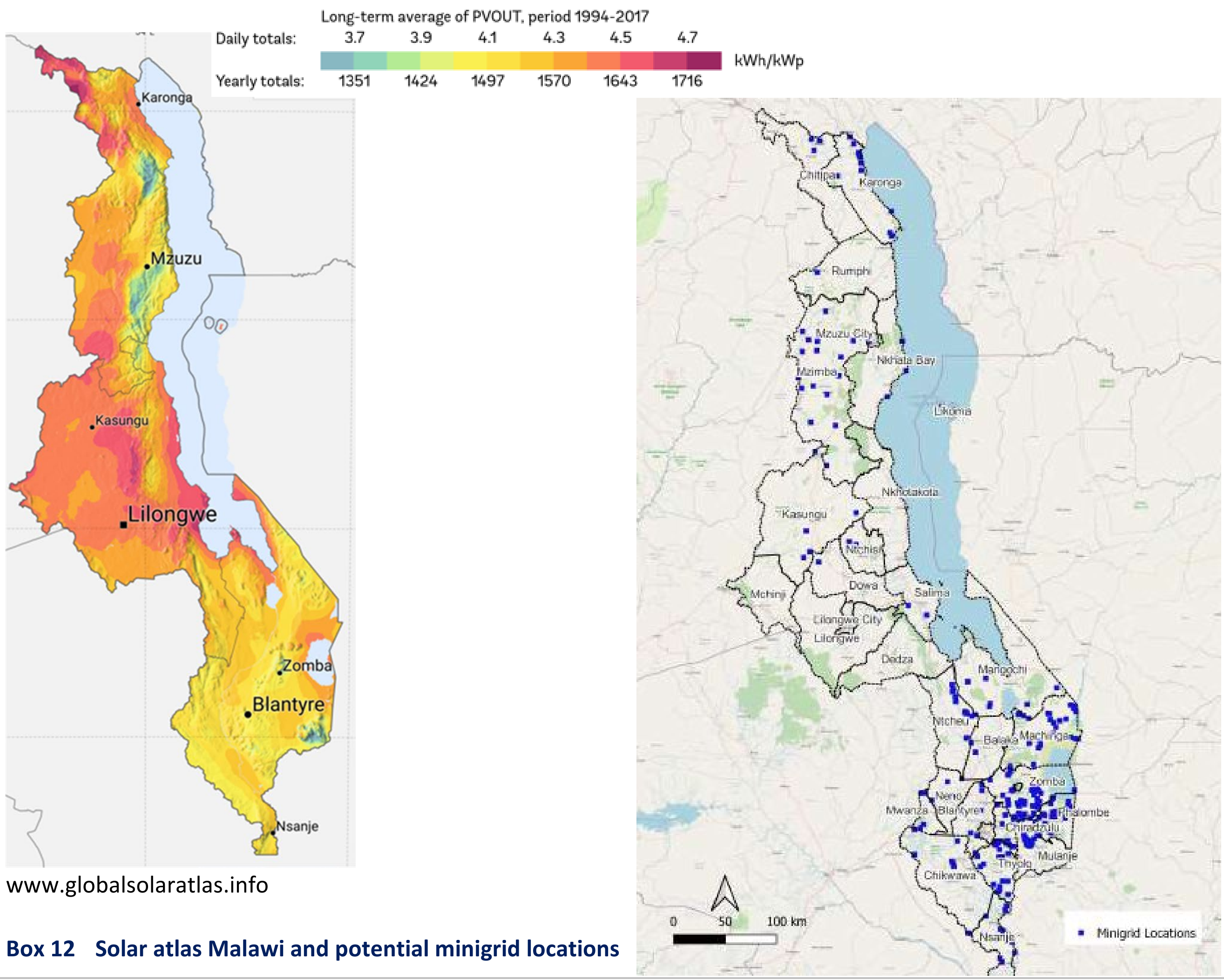
- the USAID Solar Home System Kickstarter Program (2-19-2021) with a USD 1.5 Million results-based financing (RBF) grant facility aimed at stimulating the sale/provision of 150,000 new SHS off-grid connections (providing access to working capital; debt and equity finance through various local financial institutions as well as technical assistance to SHS companies and for awareness creation.

15 Malawi EAP project (2019)

- the World Bank Electricity Access Project's off-grid market development fund (OGMDF) has been designed to have two windows, an off-grid solar home window (USD 20 million; to be implemented by the Bangladeshi-based development bank IDCOL). OGMDF consists of a USD 5.5 million Results-based Financing (RBF) Grant and a USD 14 million debt facility that will offer working capital loans to solar (off-grid) companies. The latter will allow such companies to expand their operations and speed up procurement, based on their eligibility and business plans[16]. The RBF Grant window (up to USD 5.5 million) will provide end-user subsidies to close the affordability gap of customers who cannot afford solar home systems at commercial prices. The Fund has also created a Market Catalyst Fund (MCF) of USD 500,000 to support market-based transformative solutions to scale up the renewable energy transition, especially in remote and underserved areas, and will also focus on promoting local content, by investing in the development of local capacity with the aim of reaching at least 200,000 new households with solar PV products.

1.5 Mini-grids

Across Malawi, Mini-grids offer a sustainable solution to rural electrification, combat poverty, and grow local economies. Despite a huge market of un-electrified rural communities in Malawi, the mini-grid sector is in a nascent state, with a dozen mini-grids (MGs) ranging from 5 to 300 kW providing power to homes, hospitals and businesses. An overview is given in Box 14. These MGs are owned by the Government and run by ESCOM utility (diesel-based MGs on islands) or owned and run by charities or the private sector. Several other projects are at various stages of development, ranging from pre-feasibility to procurement with less than a dozen existing initiatives currently operational in Malawi



Box 12 Solar atlas Malawi and potential minigrid locations

[16] After a Call for Proposals, the following co,panies were shortlisted: Perennial Holdings, Green Impact Technologies, Zonergy Company, StarTimes Mrdia, Vitalite, SunkIng, Engie Energy Access Zambia, Zuwa Energy, Solar Africa. https://www.energy.gov.mw/1008-2/?dm_i=6OQE,OBK9,46C78V,30H8P,1#35-35-wpfd-advertisements-p1

by development organisations, with most MGs having a community ownership or co-ownership model. Organisations active in the MG space in Malawi are Community Energy Malawi (CEM), MEGA, Practical Action, the Catholic Church, and Self Help Africa (f.k.a. United Purpose; in partnership with the University of Strathclyde).

The limited evaluation or case studies undertaken show several opportunities, including a high rural off-grid population, abundant renewable resources, significant global and national policy drivers, recently proposed changes to the regulatory environment and identified funding opportunities. Currently, national grid access covers only about 15% of the population. The recent SE4All-supported Integrated Energy Plan include specific targets for the year 2030 for grid extension and expansion, MGs and stand-alone systems. Malawi has well-endowed renewable resources which offer a good opportunity for renewable energy mini-grids. Solar Resources are well-mapped in Malawi through online repositories such as IRENA and an ESMAP report commissioned by the World Bank. Solar PV is likely to be the predominant power source for mini-grids. While hydro is cheaper than solar PV per kWh produced, hydro sites can be far from population settlements. On the other, if the hydrological resources are adequate the system can often better accommodate productive uses.

Box 13 Tariffs; willingness and ability to pay (ATP/ATP)

The average incomes and current energy expenditures provide good indicators for the ‘ability to pay’ (ATP). The ‘willingness to pay’ is the maximum amount that a person expresses that he or she is willing to pay for electric or energy service, typically registered in monetary units per unit of time (day, month). A SHA survey in Dedza, establishes monthly rural income in villages as an average USD 27.3 (MWK 20,220; form agriculture MWK 18,143 and non-agric MWK 2,077). The average money spent on energy was MWK 3,648 (USD 5.11), of which MWK 2,228 was on dry cell batteries and phone charging (USD 3.12). Willingness to pay was estimated at USD 6.77 per month.

The ESCOM prepaid tariff is about MWK 79.3 (USD 0.072) per kWh and the lifeline tariff is MWK 56 (USD USD 0.051) per. This tariff reflects national-level economies of scale and is subsidized by the government. At this tariff, a recent energy survey has estimated energy use in grid-electrified households. Average household expenditure is about 3.00-4.23 a month (consuming 47-66 kWh per month). About 0-20% of households spend USD 11.61-25.35 (consuming 182-396 kWh/month, 20-50% spend USD 6.21-8.00 (consuming 97-125 kWh/month), while the lowest decile (50-100% of households) spend USD 2.65-2.88 (consuming 41-45 kWh/month). Data based on IEP 2022.

For off-grid electrification, the investment costs are high and the costs of system operations are allocated to fewer users at a smaller scale, which requires a higher energy tariff for sustainable operation than the main grid tariffs. Mini-grids typically have higher financing costs and shorter-term debt than public utility infrastructure, which also increases the cost of electricity service. Therefore, the IEP (2022) assumes that mini-grid tariffs are, in the range of USD 0.45/kWh and the associated monthly electricity consumption is 12 kWh/month-consumer, implying an expenditure of about USD 5.4 per month. SHA has introduced two tariff types in its Dezda area solar MGs. One is a flat tariff (MWK 200 per day; equivalent to about USD 5 a month). Clients that need more electric energy pay MWK 280/kWh (about USD 0.30 kWh at 2022 exchange rate) during the day (6am-6pm) and MWK 1200 (USD 1.28) for the first 2 kWh in the evening (MWK 800 for the next 2 kWh; USD 0.86). Institutions get free 3600 kWh per month. The connection fee is MWK 22,000 (about USD 25). MEGA (in Mulanje) charged MWK 32 for institutions (USD 0.04/kWh, at the 2018 exchange rate), MWK 64/kWh for households (USD 0.09/kWh) and MWK 106 for commercial clients. Recent UNDP-supported feasibility studies for solar MGs in Chisi, Malidadi and Mwansambe propose domestic tariffs of USD 0.02 to 0.07; commercial of USD 0.40-0.84 and social amenities of USD 0.03-0.07 per kWh. The SE4RC/CVARD supported MGs charge households MWK 86.2 (USD 0.12/kWh), businesses (MWK 96.6, USD 0.13/kWh) and social facilities (MWK 67; 0.09/kWh) with a connection fee of about USD 25.

Solar Home Systems (SHS) typically charge monthly service fees rather than direct consumption-based tariffs for end users. These costs depend on the SHS size and the provider’s prices, however, a MTF-Tier 1 system is commonly USD USD 12 a month or higher, and Tier 2 systems exceed USD 25/month, which exceeds the WTP. Therefore, SHS affordability will require subsidies for low-decile customers. There is a potential USD 265 million market of stand-alone systems, Of the off-grid population, 24% could afford pico and solar home system (SHS) with multiple lights and phone charging, 9% could afford SHS (>10W) with multiple lights and other basic appliances, and only 1% could afford Tier 2 SHS (>50W) equipped with TV and other appliances

Source: World Bank MTF Survey (2019); EAP project; *Stand-alone Market Update,* TetraTech (2021); *Malawi Integrated Energy Plan* (2022); MEGA (2018); *Feasibility Study Solar Minigrid in Dedza (*by. E.Ales and Ll. Archer; Un.of Strathclyde; United Purpose). *Overview of Communikty Energy Systems in Maawi,* C.Hara (Mzuzu University)

Box 14 Existing minigrids and experiences in Malawi

Government-owned	
Wind-solar MGs (solar villages) in Elunynei (Mzimna), Chingunda (Lilongwe, Kadambwe (Ntcheu), Kadzuwa (Thyolo) and Chitawo (Chiradzulo) 20 kW per site	None has been working since 2012. Systems were characterized by failing design and maintenance issues as well as a lack of community participation in design and during implementation. The design was fraught from the beginning and the projects were to showcase the government's commitment to renewable rural power. In the drive to get the projects realised quickly, no proper technical and social assessment was made of demand and supply options in the villages concerned. With a lack of financial and business model, in which low revenues (power was sold at low tariffs) provided too big a challenge for proper maintenance. Systems have failed at the stage of major repair or battery replacement due to insufficient revenue when disaster struck (damage of turbines by wind and lightning in storms).
ESCOM diesel Island 750 kW on Likoma island and 300 kW at Chizumulu Isl.	The systems are owned and operated by ESCOM. Customers pay ESCOM's uniform tariff (around USD 0.08/kWh) but costs are much higher (about USD 0.8-0.9/kWh). The main challenge is the high cost and erratic availability of diesel. A proposal has been formulated to set up a 1 MW solar plant in a hybrid configuration with the existing diesel plants plus battery storage.
MAREP MGs supported	Government-supported, Gumulira (Mchinji) solar, Usingini (Nkhatabay) hydro, and Kasangazi MG hydro
Non-government	
Hydro MG, MEGA, Muilanje. Total of 220 kW is operated by the social enterprise MEGA (owned by MMCT).	The system connects about 1650 HH, 1 health Centre, 1 health post, 4 primary schools, 1 day secondary school, 6 maize mills. As Malawi's first community-based mini-grid enterprise, MEGA is a pioneer for future project developers and government stakeholders and has inspired the development of a mini-grid market in Malawi and beyond. A small shop sells solar lanterns. Watershed management aims to protect and improve the hydro system's catchment area and the generation infrastructure. The powerhouse is 8 km from the national grid, though the mini-grid extends to within 3 km at the closest point and discussions are going on about connecting with the ESCOM grid. MEGA is the first licensed (social) independent power producer (IPP) in Malawi; MEGA is being set up as an independent social enterprise. The MEGA business model aims to achieve better economies of scale for central operations by developing multiple sites, thus the the original capacity of 80 kW has been expanded to 220 kW. MEGA is currently seeking funding to extend distribution lines so that 3500 HH will be connected. Funded by several sources; the initial 80 kW with USD 800,000 from OFID, Scottish Government and Practical Action; and an additional USD 0.8 million for another 80 kW (funded by UNDP; with technical assistance by PA and SgurrEnergy
Solar MG, Sitolo, Mchinji 80 kW (owned by Community Energy Malawi).	Initially planned to be 45 kW, a 80 kW system (with 7.2 km HV and 11.4 km LV line) was installed in 2019 providing power to about 675 HHs, 40 enterprisers (incl. 2 maize mills, and 1 primary school. In future, the system may expand to serve up to 900 HH (in total) with 2 irrigation schemes and a milk cooling and storage facility but already the system's power may reach peak demand limit. Located 23 km from the grid and USD 750,000 funding provided by Community Energy Scotland (CES) and UNDP/GEF. Connection fee of MWK 20000. Tariffs USD 0.18/kWh per HH, USD 0.19/kWh business, and USD 0.09/kWh social. Other CEM projects included a) cold storage and SHS for small fishermen (Nkhotakota, Salima), b) installation of solar PV in health centres (five 14.5 kW and one 7.5 kW system)
Sustainable Energy for Rural Communities (SE4RC), implemented with CARD Malawi	The HIVOS-Praxrical Action programme (2015-2019) has delivered clean energy, and new opportunities through seven energy kiosks as well as power for irrigation schemes, schools and clinics. Solar lanterns can be charged at the kiosk that also provides such services as TV shows, cold drinks, printing and internet services. Minigrrids include, in Nsanje District: 30 kW (Nyamvuwu; solar minigrid), 15 kW (Chimombo) and in Chikwawa District: 15 kW (Mwalija) and 25 kW (Oleole). Systems are managed by community energy service companies,
Usingini hydro MG (300 kW)	The MG is an example of MG with an anchor load (coffee processing with power demand during the day of about 50 kW, mostly in the period May/June-Aug/Sept). Current demand (PUE and HHs) is about 110 kW which could go up to about 480 kW (coffee PUE, 230 kW; households, 225 kW; maize mills, 25 kW). Financed by UNDP, Practical Action, and others. Supporting activities included community participation, skills transfer, commercialization, and entrepreneurship development strategy
Chiponoma hydro MG 50 kW	Supported by the UNDP ACRE project, the Chipopoma Hydropower connects 95 HH, 1 maize mill and huller Some 115 more HHs ready for connections,. The MG aims to promote as PUEH (PUE hub), a tourist resort (Mushroom farm resort), Yewo Jewellery Craft Centre and Mtende Homecraft Foundation. No meters are installed yet, causing issues with revenue collection (meter-billing systems of MEGA or Sitolo MG should be replicated)
Pico hydro	About 25 pico-hydropower schemes are found in Nkhata Bay District in the Northern Region, situated at 15 km distance from Mzuzu city. Most pico-hydro schemes service one house only and can provide a basic power service (for one or two lights, TV, phone charging, and for haircuts), however, a few pico-hydro schemes power two or even five houses.
SHA solar minigrids, Dedza distric	Supported by Self-Help Africa (United Purpose), micrograds have been installed (12 kW Mthembanji, serving 47 households, 11 businesses, 1 church and 1 school; costing USD 8869/kW); and Kusembe (12 kW Solar PV, 60 customers); costing USD 9924/kW). Demand in 2021 in Mthembanji was 325-350 kWh/month and small business demand (65-103 kWh) The MGs will be supported by the UNDP/GEF project Africa Minigrids with PUE and demand stimulation (rice mill Mthembanji and oil processing Kudemba; e-cookers, microfinance). SHA set upp a social enterprise , Kuyatsa, to own and operate microgrids in Malawi
Catholic church	Mthengowathenga (50 kW) (35 kW) and St Gabriel. Reportedlly, 24 hrs supply but costs for public electricity and fuel for the two diesel generators a significant financial burden. Reliable 24 hours energy supply (before power cuts affecting the connected hospital)
In preparation	WB EAP: 10 studies MG to be tendered. UNDP ACRE: Studies Chisi Island Zomba (solar PV 30 kW under construction), Mwansambe (Ntcheu), Manolo/ Malidali (Mzimba)

The Least-Cost Electrification study has identified some 74 sites that (see Box 12) are more than 10 km from the grid (i.e. ESCOM MV line) and with a population size of over 750 people (about 250 households). Of these, 39 are in Central Region, 8 in Northern and 27 in Southern Region (with an average distance from the grid of 14 km, and an estimated 255 households on average). The minigrid market potential is likely to be much larger once the opportunity of agriculture productive hubs is understood better, e.g. by including productive hubs between 5 km to 10 km from the grid that will not be powered in the coming 5 years.

The Regulatory Framework for Mini-Grids in Malawi (published July 2020, see Box 15) makes allowance for a range of delivery models and procurement scenarios, covering both “solicited” and “unsolicited” processes. It recognizes different ownership options as eligible for licensing, including (i) community-based, (ii) public-owned and operated by an institution with state shareholding; iii) private, (iv) public-private partnership established as a Special Purpose Vehicle (SPV) with clear shareholding and risk sharing arrangements; and (v) a hybrid ownership model where different persons own different components of the mini-grid system (see Box 20 with more insights on business models). The different models span EPC contracting, ESCO model/concessions through private sector delivery. The framework makes provision for cost-reflective tariffs, following a tariff methodology and structure provided by the Regulator. The tariff methodology sets a broad framework or principles for the formulation of tariffs. Innovative tariff formats will be considered for approval by MERA.

The framework provides for a subsidy programme to be arranged, and structured as a (i) capital subsidy, (ii) output-based aid (performance-based), (iii) operational subsidies to close the gap between affordability and cost recovery and (iv) pro-poor rates (cross-subsidization between customer types). The Rural Electrification Fund, collected from a levy on electricity sales, is theoretically available for rural electrification activities including mini-grids but has not been utilized for such to date as the subsidy provision has not been functional.

High initial investment cost, low ability/willingness to pay and lack of business models

In general, the cost of minigrids is high due to the cost of equipment. It seems like the cost of solar-powered mini-grids in Malawi (about USD 9000-10,000/kW) is on the high end in comparison with benchmarks of other projects in the region (about USD 4000-11,000 with USD 8500/kW on average in 2020)[17] giving high levelized cost of energy of about USD 0.9-2.0 per kWh. In general, costlier projects had larger shares of grant funding with costs increasing due to lack of competitive tendering. Most mini-grids (MGs) in Malawi have been financed by a select group of donor organisations (Scottish Government, Irish Government, UNDP, and international NGOs) and implemented on a project-by-project basis. Globally, there is a tendency for MG component cost to drop over time. A recent ESMAP report mentions that the cost of ‘best-in-class’ minigrids dropped from USD 0.55 to USD 0.38 kWh (at 22% load). In reality, the cost per kW can vary widely (see Box 16).

The current MG regulatory framework allows tariffs to be set on a case-by-case basis, reflecting the costs of investment and operation of the facility. In reality, setting tariffs at a financially sustainable price is quite difficult. The willingness or the ability (WTP/ATP) of customers to pay is a large factor that determines what the upper limit of an off-grid system tariff can be. Poverty and low disposable income of households in rural areas create a challenging environment to justify cost-reflective and financially viable tariffs. Electricity tariffs in the mini-grids are often set as is typical of any social project, where the operator is obliged to provide an affordable service to its people. For the majority of mini-grid developers in Malawi, OPEX (administration, repair and maintenance) and revenue are almost the same, due to high operational expenditure from challenges of reaching remote locations, leaving little for savings for future larger repairs or battery replacement. Determining the ATP/WTP of customers is an inherently difficult process. High uncertainty exists in determining the expected electricity demand of previously unconnected communities and considerable variation can exist between relative wealth levels in the village. See Box 25 for a discussion on ATP/WTP in Malawi.

In general, there is poor information on demand characteristics and matching technical and financial solutions to the target population’s ability to pay (ATP) and preferences in minigrids. A social problem is high expectations against a background of limited resources. As already pointed out above, mini-grid projects tend to raise high expectations within the areas where they are being implemented.

[17] See Box 26 (Malawi) and Box 28 (international, Zambia and examples)

Box 15 Regulatory framework for minigrids

Overall legal-regulatory framework

- Rural electrification is defined as the grid or off-grid extension of distribution lines and generation of electricity in rural and remote areas whose internal rate of return is up to a maximum value set by the Authority, line voltage level is less than 66 kV and generation capacity is up to 5 MW. Renewable energy resource definition includes solar home systems, micro, mini and small hydroelectric power stations, biomass, biogas, wind, and other thermal electricity generation systems and technologies.
- Licensing is governed by Energy Regulation by-laws (2009). A licence is required to carry on the business of importing, selling, installing and maintenance of renewable energy technologies (By-law 42). A licence shall not be issued unless the Authority has granted the applicant an electrical installation permit (By-law 44). Every licensee shall comply with and adhere to the standards and specifications for renewable energy technologies approved by the Authority (By-law 55).
- The Rural Electrification Levy (REL) supports projects with an Internal Rate of Return (IRR) of up to 6%. The Electricity (Amendment) Act 2016 allows MERA to specify the rate of return;

Minigrids licensing

- Mini-grids of less than 50 kW shall not be licensed provided that, where such type of mini-grids are developed for public use, they shall be registered to monitor compliance with quality of service, safety and environmental protection standards.
- All mini-grids with generation and or distribution capacity of 50 kW or more developed for commercial purposes shall be licensed. Only one licence shall be issued for combined activities of generation, distribution and retailing. All mini-grids of 50 kW or more developed for private use, shall be registered for records and to monitor compliance with safety and environmental protection standards.
- The following terms and conditions shall form pre-requisites for licensing of mini-grids: (a) Permits and certificates - for sustainable use of resources, including approved Environmental Management Plans (EMPs), Water Rights and local authorities approvals on the usage of land and forests; (b) Business registration in Malawi (and compliance with registration requirement, including tax remittance, ownership and authorized operators, among others); c) workplace registration for safety of people and equipment; and d) other application requirements (any person applying for a licence or registration for operation of mini-grids, shall duly fill and submit to MERA application form
- The mini-grids shall be developed consistent with the energy policy, energy strategy and Rural Electrification Master Plan provided by the Rural Electrification Management Committee (REMaC). In the absence of the Master Plan, REMaC shall approve the mini-grid projects on a case-by-case basis. MERA shall license mini-grid proposals approved by REMaC. MERA shall consider the following to approve applications for the licensing of mini-grid projects: a) resource availability, b) willingness to pay and affordability, c) adequate financing options, d) energy mix (consistent with Government targets), location (outside areas earmarked for MAREP grid electrification).
- Where approved, consistent with the Rural Electrification Act 2004 unless otherwise directed by the Government, the developers shall enter into a Concession Agreement (CA) with the Government to develop and operate the mini-grids. The CA shall specify a) the need for subsidy (CAPEX subsidy, output-based aid, operational subsidy (to close the gap between WTP/ATP and cost recovery; pro-poor rates); b) customers targeted (incl. productive uses), and c) use of local resources.
- Various ownership models are eligible: a) public (owned by a trust or cooperative associations or ESCOM), b) private, c) special purpose vehicle (public-private partnership) or d) hybrid ownership-operation models
- Where the main grid extends to the mini-grid supply area, the continuity shall be assured by grid connection of the mini as allowed under terms and conditions specified in the Grid Code and as shall be discussed and agreed upon between the mini-grid operator, the Single Buyer (SB) and the System Market Operator (SMO). Where grid connection is not allowed, the SB shall compensate the mini-grid operator
- Light-handedness. Caution shall be taken to void over-regulation of mini-grids to the extent of destroying their commercial viability. The amount of information requested and number of reviews and approval steps for the purposes of regulating tariffs and quality standards shall deliberately be reduced.

Tariffs

Cost-reflective tariffs are to be charged on off-grid/mini-grid projects. This is also in line with By-Laws 205(g) and 211 (d) of the Electricity By-laws which allow MERA to approve tariffs for off-grid electrification which a) are cost-reflective and competitive; and b) do not impede competition in the industry*Source: Legal-Regulatiry Framework for Minigrids* (PowerPoint, Director Legal Affairs, MERA); CONREMA website

Box (cont'd) Regulatory framework for minigrids

- Subject to whether the mini-grid is connected to the main grid or isolated, mini-grid tariffs shall comply with the tariff methodology and standard tariff structure approved by MERA.
  - Grid-connected. Tariff components will include; a) retail tariff to end-user customers; b) wholesale tariff from the main grid to grid-connected mini-grid; (c) Wholesale tariff from the mini-grid to the main grid in a Power Purchase Agreement (PPA) on a format agreed between the mini-grid operator and the Single Buyer (SB) and shall comply with a standard format approved by MERA (feed-in tariff); d) energy banking (where parties agree, alternatively, that amount of energy consumed by the mini-grid be netted off with the energy sent out to the main grid and reconciliation done after an agreed period; whether PPA or energy banking arrangements, the tariffs shall be on a Take or Pay basis), unless otherwise provided by the CA.
  - Tariffs for community-owned isolated mini-grids shall best be left to be decided by the beneficiaries themselves. The approach is believed to yield tariff levels that are within the range of affordability and willingness to pay by the beneficiaries. The regulator shall verify the adequacy of the tariffs to cover operations and maintenance of the mini-grid to ensure sustainability. An attempt shall be made to set the tariffs higher than required to provide for the accumulation of adequate funds for system maintenance during major equipment failures and system breakdowns.

Minigrid system design and requirements

- A least-cost technology mix for maximum stakeholder value. Technology options shall be based on what is locally available and may include any or a hybrid system of the variable technologies of wind and solar; energy storage; or main grid backup. A feasibility study shall be conducted for each project to ascertain the adequacy of the supply chain in the long term.
- The min grid shall comply with the following technical requirements: (a) The connection code; (b) Network Code of the Grid Code; (c) Metering Code for the Grid Code; and (d) Distribution Code. The mini-grid shall have a comprehensive and clear operation and maintenance scheme. The mini-grid shall be designed to applicable standards for easy integration into the main grid without any technical constraints during the time when the main grid covers the supply area of the min grid;
- The regulator shall monitor and enforce compliance with agreed key performance indicators (KPIs), which shall include but not be limited to the following:
  - Reliability and security of supply (e.g., energy banking; energy storage; backup systems and design for minimum system losses; system adequacy to meet demand and customers' needs (avoid overdesigning; and WTP/ATP considerations
  - Compliance with Electricity By-law: a) stability of system voltage and frequency; planned/forced b) customer service (outages; complaints, faults & info requests; customer service standards)

Given a certain installed capacity (kW) not all demand may be served with imitation on energy and power use enforced by putting a ceiling on the number of households to be connected and on the capacity per household. This can lead to disappointment with some customers if they find out they cannot use electric cookers or power equipment while having doubts about the value of the minigrid tariff they have to pay. Recent experiences with MEGA, CEM and other functioning mini-grids show that after an initial period of low consumption, the demand for electricity services (in terms of potential customers that want to be connected, both household and productive uses, as well as consumption per customer) exceeds capacity. Even when a proper energy assessment is carried out in the design phase, is difficult to predict the future. Inadequate generation and inaccurate load forecasting can lead to over- or under-sizing projects, both leading to poorly designed systems with cost overruns and sustainability concerns.

Often, the tariffs are set such that these are not even enough to cover operational expenditures (OPEX) of the mini-grids, let alone having a financial provision for future expansion (generation capacity addition or transmission and distribution lines). The donor (whether government or development partner) that provided the CAPEX is often not ready to add another subsidy for purchasing equipment, which is seen as subsidising OPEX. If prices for the electricity supplied to the people are persistently not cost-reflective, the whole initiative can simply fall apart.

Solar mini grids benefit from decreasing solar module prices, driven mostly globally y large grid-connected installations; solar modules now cost about USD 200/kW. Similarly, large volumes, together with cost declines associated with the rapid expansion of other power electronic markets, such as motor drives for electric vehicles, will continue to drive down costs for PV inverters (benchmark of PV inverter of about USD 80/kW and battery inverter of about USD 115/kW,

2020) and controllers. The cost of a lithium-ion battery may have dropped to about USD 126/kWh, while smart meters may cost about USD 40 per unit[18]. Geospatial analysis allows developers to assess mini-grid sites at a fraction of the cost of traditional site assessment activities; from around USD 30,000 per site without using geospatial analysis, to approximately USD 2500 per site using geospatial analysis. To achieve greater financial sustainability, strategies must be undertaken to reduce costs through a) scaling up, and achieving better economies of scale, b) increasing operational efficiencies, and c) increasing demand through promoting PUE and demand stimulation (outside peak hours).

Scaling up

As mini-grid (MG) developers scale their portfolios from 1 to 10 and then to 100 or more mini-grids, fixed costs like administration and management are spread over more units of production; sometimes a company can negotiate lower per-unit costs enabled by bulk purchases. Scaling up also allows increased efficiencies through standardized processes[19], even more so when combined with mobile-based pay-as-you-go billing and internet-based remote monitoring. Negotiating with multiple suppliers with similar technical specifications can help drive down the initial equipment cost. Ordering multiple units and utilizing volume discounts can help reduce capital expenditures. Even if an operator is executing a single project, receiving bids from facilitating organizations, such as equipment manufacturers, can help reduce initial capital expenditures. For example, on the online MG management platform Odyssey, MG operators post project specifications for bidders, equipment providers, financiers, and others, who can then offer their services to help complete the project.

Options for reducing equipment and hardware costs include a) providing access to modular or more efficient hardware, b) promoting local manufacture where feasible and c) supporting the development of lower-cost equipment supply chains as well as clustering MGs (that can be serviced from regional service points) to achieve more economies of scale. MG project aggregation may also be helpful to attract (private) investors who might not consider individual small MG projects.

Operational efficiency

By having customers pay for electricity upfront (rather than metering and then billing after the electricity has been used), operators can often reduce the number of staff and overhead dedicated to billing and payment collection. With prepaid systems, the customer pays upfront for a certain amount of electricity, and once that has been used, the customer must prepay for another allotment. Prepaid metering is not without challenges, however. Issues to address include the need for cellular data coverage at the MG site.

Operational costs can be reduced through on-site energy demand shaping. These will include direct levers such as reducing the hours of service, developing categories of customers with restricted or time-limited energy access and indirect levers like time-of-use pricing or behavioural nudges. Operating costs can be reduced further by providing access to more efficient, higher quality equipment, reducing maintenance costs and the incidence of failure or improving revenue collection using PAYG smart meter technology.

The potential for using data and digital tools and solutions to add value at various stages of the minigrids value chain remains largely untapped. With enhanced capacity, MG developers could streamline their operations through smart metering and remote control of their assets and potentially reduce operations and maintenance costs by about 15% to 30% through reduced site visits, labour and component replacement costs.

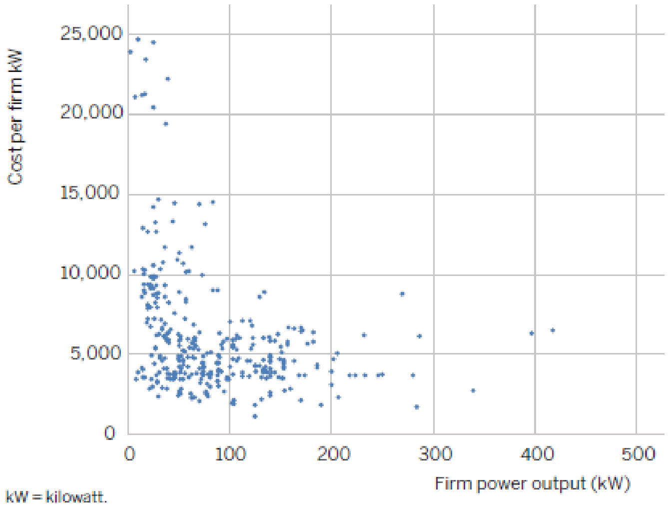
Digital technologies, such as mobile payment or remote monitoring, can help reduce operational costs, and thus directly improve profitability. As noted earlier, using prepaid meters with mobile payment can help reduce overhead by eliminating the need for staff to collect cash or to pursue customers for payment. Remote monitoring tools can help monitor different MG equipment, ensure that it is functional, and proactively address any issues that may arise, reducing overall maintenance costs. For example, mini-grid equipment providers, such as SMA Solar Technology through its Sunny Portal system, allow operators to monitor a variety of parameters in real-time to assess system performance (applied in the Mthembanji and Kudembe microgrids of the EASE project).

18 See *Minigrids for a Half a Billion People*, World Bank/ ESMAP (2022)

19 For example, the company Standard Microgrids offers a standard standard 15 kW systems in Zambia (that serve about 150 households). Engie's PowerCorner (now called MySol) is designed for a demand of 20 kW.

Box 16 Investment, operating costs and tariffs: international, Zambia, Malawi examples

	EU IAREP project					UNDP	IEP	UNDP/ACRE-supported			SHA	CEM
	Feasibility studies		Call for Proposals		AMDA	Afr MG	Malawi	feasibility studies, Malawi			Malawi	Malaqi
	Lunga	Chishi	> 100 kW	< 100 kW	2020	Zambia		Chisi	Malidadi	Mwans	Dedza	Sitolo
CAPEX (in cost USD)]	2,858,000	1,691,000	728,888	345,798		303,638	291,096	544,363	664,141	619,656	105,184	750,000
- generation	61%	44%			36%	57%	35%	42%	78%	57%	46%	
- T&D, meters	28%	45%			47%	9%	52%	57%	14%	42%	32%	
- site prep, logistics	11%	11%			17%	34%	14%	1%	9%	1%	22%	
Capacity kW	537	222	145.5	40.5		104	28	29.58	95.6	59.8	11.5	80
Connections	1510	888	458	373		214	207	170	350	270	60	715
- PUE clients	406	47				14		21	45	15	4	40
Cost/kW	5,322	7,617	5,010	8,538	8,158	2,920	10,555	18,403	6,947	10,362	9,146	9,375
Cost per connection	1,893	1,904	1,591	928	930	1,419	1,434	3,202	1,898	2,295	1,753	1,049
Watt per connection	356	250	318	109			133	174	273	221	192	112
Energy kWh/yr	656,567	272,811						45,789	100,503	75,533	6,369	14,213
- share non-HH	8%	13%						93%	88%	96%	17%	
Peak demand (kW)	115	105						13	18	6	10	
Tariff (w/o grant), $/kWh	0.990	1.45				1.27		2.01	1.06	1.17		1.00
Grant CAPEX	47-75%	47-75%	47%	47%		40%	40%	100%	100%	100%	?	?
Tariff (w/ grant), $/kWh	0.33-0.58	0.50-0.87				0.78		0.98	0.49	0.54	0.49	0.18
O&M costs	23,100	19,333				6,073		7,900	11,762	9,289	3,797	5,400
- $ per customer/mnth	1.3	1.8			from 1-4	2.4		3.9	2.8	2.9	5.3	7.6



In general, mini-grids display economies of scale in generation capacity, with smaller mini-grids (microgrids) costing more per kW than larger mini-grids, although statistics give a misty result. A recent ESMAP publication shows there are wild cost variations per kilowatt of firm power (kW_{firm}) output (kWfirm is defined as $kW_{generator}$ + $0.25*kW_{p,pv}$. The median economic cost was USD ,084 per kW_{firm}, while the 25th and 75th percentile economic costs were USD 3,760 and USD 6,953 per kW_{firm}, respectively. Most mini grids below 200 kW_{firm} have costs around or below USD 5000 per kW_{firm}. Also, projects with (backup) diesel generators will have a lower cost per kW_{firm} than 100% RE projects. Other minigrids differ in their distribution network and may overbuild to accommodate future updates as the load grows.

The ESMAP report further mentions that there are other factors explaining the wide variation, such as the way the amounts and ways in which project development costs are internalized into a project (not all costs are reported as a mini-grid development cost if borne by a donor, or the other way around, to get more donor funding cost estimates are inflated).

Compiled from: EU Capacity Building for Renewable Energy And Energy Efficiency: Feasibility Studies and Demonstration Projects, data from submissions in Call for Proposals 92019, p.c.; *Benckmarking Africa's Minigrids,* AMDA (2022), UNDP/GEF Zambia Minigrids Project Document (2019, Annex G); ACRE-commissionesd feasibuilioty studies (Chisi, Mwansambe, Malidadi; 2022), *UNDP Sitolo Solar PV Mini-grid Technical Assessment Review* (2017); *Minigrids for a Half a Billion People*, World Bank/ ESMAP (2022); *A first look at data from the Mthembanji microgrid,* by A. Eales (2021); and other info and data available at EASE project https://ease.eee.strath.ac.uk/ and website

Promotion of productive uses

When income-generating machines and appliances boost demand for MG electricity, a mini-grid's load factor gets a corresponding boost too. Meanwhile, a higher load factor (jumping from 22% to 40% in the example of Box 17) cuts the levelized cost of energy. Including both anchor and business clients will enable the project developer to connect households at affordable rates, because these clients (1) may cross-subsidize connection and consumption fees for households and (2) will consume the lion's share of the energy generated during the day, whereas household consumption tends to intensify during the hours before and after work. This increases the MG developer's margins and therefore financial viability. Entrepreneurs and small businesses benefit from switching from expensive diesel generators to affordable MG electricity. Communities benefit in the long run from the new jobs that MGs create and the increased economic activity. Stimulating demand for electricity from productive activities can, in particular, assist women-run enterprises to boost their earnings through the use of lighting, electrical equipment for cottage industries, baking, ceramics, and so on.

Box 17 Increase demand/load factior and levelized cost of energy (LCOE)

Source: *Minigrids for a Half a Billion People*, World Bank/ ESMAP (2022).

From the perspective of the minigrid operator, productive users of power are the most valuable. Their usage tends to be a significant and predictable addition to the MG's revenue stream. Importantly, generating additional income increases the user's ability to pay for services directly and contributing to the economic vibrancy in a village indirectly improves the willingness to pay from other community members. Examples of specific PUE interventions include (see also A-B-C energy use in Box 18):

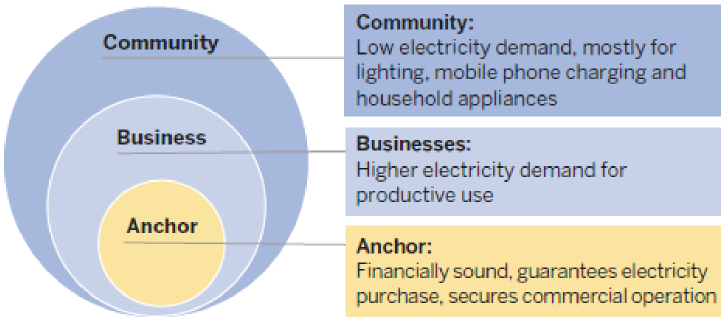
- Service/business centre: internet services (e-hub), sales or leasing of solar products and electric appliances (solar kiosk), including TV, lighting, high-efficiency cookers and small workshop equipment
- Value chain support (e.g., convert existing diesel equipment to electric equipment or new equipment, e.g., cooling for artisanal fishing communities or agricultural processes, such as maize milling, oil pressing, rice de-husking)
- Stimulation of off-peak household demand, including high-efficiency cooking
- Anchor loads (collaboration with social services, such as schools and clinics, or telecommunications)

Electricity demand does not rise automatically with the arrival of a mini-grid. The barriers to demand are numerous, among them limited markets, information, lack of skills, up-front costs, inefficient appliances, and scant access to financing. For MG developers, adding productive users to their customer base adds complexity to the project design, because they have to determine whether and how to connect these loads, which differ in terms of time of use, magnitude of power and energy demand, and seasonality. Demand can be promoted by giving priority to productive use anchor loads, then businesses and finally household customers. This approach will guarantee more daytime usage, reduce wasted generation and increase revenue

Malawi has a very small productive base in the rural areas, the mere availability of additional power may not necessarily lead to an increased use of energy. The low commercial power demand and lack of anchor loads may dissuade potential investors from investing in mini-grids. Productive use can be promoted as a driver towards sustainability, especially effective if coupled with training on skills, and access to microfinancing for enterprises. However, the situation on the ground does not offer many opportunities with PUE which is often already being supplied by diesel generators for example. This means a promotion of business and entrepreneurship is required as well as energy supply, increasing the time and resource requirements to get a project off the ground. During the early stages of the PUE program, a team's direct engagement with communities is important in identifying high-priority appliances and machines. The ESMAP report Minigrids for a Half a Billion People mentions that typical up-front investment ranges from USD 50 to USD 1,500, with an average of about USD 1,200. After the payback period, the appliances generate between USD 50 and USD 500 in monthly revenues, with an average of USD 300.

This also requires a good understanding of where opportunities for productive use lie to inform the design of cross-sector support structures that will enable localized productive use interventions. Unfortunately, the lack of collaboration between the agriculture sector and electricity providers makes planning and budgeting for productive use in project design difficult. While capacity exists at the national level on electrification and rural energy, such capacity at the local level is harder to find. For example, unlike other ministries, the MoE, until recently, did not have Energy Officers represented at the local (District) level. With no clear link between national planning (and target setting) and district or village implementation (where energy infrastructure can be connected with productive uses in a more relevant way), it is difficult to plan with appropriate financial (and human resources) allocation.

Box 18 A-B-C minigrid users



The most financially sustainable mini-grids use an A-B-C strategy: first, identify and negotiate an agreement with an anchor load client (often in agro-processing); then identify, or help develop, small local businesses; and only last target domestic consumers." Thus, rather than trying to a socially beneficial plant profitable, the opposite approach is to make a profitable MG socially beneficial. In Malawi, the Usingini hydropower facility is an example of such an anchor load providing a core electricity demand.

However, securing anchor clients can be a challenge. These may already have their own energy supply (e.g. telecom towers) or may be reluctant to switch from diesel power to the renewable energy of a minigrid. In addition, anchor clients may have unrealistic expectations about tariffs, and operators may become overreliant or even dependent on them, threatening their financial position.

In Malawi, there is generally a lack of rural businesses, and diesel generators are not common. It may be difficult to identify an anchor load in rural economies based only on subsistence agriculture (and small-scale artisans) as the main income streams for the mini-grid (MG). Thus, there is a need to strengthen small and medium-sized enterprises (SMEs)—the B of the A-B-C model. Some developers have been combining multiple business clients to act as the anchor. In this approach, the MG's generation assets are sited near a cluster of small businesses that may be housed in the same building

Thus, identifying anchor loads that can be powered by MGs, and designing integration to the MG systems will be a game changer for microgrid business models through fostering demand and increasing utilisation rate (load factor). In addition to technical integration of PUE appliances to match generation capabilities, business design of the PUE enterprise is needed, including exploration of value chains and appliance financing to stimulate demand.

Business models

Any business model for commercially viable mini-grids must address the needs of three key stakeholder groups: a) customers need a guarantee of service that they can afford and are willing to pay for; b) power suppliers need to be able to guarantee a rate of return to their investors while covering all operational costs; and c) investors need to be confident of the risks they are taking. Challenges exist in devising business models that can provide viable returns through the provision of electricity to remote and dispersed poor rural communities, such as balancing the high cost of operation, maintenance and administration with the returns from poor consumers with seasonal incomes that can afford only minimal amounts of electricity. In general, there is a lack of proven business models for minigrids (in contrast to stand-alone applications and larger grid-connected IPPs) involving private companies in Malawi. Minigrids, so far, have been implemented by local NGOs or community organisations[20].

There is a mismatch in demand and supply due to low affordability, seasonal incomes, and limited anchor loads. The poor cost recovery and lack of skilled technicians lead to inadequate repair and maintenance and the inability to ensure the long-term sustainability of systems. More awareness is needed on equipment standards to identify the right equipment for meeting user needs and system constraints.

[20] For example, MEGA and Usingini NGOS/social enterprises, owned by Mulanje Mountain Conservation Trust (MCCT), Usingini is onwned by Mzuzu Coffee Cooperative Union and Usingini Community Trust, while the MGs at Sitolo and Dezda are owned by Community

Demand stimulation and e-cooking

Beyond electricity supply technologies, the availability of quality electrical equipment and appliances is limited for consumers in homes, enterprises and public facilities. Access to high-efficiency (and high-quality) products, including light bulbs, TVs, fridges, etc is all the more important for rural consumers relying on systems with limited generating capacity. Addressing the barrier of micro-finance availability for consumer products will increase the demand and profitability of mini-grid developments.

Although mini-grid energy supply is for the most part considered in terms of electricity, it should be noted as stated earlier that 95-98% of energy use in Malawi is biomass with clear links to deforestation. There are drivers to increase the efficiency and sustainability of biomass use through wood fuel and charcoal production. Generally, mini-grids focus on electrical power for lighting, communications and productive uses, not addressing from the outset the need to reduce firewood and charcoal consumption. Electric cookers powered by mini-grids present an opportunity to address environmental concerns. However, the high electrical load of current electric cookers presents a barrier to mini-grid system designers, as the cost per kWh to cook a meal will likely be higher than the equivalent cost of (almost free) firewood and above the ability and willingness to pay. The Business Case 2.4 describes e-cooking, including monthly household cost comparisons between electric cooking and no e-cooking as well as implications for minigrid capacity design.

Box 19 Electric cooking in minigrids

Until recently, the development community has not viewed electricity as a viable option for enabling access to clean cooking, because of reliability, safety, access, affordability, and sustainability challenges. Blackouts and brownouts on weak grids prevent people from cooking when they need to, and collective usage causes peak loads on already strained grids to spike and exacerbate underlying problems. For mini-grids, electric cooking is often perceived to be prohibitively expensive given the high tariff rates charged by most minigrids. Peak loading is a major concern for e-cooking on power-limited mini-grids. Thus, usually, minigrid customers still rely on costly, time-intensive biomass fuels to cook daily meals.

However, a new generation of energy-efficient e-cooking appliances has become viable. Many of these devices are highly efficient at a specific task (for example, kettles for water boiling) and can therefore be combined with other appliances to cook the range of foods that make up a full menu. The familiar hot plate may consume 1-2 kW (0.3-0.7 kW DC), while an efficient electric pressure cooker (EPC) may consume 0.7-1.2 kW (0.2-0.4 kW DC). To avoid overloading, a variety of time-shifting techniques (e.g., asking people to cook outside certain hours) can decouple cooking from overall electricity peak demands on the mini-grid, by smoothing out the load profile. The business case for e-cooking discussed in section 2.4 shows that due to demand increase the MG revenues increase, enabling lower tariffs. While the energy consumption of a household increases, the power bill may not increase proportionally under the right circumstances. If the wood fuels used have a monetary value, the resulting avoided charcoal or firewood purchase may favour e-cooking as part of the cooking fuel mix at a low marginal cost.

Between March 2021 and February 2022, a pilot study was conducted on electric cooking in the MEGA hydropower mini-grid in Malawi, in order to understand cooking demand (20 households participated, each receiving a 1.5 kW hotplate, pots and a heat retention device). The collected hotplate power consumption data was that the majority of households consume less than 1kWh per day for cooking. This indicates that the households are practising fuel stacking, as they are unlikely to meet their cooking energy demand with the observed hotplate usage. This corresponds to a World Bank report that found when using a mixture of conventional and energy-efficient appliances, cooking power consumption for an average household is 0.9–2.1 kWh (compare with assumptions on electric cooking in the Business Case presented in Box 62). The proportion of households cooking mostly indoors increased after hotplates were received, from 63% to 79%, while the hotplate has become the main cooking device in 89% of the participating households. In the MEGA study, the e-cooking on a mini-grid in Malawi varied from 22% - 50% of total household energy consumption, implying that e-cooking will have a substantial impact on tariff payment of e-cooking households. The WB study further reports that, regarding electrical network constraints, the study found that e-cooking penetrations above 20% created serious generation capacity constraints unless substantial diesel generation was added and that the network would need to be designed as typical national grid loads (which is often not the practice of minigrid developers). The MEGA pilot study concludes that e-cooking may present a solution to utilising surplus power, however, it faces two major barriers. Firstly, at least for solar mini-grids, the availability of surplus energy is during the daytime, while peak cooking loads occur in the evening, requiring effective demand-side management (to shift cooking hours away from peak hours). Conversely, for hydro-power mini-grids off-peak time use is an opportunity to level the demand curve with less requirement for capacity (kW) increases.

Source: *Cooking with electricity, a cost perspective* (World Bank/ESMAP, 2020); *Electric Pressure Cooking: Accelerating Microgrid E-Cooking through Business & Delivery Model Innovations,* PowerGen, CLASP (2020). *Opportunities and challenges for eCooking on Minigrids in Malawi,* by A. Eales, et.al. in: 2022 IEEE PES/IAS PowerAfrica, Conference Paper. *Cooking with electricity, a cost perspective* World Bank/ESMAP (2020)

Box 20 Mini-grid business models

<table>
<tr><td rowspan="2">Public sector delivery or EPC contracting</td><td rowspan="2">ESCO with service charge or tariff-based contract</td><td rowspan="2">Split assets model</td><td colspan="5">Non-government entities</td></tr>
<tr><td>Hybrid</td><td>SPV: private sector, public sector; local org coop</td><td>Coop (owned by users of the service)</td><td>NGO/ not-for-profit</td><td>For profit entity</td></tr>
<tr><td>Government builds (w/ or w/o EPC contract) and operates (w or w/o BOT, concession)</td><td>Government owns and private/non-gov builds and operat</td><td>Gov owns T&D and other entity owns generation (usage rights)</td><td>For example, community (owns) and private (operates w/o BOT)</td><td colspan="4">Entity owns and operates</td></tr>
<tr><td colspan="2">Government/donors provide CAPEX and (part of) OPEX</td><td colspan="6">Government/donors cover 30-80% CAPEX; usually no OPEX subsidies</td></tr>
</table>

A minigrid business model, determined by the national government, is the cornerstone of a country's over-arching minigrid regulatory framework. It defines who finances, builds, owns and who operates and maintains the minigrids. Where applicable, it seeks to engage the private sector. The minigrid business model determines key components of a minigrid framework, including tariff structures, subsidy levels and financial mechanisms. The models with text in *italics* are implemented in Malawi

Pros and cons of MG business models

Community / not-for-profit	• Electrification of remote areas where projects are not cost-effective for utilities and private investors, and therefore respond to community energy needs. • Communal ownership can facilitate proper management and inclusive services • Locally managed projects can create local jobs and training opportunities. • Communities can use profits from mini-grid projects to support other community development projects.	• Communities often lack the financial and technical capacity to install, operate and manage mini-grids. • Communities sometimes set tariff levels too low, compromising the financial viability of the project. • If the project lacks an effective mechanism to monitor consumption, some members of the community might overuse electricity. • Corruption in certain cooperatives can divert resources or decrease community support; Local politics can impede the project. • Enforcement and ensuring payment can be challenging.
Private / for-profit	• Operations, maintenance and management tend to be more efficient. • If the private investor has a stake in another business in the region (like an agro-processing facility), they have an incentive to maintain high-quality electricity services. • Political motivations, which can influence the public sector/utilities, are less likely to influence private-sector actors. • Private-sector investors can scale up operations making investments more profitable	• Without supportive policies (subvention), regulations and financing for mini-grids, rural electrification may not be cost-effective or be too risky for private actors. Even with MG regulatory frameworks established, lengthy approval times and tariff approvals can delay projects. • Small-scale project developers, who are more likely to implement rural electrification projects, may lack financial management capacity and access to financial (debt) resources
Utility / public sector	• Utilities often have strong technical expertise, maintenance capacity and financial management systems. • Utilities often have good access to legal services and systems to manage regulations. • Utilities can more easily connect mini-grids to main grids. • Utilities may be able to provide subsidies for mini-grid consumers through tariffs collected from grid-connected customers.	• When short-term political agendas drive projects, projects are vulnerable if conditions change or sites are chosen according to political reasons • Profit-driven utilities have little incentive to electrify poor communities; mini-grids generally are not a utility's core business, so the project might not receive the attention it needs • If utilities don't engage communities and promote a sense of local ownership, projects can fail. • The utility's corporate structure might not work for smaller projects.

Capacity building; innovation and digital technology

A lack of knowledge and market availability of modern technology options, particularly recent innovations using hybrid systems, demand management and payment solutions is a barrier to minigrid development. Technologies and their development methodologies including financing mechanisms should be adapted to the context in which they would operate. This requires in-depth knowledge of several aspects such as energy needs and requirements; prioritisation of energy services; purchasing power; satisfaction of energy services and experiences with prevailing energy technologies; social practices and social set-up of communities; and available technical skills. Similarly, the use of poor-quality materials is also a challenge in Malawi.

Capacity development is required at various levels to make microgrid development a success, especially local capacity building for operation and maintenance. A shortage of skilled technicians for the operation and maintenance of renewable and/or decentralised energy systems is a major barrier to the uptake of renewable energy in Malawi. With so few systems in place, it is difficult to identify technical people experienced in the specifics of village power technologies. To address this issue, the Government (and its development partners) can provide support for technical short courses, degrees offered through local universities, online training and internship opportunities both local and international. The government can also support private sector capacity building through business development initiatives such as tailor-made technical assistance, business incubation and acceleration programs. Capacity building can also be supported for private sector operators on access to finance through bank loans and also business planning/management skills.

At the local level, skills strengthening and community engagement need to be prioritised for effective minigrid enterprises to function and grow sustainably, with a budget allocated to support these interventions. Community engagement should be a key focus embedded in the service offering of a microgrid developer, with financial and human resources set aside in the mini-grid's business plan

Digitization is proving a key enabler for individual systems and national planning and decision-making. Smart metering, data logging, remote monitoring and control need to be embraced by mini-grid developers to offer efficient, technically robust and sustainable systems resulting in reliable electricity provision. The value of remote monitoring has the value of smart meters is clear, through remote access to customer data, remote switching and dynamic tariff changing. Remote monitoring is a tool for troubleshooting and providing early warnings when issues are about to occur, Remote monitoring is a tool for troubleshooting and providing early warnings when issues are about to occur. This helps lower OPEX in terms of reducing maintenance costs and providing a better understanding of system performance. The technical challenges experienced with the smart meters are usually outweighed by the benefits in terms of data and control, and in the long run, are seen as an essential element of any (solar PV) mini-grid.

The nascent state of mobile money platforms for energy payments in Malawi presents a barrier, increasing costs through the necessitation of an on-site vendor at the mini-grid site to take customer payments. Opportunities exist to collaborate with telecom companies and mobile money operators, exploring potential relationships and requirements for utilising mobile money for energy transactions. Thus, the success relies on the availability of mobile finance or 'pay-as-you-go' platforms. In Malawi, mobile money operators have not yet reached a critical mass to allow cheap enough transaction fees for customers. A 10% commission charge is still taken from each transaction which can have negative effects on businesses relying on the service. There is also low mobile network penetration in rural areas. As more customers sign up to use the service the transaction costs will reduce the service costs.

In general, the government needs to broadly improve sector oversight to carry out systematic monitoring and evaluation of electrification activities, feeding back into their planning and decision-making. Monitoring Key Performance Indicators (see also Box 21) in technical, economic and social impact domains, and sharing this data, will aid in building the knowledgebase and accelerating the nascent mini-grid sector. Measurement of load profiles, quantification of load growth over time and providing insight into demand patterns and seasonal trends are essential for designing cost-effective and technically efficient minigrids. Measuring and sharing demand disaggregated by customer segments is especially important for informing business models and settings of appropriate tariffs.

Box 21 Experiences of Self-Help Africa microgrids, Mthembanji, in digital technology application

Since the start of the operation of the Mthembanji microgrid, the EASE project has been collecting valuable data on technical, economic and social impact performance through smart meters, remote monitoring and enumerator surveys:

- A *visualisation platform* (developed as part of the Solar Microgrids for Sustainable Development VIP4SD project.) is used as a tool enabling monitoring and evaluation of data to understand microgrid performance, ultimately informing business strategies for scaling microgrid operations in Malawi
- *Data collection.* Smart Meter data utilises the SteamaCo platform, which offers an innovative solution to monitor energy use, lets people pay for power using their mobile phones, and quickly troubleshoots problems. SteamaCo's mobile-enabled smart meter, bitHarvester, collects real-time data on revenue, demand and smart meter uptime, accessed through the cloud and presented on the platform. Remote monitoring data on generation and energy storage is logged through the Sunnyportal (an online portal offered by the equipment provider SMA) which enables mini-grid system operators and researchers to monitor and configure PV generation systems and visualize system data
- *Social Impact surveys* tracking the 'customer journey' were conducted by project-contracted enumerators with the MG customers, through smartphones on the platform Kobocllect. Surveys uploaded to the online platform are downloaded for analysis as spreadsheets.
- *Data analysis*. Technical Indicators relate to the performance of the generation system taken mainly through the Sunny portal API. These include PV generation, inverter consumption, battery temperature, system downtime, and system efficiency. Demand Indicators include revenue, monthly demand and hourly load profiles. Social Impact indicators, from analysis of enumerator surveys. KPI include energy access (number of connections, electricity consumption), social services (access to information in schools; cases of illness treated), work and income (household income, jobs created due to the microgrid), gender (women employment, female free time), and tariff and service (satisfaction with tariff, issues with mobile payment)

Source: website https://ease.eee.strath.ac.uk

Customers have on-demand prepaid plans. Customers can use an app to manage their profile, inquire about service usage and pay for service through the app. The company's software manages customer profiles and site profiles with real-time and historic reports to monitor and control the customer's usage. The hardware is controlled and monitored remotely which facilitates maintenance.

Government stakeholders often lack specific knowledge or face budgetary and technical capacity constraints to fully utilise the potential of digital solutions (e.g., real-time data gathering, common data reporting protocols streamline licensing, and monitor the quality of service) to broadly improve sector oversight and planning. And while data could be a tremendously valuable asset in the minigrid sector, this potential remains largely underutilized due to the lack of standardization and common data reporting protocols and the fact that this sector is still very nascent and remains relatively fragmented. Different MG developers use different software and data reporting protocols making standardization difficult.

1.6 Productive users: MSMEs, agriculture

Rural enterprises

The viability of minigrid systems will be directly dependent on the concurrent and active development of economic activity and productive use of energy. PUE can be found in agriculture (e.g. irrigation, grain milling, electric fencing, cold storage), manufacturing (e.g. carpentry, tailoring, welding, and looming), and the service sector (e.g. bars and restaurants using electric lights, sound systems, refrigerators, charging stations for mobile phones). Common use applications include electricity used for potable water, public lighting, education, and health (e.g. refrigeration of vaccines and anti-venom).

The country already benefits from an active small business sector[21]. In 2019, 1.14 million micro-, small--, and medium-sized enterprises (MSME) were active in Malawi, with 1.825 million people working in the sector[22]. The majority of these (74%) are classified as micro-entrepreneurs, either employing 4 people or less (including the owner) or with a very low annual turnover (up to MWK 5,000,000, about USD 6,720 in 2019). A further 23% are small enterprises, employing 5 to 20 people, or with a turnover between MWK 5,000,001 to MWK 50,000,000 (USD 67,200). Only 3% is considered medium-size. Very few MSMEs have been registered or licensed, with 89% considered informal. Only 38% report operating from a business premise, suggesting that many are operating from residential premises. Women own 56% of micro-enterprises in the country, while the majority of small and medium enterprises are owned by men (68% and 87%).

The majority of MSME owners are based in urban areas (78%), located near the main cities, whilst just 22% are located in rural areas. MSMEs are most active in the trade (63%) and agriculture (24%) sectors and 78% are located in rural areas. About 189,000 farmers (16.5% of the MSME sector) operate in the primary agriculture sector, the major commodities being tobacco (35%) followed by edible nuts. This is in line with the high-value cash crop system in Malawi since the farming of maize and corn is usually for household consumption rather than profit. The research found that the main source of capital for funding agricultural businesses was through selling crops or livestock (24%), borrowing from an agricultural supplier or using personal savings (13%). The average landholding size is 5 hectares and the main market for agriculture production includes collection centres (41%), retailers (31%), and directly to the consumer (2%). The findings show that the agro-processing sector has about 40,000 owners (4% of all MSMEs), of which 85% fall under micro-enterprises, 14% under small enterprises). At 34%, fruit and vegetable processing form the largest sub-sector within agro-processing followed by 'other food products' at 28%, nuts and animal oils at 25%, and grain milling contributing 9% to the sector.

Interestingly, considering the low electrification rate in rural areas, 26% of MSMEs report having access to electricity (18% supplied by the grid and 9% with access to solar or diesel generator power). As suggested by the electrification numbers, electricity access is however predominant among urban-based MSMEs (51%) compared to rural areas (9%). Male-owned (typically larger businesses) also have higher access (25%) compared to women-owned businesses (11%). With access to electricity above that of the national average, it would suggest that MSMEs are dependent on electricity supply. Yet, only 6.5% of MSMEs indicated electricity as a barrier to operations when selecting barriers from a list of options[23]. Small, rural-based MSMEs found lack of electricity a more significant barrier than larger and urban-based counterparts (small 13% vs medium 1%, rural 7% vs. urban 4%). This suggests that rural electrification can support small business development while small business development can support the viability of clean energy minigrids, collectively contributing to the transformation of the rural economy.

Some 25% of MSMEs have access to financial (bank) services, while 47% use non-bank services, mainly mobile payment accounts and SACCOs; 40% of MSMEs are informally served (farmer associations, saving groups, private money lenders).

[21] Malawi: Energy and the poor: the need to invest in off-grid cleaner energy. Draft. 29 October 2020. UNCDF and UNDP.

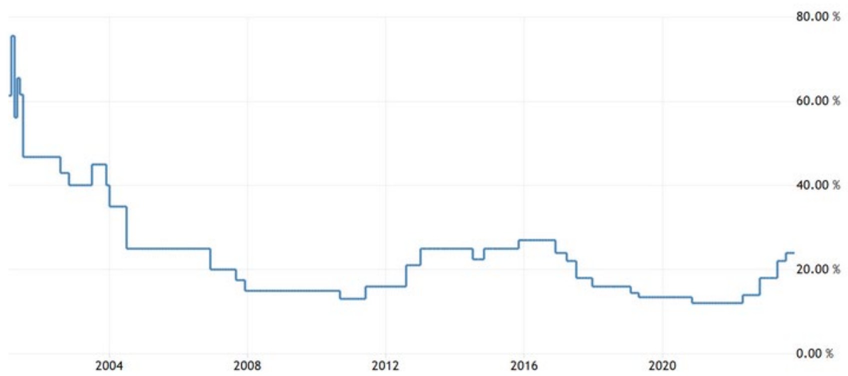
[22] FinScope Malawi MSME Surevy 2019.

[23] Major barriers were identified as sourcing money (53%), lack of customers (31%), selling prices lower than expected (26%) and transportation of stock (24%). Most of these are likely to also impact minigrid operations.

Less developed sectors, such as farming, and wholesale and retail sectors, have lower levels of formal access. About 36% of MSMEs cited access to finance as their biggest obstacle to growth in 2019 in the FinScope report (2019). Micro-enterprises commonly depend on informal credit mechanisms as well as family and friends, who become critical for business cash flow and working capital. Only 10% of medium enterprises, 5% of small enterprises, and 3% of microenterprises have credit from a commercial bank. Access to formal credit, concentrates on MSMEs working in tourism, construction and business services. The remaining sectors have lower formal credit access, particularly manufacturing and agro-processing, both deemed to be industrial drivers within the MSME sector.

The cost of credit for MSMEs remains highly unaffordable (see Box 22), and collateral requirements are often reported to be high by MSMEs further deterring borrowing by MSMEs. The low financing access is compounded by the low number of people and microenterprises with a bank account. Thus, longer-term bank financing is limited. The total value of credit or finance extended to MSMEs stood at USD 82 million in 2018. Of this, banks provided 68%, followed by the MFIs (18%) and the donor agencies (8%). Most of the MSMEs in Malawi are served by MFIs, whose focused products and offerings have been a key attraction to MSMEs. Agriculture and the trading sector receive up to 60% of the overall loans provided by MFIs, with 60% of the MFIs' loan portfolios consisting of loans from micro and small enterprises. The banks generally focus on the formal small enterprises, which constitute a very small proportion of the MSME sector.

Box 22 Reserve Bank of Malawi's lending rate



https://www.ceicdata.com/en/indicator/malawi/bank-lending-rate.
The RBM reference rate was about 20% in Jan-Apr 2023. Being part of the interest rates charged by banks on loans, borrowers pay between 22-33.5%. The RBM reference rate was again raised to 24% in Oct 2023

The most common risks facing MSMEs are theft of business stock (34%), rain damage (24%), and fire, flood or natural disaster (23%) With the bulk of MSMEs being informal and sole proprietors, risk transfers to the household, further jeopardising the livelihoods of MSME owners. While the bulk of risks facing the sector are insurable, the uptake of insurance coverage remains low, covering only 3% of MSMEs. The majority did not take any risk measures, and those who did take action to deal with risk used their savings or borrowed capital.

Agriculture

The economy of Malawi is predominantly agriculture-based. Agriculture accounts for 30% of GDP and generates over 80% of national export earnings. The agriculture sector employs 64% of the country's workforce and contributes to food and nutrition security. The main economic products of Malawi are tobacco, tea, cotton, groundnuts, sugar and coffee. These have been among the main cash crops for the last century, but tobacco has become increasingly predominant, while also tea and groundnuts have increased in relative importance. The main food crops are maize, cassava, sweet potatoes, sorghum, bananas, rice, and Irish potatoes, while the average farmer also raises cattle, sheep and goats.

On the large farming estates, the main crops are tobacco (60%) tea (20%), and sugar (18%) and the balance (2%) is used for growing other cash and food crops. Estate agriculture accounts for more than 25% of agricultural GDP, 10% of agricultural employment, 9% of total GDP and 90% of export earnings. The estates access improved technologies and have better access to inputs, credit, supporting agricultural services and markets, hence have higher productivity levels than smallholders.

The smallholder farmers group in Malawi are comprised of approximately 3.1 million farm families sharing 6.5 million hectares of land - 69% of Malawi's total land area of 9.4 million ha available for agriculture under customary tenure system. The average farm size is 0.7 hectares and about 60% of smallholder farmers cultivate less than 1.0 ha of land[24].

Agriculture relies mainly on rain-fed crop production whereas production and consumption of animal products are very low. As a result, the country continuously faces food shortages at national and household levels. Irrigation potential in the country remains under-exploited despite being one of the priority areas in the national agricultural policy. Out of the estimated potential of about 407,862 hectares (ha) only about 116,249 ha (29% of the potential area) have been developed for irrigation purposes as of 2017/18. This hurts agricultural growth, exports as well as food and nutrition security.

Malawi has also been hit by fall armyworm attacks in the recent past and this has significantly affected the production of maize. The 2021/22 rainy season attests to the fact that Malawi is vulnerable to weather shocks. Malawi was hit by floods emanating from cyclone Ana. In January 2022, a state of disaster was declared due to Cyclone Ana. According to Flash Appeal 2022, more than 71,700 ha of cropped area belonging to more than 91,000 households were severely affected through either complete wash-away or submersion. Initial estimates showed significant damage to crops. Nsanje and Chikwawa were the hardest hit, with rough estimates pointing towards one-third of all crops being lost. On livestock, the update indicates that 36,803 combined livestock species owned by 12,655 livestock keepers were either killed or injured by the floods. In March 2022, Malawi was hit again by another cyclone Gombe, and a total of 9 districts and 2 cities were affected.

1.7 Financial sector in Malawi

Overview

Malawi's financial sector consists of nine banks[25], 13 insurance companies, several pension funds and a stock exchange. It is dominated by banks, which represent about two-thirds of financial sector assets. The formal financial sector is dominated by two commercial banks, namely the National Bank of Malawi (MBM) and the Standard Bank.

The microfinance sector consists of microcredit agencies, ten microfinance institution (MFI)[26] and 47 approved financial cooperatives (SACCO, savings and credit cooperatives), six of which are community SACCOs (2018, data)[27]. MFIs are regulated and supervised by the Central Bank, while prudential supervision of SACCOs is carried out jointly by the Malawi Union of Saving and Credit Cooperatives (MUSCCO), a national umbrella organisation. The about 26 microcredit agencies are supervised by the Malawi Microfinance Network (MAMN), established in 2001. The laws on financial services and microfinance published in 2010 constitute the legal framework governing the regulation and supervision of the microfinance sector. The microfinance sector serves most of the financing needs of MSMEs and the rural population. Less than 1% of Malawi's population is registered with the Savings and Credit Cooperative Society (SACCOS). Typically, SACCOS are rural-focused and inclusive of teachers, police, hospitals, and organizations such as women's groups. The total number of clients served by licensed savings and credit cooperatives (SACCOs), however, has been growing.

Lending for off-grid energy in Malawi

Regarding MFIs in the country, their ability and willingness to lend to households for stand-alone solar products is still limited. Some financing for off-grid solar products is only tentatively becoming available, but interest rates are as high as 10-20% per month. Most of the 47 SACCOs buy solar PV products in bulk and then sell them on credit to their

24 https://www.ccardesa.org/malawi; Sector Position paper (JICA, 2022)

25 Deposit-takling banks are National Bank of Malawi Plc, Standard Bank Malawi Ltd., and FDH Bank Ltd account for 65% of the market share. The remaining 35% is composed of six other banks: CDH Investment Bank Ltd., Eco Bank Ltd., First Merchant Bank Ltd., NBS Bank Ltd., Nedbank Malawi Ltd., and New Finance Bank Ltd. Source: Reserve Bank of Malawi (2018)

26 Key microfinance institutions (MFI) include: Opportunity Bank of Malawi, FINCA Malawi Ltd, NBS Bank Limited (Small-Medium Enterprise Department), Finance Trust for the Self Employed, the Centre for Community Organization and Development, CUMO Microfinance Ltd., and Finance Savings and Credit Cooperative (Source: Transparency Pricing Initiative in Malawi, 2013).

27 https://www.mfw4a.org/country/malawi.

members. Community Finance is offering soft loans for solar products. FinCoop [28]and Microloan Foundation do provide low-cost loans for small solar lanterns.

None of the commercial banks in Malawi have specific products for SAS companies. However, banks lend to these companies just like any other business. Such banks include the National Bank of Malawi, FDH Bank, NBS Bank and FINCA. The Bangladesh-based Infrastructure Development Company Limited (IDCOL) assists the Ministry of Energy as the Fund Manager of the WB-supported Malawi Off-Grid Market Development Fund (OGMDF) to develop the solar market. To solve the difficulties of expanding the off-grid market, IDCOL will operationalize the USD 20 million financing window by providing debt financing as working capital assistance, grant facilities to give end-user subsidies, and Market Catalyst Fund to promote the local businesses.

Malawi's Rural Electrification Fund, collected from a levy on electricity sales, is theoretically available for rural electrification activities but has not been utilized for such to date as the subsidy provision has not been functional concerning off-grid electrification. There seems to be an 'unwritten' practice of Government providing on-grid and donor partners on donor agencies and philanthropic donations providing for off-grid electrification. Thus the financial ability to cover the viability gap in off-grid projects has been limited and does not reach the amounts needed to reach the 2030 universal access targets. This is typical of many countries in Africa with large government investments going into national utilities' programmes and considerably smaller minigrid programmes. This structure creates incentives to expand on-grid programs into unviable areas when it is not the most effective or best-quality electrification option.

Commercial financing for minigrids is non-existent. Market technology and business models of minigrid companies are rather unknown to local commercial banks. Individual MG investments are often too small and considered high risk[29] and for minigrid project developers to get commercial debt financing is nigh impossible. Private-sector mini-grid developers face seven main barriers to accessing finance:

- Many potential private financiers consider mini-grids too new and hence too risky as investments. Uncertainties around future demand for the mini grid's electricity services create a risk for developers and financiers alike. Not all potential customers will be connected in the first years and thus tariff revenue is less in the first years than in later years, while substantial PUE may only be added later. Revenue growth is an essential part of the business model, but it's difficult to predict or guarantee. In addition, mini-grid customers are typically rural households and small business customers with no long-term contractual obligation to buy power from the mini-grid.
- Many potential consumers are unable to pay the full costs of the mini grid's electricity (with tariffs set such that revenues are not sufficient to cover OPEX or future large repair costs. Even households that do connect to the mini-grid may end up consuming little electricity because of the high tariff. Minimal energy sales will make it more difficult for the mini-grid to recover its costs.
- Unlike larger project developers, small companies, or local for-profit and community developers often do not have enough of their own financial resources to meet the equity. requirements imposed by conventional lenders. Mini-grid investments often create an unacceptable asset-liability mismatch for local debt financiers. Mini-grid assets in rural areas offer little collateral because they are difficult to repossess and have limited value when moved from their installation location. Mini-grid projects typically require long-term funding (8-10 years) at a low cost of capital. Banks in developing countries (such as Malawi) are often reluctant or unable to offer long-term loans, either because they lack funds or cannot risk losses due to uncertainty about future macroeconomic conditions (particularly exchange rates, inflation, and the economic growth rate). In Malawi, interest rates for commercial loans may be around 21-32% (in 2023, about 27% on average) and banks have high collateral requirements (sometimes reaching 300% of the loan amount).
- Private capital lenders for renewable energy still prefer grid-connected renewable energy investments, because they have a larger scale, are perceived as lower risk and provide contractual guarantee features such as feed-in tariffs and off-taker insurance, which protect their investments.

[28] FinCoop has piloted end consumer financing for off-grid solar products by securing a USD 350,000 from the AECF (US$100,000 in interest-free loans and US$250,000 grants) to provide loans to end consumers for the purchase of solar equipment., collaborating with Sunny Money as a provider of solar systems through its teachers' programs and village service centers

[29] Uncertainties around demand for the mini grid's electricity services creates a risk for developers and financiers alike. Many potential consumers are unable to pay the full costs of the mini grid's electricity

While it is common for commercial debt to be the largest part of the financing package for a typical investment project, most mini-grid projects in Malawi (and elsewhere in Africa) to date have been financed mostly with grants and a smaller portion of equity and debt.
debt.

Usually, capital investment requirements do not include the cost of implementing the productive use program as they may be financed through other channels. However, this implies that it is difficult to design the supply-demand balance of a minigrid if it is not certain if a large (anchor load) PUE will be financed as well. In any case, access to finance represents a challenge to all sizes of businesses in the country, relevant to both the minigrid developers and operators as well as small businesses. Malawian businesses have limited access to credit from formal providers (as discussed in the previous Section A.6). The cost of credit in Malawi, measured by the official bank lending rate, is also a prohibitive factor. Bank lending rates had fallen from over 40% to 18% over the last twenty years, however, recently has gone up to about 24% by the end of 2023.

Access to high-efficiency products including light bulbs, TVs, fridges, etc. - is particularly important for rural consumers relying on systems with limited generating capacity. Addressing the barrier of micro-finance availability for consumer products will increase the demand and profitability of mini-grid developments. However, stakeholders report typical lending rates above 30% and up to 100% for microloans, making debt (other than small amounts to be paid back in a few months) unaffordable.

Selected business support programmes in Malawi

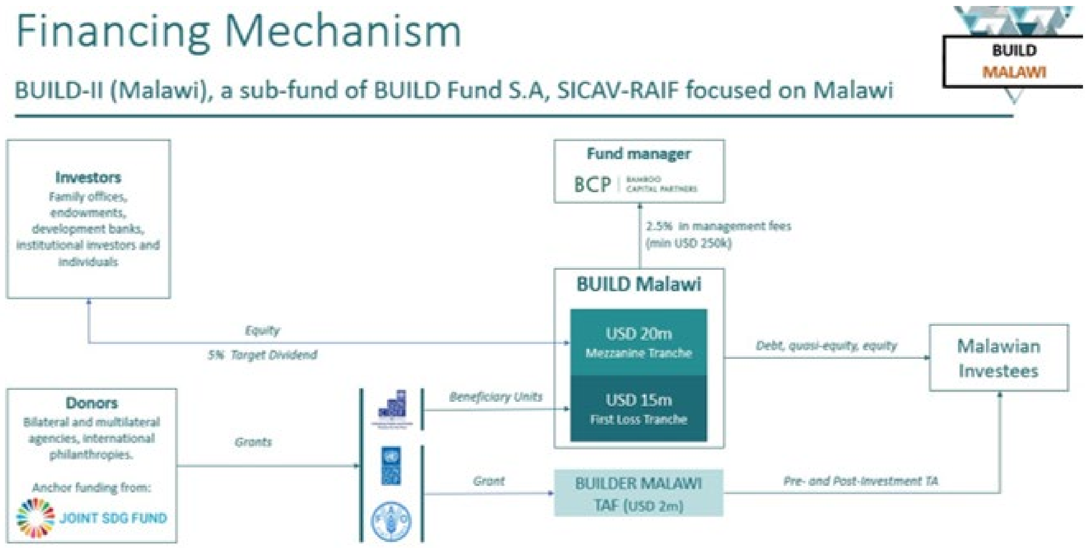
The World Bank has been implementing the FinEs (Financial Inclusion and Entrepreneurship Scaling) programme since 2020 withn the aim to increase access to financial services, promote entrepreneurship and capabilities of micro, small, and medium enterprises (MSMEs) in Malawi (including addressing Coronavirus disease 2019 (COVID-19) implications). FinEs included a USD 47 million credit line (liquidity extended through the Reserve Bank of Malawi (RBM) to commercial banks, MFIs and SACCOs for on-lending to MSMEs (in particular those engaged in agribusiness, export-oriented farming, trade, clean energy and e-commerce). In addition, FinEs has provided support to MAICC (Malawi Agriculture and Investment Corporation, a development bank established in 2018) well as a de-risking financing (USD 14 million) consisting of partial credit guarantees for for MSMEs (affected by COVID-19) and equity and quasi-equity financing and concessional debt for innovative start-ups and SMEs. Other activities included technical assistance accompanying the credit lines (USD 4 million), building the capacity of firms and business service providers (USD 7.5 million) and strengthening the enabling environment for MSME financing (USD 9 million). Thus, loans at 11% could be provided to MSMEs, over half of commercial interest rates, but most funding has been committed now.

UNDP has several instruments to support MSMEs in Malawi:

- The *Growth Accelerator Entrepreneurship Challenge* (established in 2018), is intended to provide innovative, impactful and early-stage entrepreneurs across Malawi and across industries with technical support, mentorship and financing through private equity and matching grants. The program is implemented by MHub in partnership with Growth Africa, Accesserator, and Kweza Equity Partners, with USD 8 million in support from UNDP, KfW and the Royal Norwegian Embassy. Entrepreneurs may request any amount between USD 10,000 and USD 40,000. The funds requested are unlocked by entrepreneurs matching the requested amount from the accelerator with 30% of their own funds or from an investment partner. The program is cohort-based, providing six months of business development support and TA and three months of mentorship to selected ventures (a total of nine months). Six cohorts have been implemented, supporting 46 ventures, with two cohorts being launched.
- Established in 2014, the *Malawi Innovation Challenge Fund (MICF)*[30] has launched 11 competitive rounds of funding targeting: agriculture and agribusiness, manufacturing, logistics, irrigation, SME finance and tourism. The Fund has invested in over 60 companies (about USD 30 million and leveraging USD 36 million in private sector contributions).
- With EUR 13.5 million support by EU/UNDP, *Zantchito* provides support to incubate sustainable, yet impactful, business ideas from entrepreneurs and bring them to market. Business development and finance services support are provided to TEVET/university graduates and MSMES, as well as strengthening of business incubators

[30] Supported by International Fund for Agricultural Development, the Royal Norwegian Embassy, Federal Republic of Germany through KfW and the UK Foreign Commonwealth and Development Office,

- The *BUILD Malawi* Facility, under the BUILD Fund, seeks to provide access to strategic risk capital to companies in agriculture and agribusiness, interested in advancing Sustainable Development Goals outcomes. BUILD Malawi (managed in Malawi by Bamboo Capital) provides long-term debt and/or equity to SMEs that need impact capital, unavailable in Malawi, and that are on track to invest further in inclusive business models. The USD 35 million impact fund has a USD 15 million first loss layer and a US$ 20 million mezzanine tranche. It will employ senior loans, subordinated loans and mezzanine equity ranging from USD 250,000 to USD 2.5 million to support projects in the target sectors. The average timeframe for investments is 3 years, but they can last up to 8 years. The Fund has an estimated IRR of 5%. So far, 21 projects have been supported and the Fund is now being restructured into Build-II.



- The *Green Economic Transition Facility (GETF)*, was launched in 2023, seeks to tease out the green innovation landscape and unearth green, inclusive, future smart business solutions for Malawi led by the private sector, and can provide performance-based support between USD 40,000 and USD 300,000 (with up to USD 35,000 technical assistance. It currently has two Windows, launched each with the first rounds of Calls for Proposals. Window 1 (Accelerating Alternative Energy and Fuel-Efficient Technologies) receives EUR 4.7 million from Irish Aid, Window 2 (Accelerating Green Business Solutions) is funded through KfW, and Windows 3 (Accelerating private sector investments in climate change, funded by the Government of Flanders) will come up soon.

A number of other donors and development partners have been supporting MSME and agribusiness development, including AfDB, USAID, IFAD, United Kingdom (DFID/UKAID/FCDO) and FAO

1.8 Overview of financing sources and mechanisms for minigrids

Grants and subsidies

Subsidies should be part of the financial package available to mini-grid (MG) developers and proponents. The subsidy provider will want subsidies to be properly targeted, easy to administer, and not be a financial burden:

- *Pre-investment subsidies.* MG developers face certain expenses before they decide to undertake their investments, such as market assessments and prefeasibility and feasibility studies. Developers may be hesitant to incur these costs because they are not sure that their firm will build a MG at the site being considered;
- *Capital cost subsidies* should be designed so that the financial package, consisting of equity, debt, and subsidies, is sufficient to finance all capital costs and allows setting tariffs and connection fees in such a way as to find a balance between WTP/ATP and annual OPEX and debt servicing. Regarding connection fees, poorer households will find it difficult to pay the up-front connection and internal wiring costs needed to connect to a MG

If a project is deemed viable at the pre-feasibility stage, the next stage is the feasibility study, which answers questions about how much the project will cost and the likely financial returns on the investment. The feasibility study includes a business plan, detailed system design and financial model outlining which portions of the project will be financed by equity, grants and debt. This stage of the project also addresses permitting and licensing, which can be time-consuming if the MG project is among the first built in a country or region. The feasibility study is crucial; mistakes in the business plan or financial model can lead to substantial cost overruns later or jeopardize the viability of the project. funding typically comes from the project developers themselves, sometimes with funds or technical support from donor-funded programs, grants from government or angel investors.

Once the feasibility study phase is complete, mini-grid project developers seek out either private or public financing sources to back the project. Most of of capital needed in a mini-grid project is for construction (including the purchase of any land), equipment and materials. Once funding is secured, project developers typically commission an engineering, procurement and construction (EPC) contractor to execute the work. EPC contractors specialize in quantifying materials needed such as cables, solar panels, wind or hydro turbines, thermal generator equipment, switch gears, transformers; utility poles and cables; procuring and transporting the required materials; and installing them correctly and in the right sequence. The construction phase of mini-grid development is most prone to cost overruns and management challenges. Any unanticipated factors that can change the project timeline, such as exchange rate changes, poor communication, resettlement issues, adverse weather, local unrest or supply chain trouble are elements that can impact the mini-grid project cost.

Common sources of grants are government agencies or ministries, international donors, private foundations and non-profit development organizations (see the international examples in the Boxes 23 to 30). A subsidy scheme must have an exit policy and the need for subsidies should diminish over time as a result of the following factors:

- Experience should allow financiers to assess risks more accurately, reducing risk perception. Thus, the availability of debt and equity finance is likely to grow.
- The need for pre-investment subsidies should fall as mini-grid developers become active in particular markets
- Costs are likely to fall as firms gain experience, and invest in a larger portfolio of MGs
- Cost of components (e.g. solar panels, batteries) decline due to innovation and as the scale of the industry increases globally';
- On the other hand, as MGs move into poorer, even more remote areas, capital costs may increase, while consumer affordability may decline, making it more difficult to taper subsidies. Thus, like grid extension, minigrids will continue to rely substantially on subvention.

Capital cost subsidies can be *upfront or performance-based*. Subsidies for minigrids can ideally be a mix of these, with a large part covering the initial investment cost (as usually commercial debt is not available) and a part linked with intermediate results (e.g. progress milestones in construction, installation and commissioning) and the performance during first years of operation (e.g. ability to connect clients and increasing the system's load factor). The capital cost subsidy is usually a share of 'reasonable' capital cost (e.g. 40 or 60%) or can also be based on 'lowest-susbidy' bids in competitive tenders[31]. A special subsidy category consists of providing grant support for connection households to the MG (covering connection fees) and supporting the purchase of energy-efficient domestic appliances or efficient electromechanical equipment for productive uses.

Results-based financing (RBF) has been a popular means of increasing the effectiveness of public financing measures in different markets for some time. RBF is an umbrella term that characterizes various approaches in different countries, such as, among others, performance-based financing (PBF), output-based aid (OBA), or cash on delivery (COD). Unlike upfront (input-based) grants, RBF provides the funding partner greater influence over the implementing process and ensures that funds are spent correctly and according to the agreed budget. However, RBF does little to enable access to the up-front capital required to design and raise finance around a minigrid investment. MG developers eligible for RBF would still face the difficult challenge of acquiring working capital to pre-finance business revenues and RBF cashflows.

[31] Upfront grants be provided in *minimum subsidy tenders* (MST). A MST is generally defined as a tender process in which mini-grid developers compete based on their technical (technical proposal) and financial (financial proposal) qualities. The financial bid that has the lowest subsidy requirements scores the highest. A variant *minimum cost tender.* The MCT is defined here as s a bidding process in which mini-grid developers compete based on their technical (technical proposal) and financial (financial proposal) qualities. The financial bid that charges the lowest additional cost (monthly service fee on top of the set tariff) scores the highest.

Box 23 Financing minigrids in Myanmar

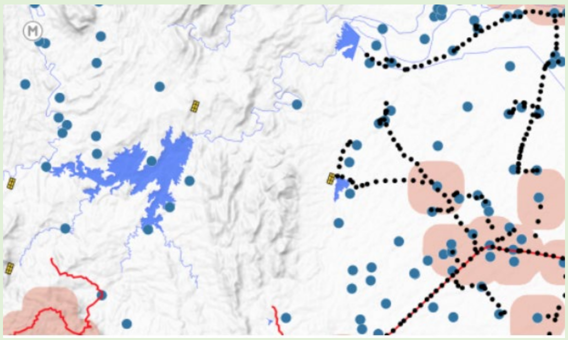
a) World Bank National Electrification Programme, Myanmar (2016-2021)

Before the general's coup d'état in 2021, the World Bank supported Myanmar's National Electrification Policy (NEP) with the grid electrification implemented by the Ministry of Energy and the off-grid component by the Ministry of Agriculture. The off-grid component is funded by World Bank-IDA with USD 90 million (of which USD 10 million is for technical assistance, USD 7 million for mini-grids, USD 53 million for solar home systems, and USD for community/public institutions), in addition to the Government's budget of about USD 75 million. The off-grid component aims at providing electricity to about 650,000 households in about 8,900 villages (of which about 33800 households in 345 villages are covered by minigrids). The implementation model of the SHS component of the WB-DRD National Electrification Plan (NEP) involves procuring solar home systems from private companies (contractors) through international competitive bidding, with these contractors also responsible for installation and after-sales service. The contracts for SHS and minigrids were organised in five lots during 2016-17, 2017-2018, 2018-19, 2019-20 and 2020-21.

Subsidies before 2016 on SHS were a full 100%. Under NEP, subsidies offered to off-grid households range between 81-90% depending on the SHS configuration opted by each household. The subsidy is to come down to 85% in year 1 and 80% on average in year 5. The subsidy for mini-grids was 80-20% in the first year and is expected to come down to 50-50% by year 5 (in 2021) of the DRD-NEP project. Currently, the subsidy is based on 60-40%, i.e. the government supports up to 60% of the eligible cost and the equity share of the remaining balance is divided by the developer and the village electrification committee (VEC), in which the community has to provide at least 20% of the cost (in cash and/or in-kind).

The NEP relies on a self-reliant electrification approach. The government will provide the grid at the township level. Villages within the township must then organise and collectively finance the final stage of connection. They must also organize the village mini-grid proposals and apply in Calls for Proposals (see further). Village Electrification Committees (VECs) are formed by community members. This body then works with local township electricity officials to devise a connection or mini-grid electrification plan, and crucially, to raise the funds from collective household savings. However, financial support for their functioning is very limited. Also, VECs receive in practice little guidance or technical support, and may not have the expertise to formulate rural energy proposals. This may explain why in the DRD-NEP Call for Proposals, most projects presented are drafted by project developers (o contractors on behalf of VECs) rather than the VECs themselves. Project developers will be entitled to operate the mini-grids for a specified number of years (e.g. 6 to 15 years, although the exact period of operation is to be determined as part of a comprehensive business model and agreed with DRD and the respective communities) and are expected to supply 24-hour, grid-quality electricity during this time. After the developer's period of operation, the mini-grid assets are to be transferred to the local Village Electrification Committee (VEC) for continued operation. For this reason, all mini-grids developed under the CfP were classified as Build, Operate, Transfer (BOT) or Build, Own, Operate, Transfer (BOOT). In addition to the capital grant support, DRD will provide capacity-building and community mobilization assistance via DRD township offices. mini-grid projects developed under the NEP must comply with the Environmental and Social Management Framework (ESMF) of the World Bank-Assisted National Electrification Project.

The programme has been accompanied by technical assistance provided by GIZ in supporting DRD in a) developing a regulatory framework for mini-grids (e.g. financial support mechanisms, ownership structures, tariff schemes, grid interconnection), b) supporting WB/DRD in assessing proposals in various rounds of Call for Proposals (supported by World Bank), d) strengthen the competence of government, private sector, and community stakeholders. Smart Power Myanmar has developed a digitalised electrification planning tool.



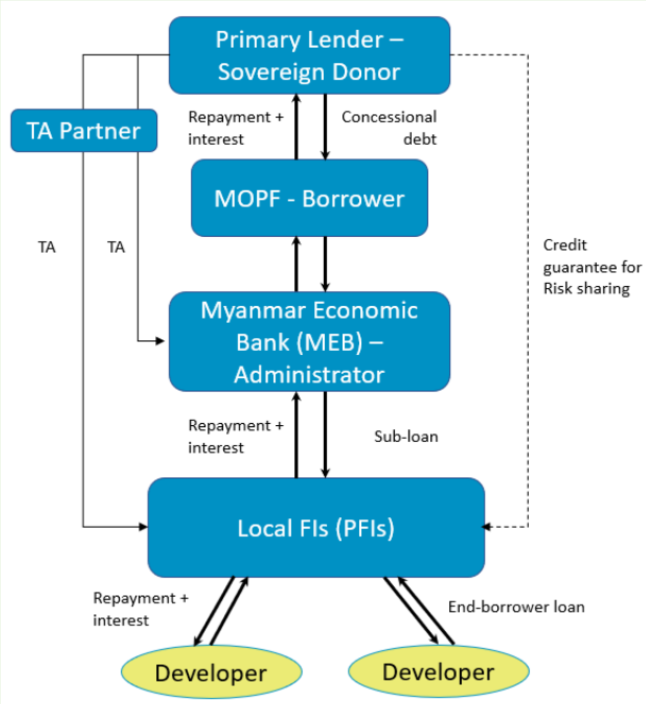
b) Smart Power Myanmar

While most donors and development partners froze or withdrew their (energy) activities after the 2021 military coup, SPM has continued operating. This includes technical assistance (e.g. liaising with VECs on productive use development and demand stimulation), data analytics and site selection (using the above-mentioned tool with minigrid viability assessment), and advice to financial institutions, development organisations and private investors.

Source: UNDP/GEF project document *Myanmar Rural Renewable Energy DevelopmentProject,* Annex E, *Baseline Rural and Renewable Energy Siuation* (by. J. van den Akker; 2018). Website www.smartpowermyanmar.org. *Closing the Financing Gap, Accessing Options for Renewable Energy Minigrids in Myanmar* (Delphos; SMP; 2019)

Box (cont'd) Financing minigrids in Myanmar

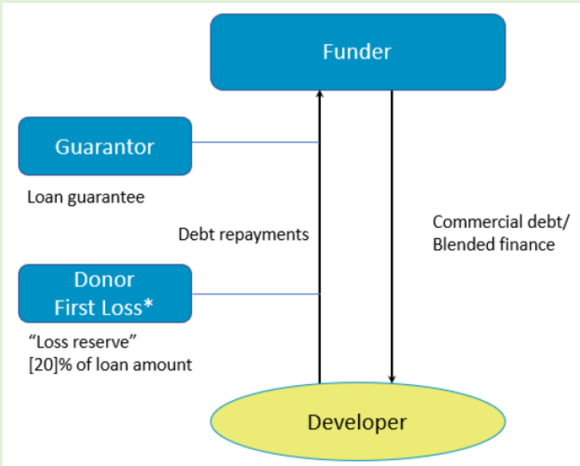
Thinking of the post-World Bank situation, attention shifted from lowering the DRD-WB backed subsidy through a concessional debt facility, making available debt financing through local instituions to developers (to top up the DRD grant or to support unsubsidised mini-grids) One proposal, elaborated by SPM-Delphos, was to set up a **"two-step loan" (TSL) facility (credit line)** with a sovereign lender making available EUR 30 million for the credit line and guarantee to the Ministry of Planning and Finance (on behalf of the government and administered by the Myanmar Economic Bank (MEB).



The MEB would on-lend to local finance institutions (at 4% annual interest) that would pass on the loan to eligible borrowers (at 8.5% annual interest and 50-8 years tenor; unlike the 13-16% Myanmar banks charged at that time with mandatory 3-year loan maturity cap). In addition, in the structure, the donor (or another party) can also potentially offer a credit guarantee for risk-sharing as shown above. A credit guarantee can be structured as a first-loss instrument for less bankable projects. The guarantee can serve as a further incentive for PFIs to lend to developers by lowering their risk exposure. Several local banks expressed interest, such as A-Bank, CB Bank, KBZ Bank, and Aya Bank.

AFD (France), before de coup d'état, expressed interest in such a TSL credit line, with a guarantee scheme, managed by PROPARCO (a subsidiary of AFD with a private sector focus) that could complement the structure). Depending on the leverage, the TSL scheme could support the development of 170-350 mini-grids (with funding between 20%-65% of capital cost).

A second funding mechanism mooted in the SPM study was **direct funding with a credit guarantee** (50% of the loan amount) **and a donor-funded 'first loss' mechanism.** Guarantees could be provided, for example, by multilateral and bilateral DFIs, and the multi-donor-backed GuarantCo. The guarantee aim would be to entice banks to enter into the market of minigrid lending by reducing their risks. The advantage is that a scheme could be implemented faster (not requiring sovereign approval) with commercial interest rates. A first loss mechanism could help crowd in a funder and guarantor by improving the risk-return profile of the transaction. A variation of such a pure first-loss facility would be to provide an interest rate subsidy.



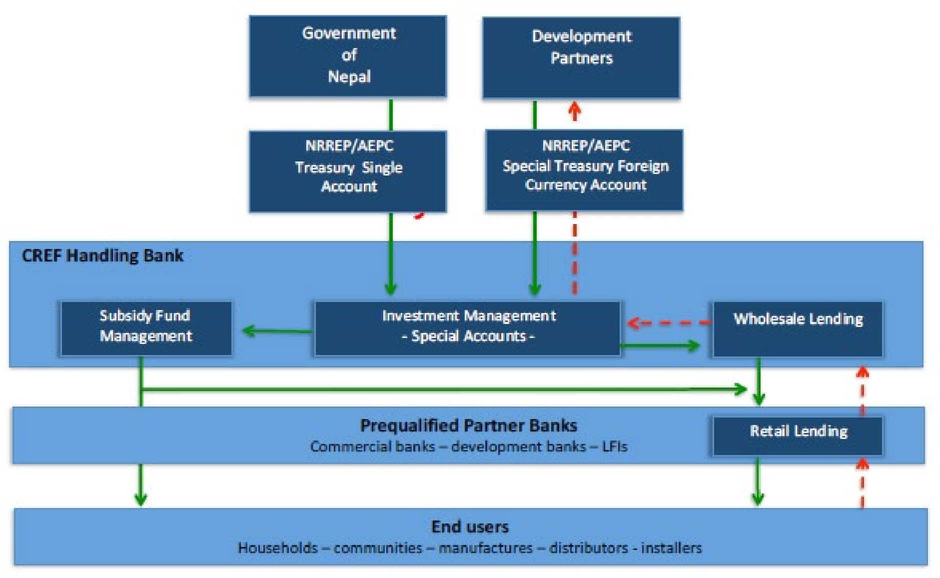
While these initiatives were cut short by the 2021 military coup, SPM has continued with setting up **short-term direct funding** for mini-grids:

- **The Equipment Sourcing Bridge Facility** gives developers a possibility to borrow short-term funds to purchase the required equipment for the mini-grid (up to date USD 18 million has been made available)'
- Working alongside local commercial banks and international guarantors, the **Last Mile Electrification Facility** allows communities to connect to electricity through flexible instalment plans.
- SPM's revolving credit facility, the **Energy Impact Fund (EIF)** operates at the community level to fund household connections, productive uses of energy and catalytic financing (up to date has invested USD 400,000
- SPM works with **microfinance** institutions to design, facilitate and promote loans for electrification (e.g. by providing loans to households to pay for connection fees and/or small devices)

In Sub-Saharan Africa, minigrids need grants and government subsidies to bridge the gap between the high cost of infrastructure and low-income communities' initial inability or unwillingness to pay. An AMDA survey of MGs that

Box 24 Financial support programmes in Nepal and Bangladesh

The Alternative Energy Promotion Centre (AEPC) is a government development institution established to support rural and renewable energy projects with funding coming from GoN and development partners. Initially, funding for projects was mainly provided through subsidies. To facilitate a shift to credit-based funding the Central Renewable Energy Fund (CREF) was established under AEPC.



The idea is that AEPC itself focuses on technical aspects, policy formulation, promotion and awareness, while CREF takes care of channelling credit and subsidy. A 'handling bank' operationalises the three core functions: i) wholesale lending to partner banks; ii) subsidy fund management; iii) investment management; and iv) fund administration (CREF Secretariat). NMB Bank is currently the 'handling bank'. CREF is overseen by an Investment Committee (with the participation of AEPC, Ministries, a representative from the Nepal Bankers' Association and a private sector representative).

In a competitive procurement procedure, a number of partner banks have been selected (BOK, CEDB, Civil, NIBL, SBL, MBL, ADBL, other). CREF acts as a 'wholesale bank' to its partner banks that utilise CREF's credit as 'retail banks' for investment in the RE sector. RERL has been working closely with CREF to identify prospective incentive packages for BFIs to finance not only RE projects but also manufacturers and installers to acquire modern technologies related to mini hydro and large solar PV systems.

Although the subsidy generally covers around 40% of the total costs, the actual amount differs according to technology and region, Out of the remaining amount, around 30% is from credit and around 30% from private sector investment or community or households in kind and/or cash can be mobilized. Subsidy prioritization can be based on the least-cost and/or energy output from among the available renewable energy technologies (such as mini/micro hydropower, improved water mill, solar energy, biogas, biomass energy, wind energy, etc.), of which this text box focuses on mini/micro hydro and solar PV.

Wwnership, operation and management should be the hands of clearly defined legal entity, sometimes referred to as a (R)ESCO, a (rural) energy services company. This can be a cooperative, a private sector enterprise (developer, locally based entrepreneur) or a Special Purpose Vehicles (SPV). Cooperative provides (electricity) services to its members (individuals or corporations) and is owned by the users of the service (although not all users need to be members). A standard SPV in the Nepalese context is a Limited Liability Company that promotes a public-private partnership model facilitating cooperation between the private sector, public sector (municipality) and local organizations. Another model is the Community-Private Partnership model, in which the community leases out the electricity facility to a (local) private company for the day-to-day operation and maintenance against a fee.

Source: *Terminal Evcaluation, UNDP/GEF Renewable Energy for Rural Livelihoods (RERL)*, by J. van den Akker, D. Gautam (2019); *CREF Financial Intermediation* (AEPC); see www.aepc.gov.np

received a combined total of USD 60 million between 2013-2020, of which about USD 41.41 million in the form of grant funding (from government, donors, foundations, or others), mostly for CAPEXC (USD 34.0 million) and USD 8.81 million of corporate funding (equity providers) with USD 10.47 million of debt funding, USD 10 million, crowdfunding USD 0.3 million, and donor lending, USD 0.17 million)[32]. So far, minigrid projects have been reliant on grants and subsidies from donors and DFIs.

[32] *Benckmarking Africa's Minigrids*, AMDA (2022)

Large mini-grid programs with public funding support have been launched in countries such as Benin (USD 40 million from MCC), Sierra Leone ($44 million from FCDO, Nigeria (USD 150 million from the World Bank), Zambia (USD 28 million from the EU), and the DRC (USD 39 million from the FCDO and $147 million from the World Bank)[33].

Equity

Mini-grid developers invest some of their own money as equity. Most mini-grid projects are relatively small, so they do not necessarily benefit from economies of scale; competition among investors is rather limited for a variety of reasons; and high up-front CAPEX subsidies are needed to make project economics work.

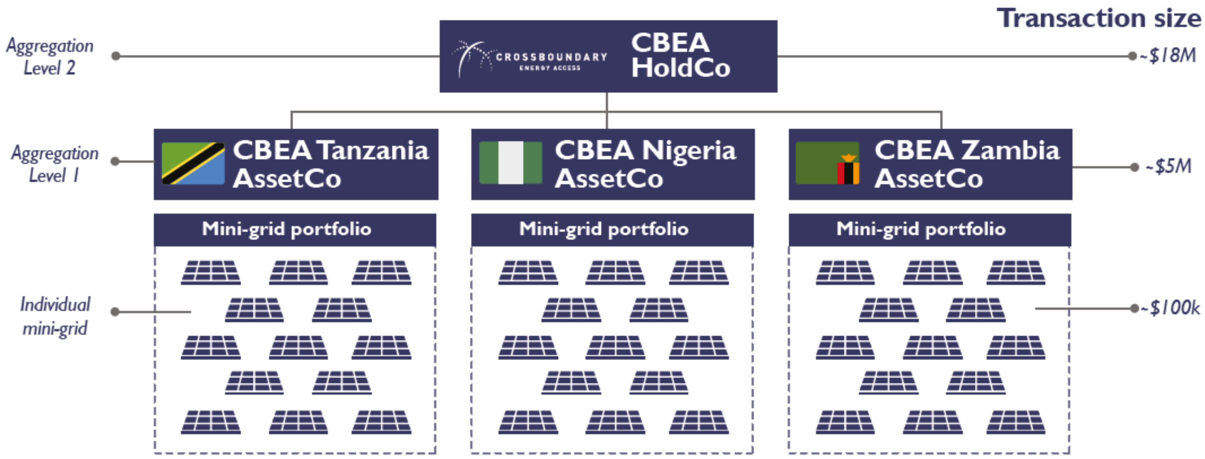
Project developers also look for equity from other sources. Various innovations in equity financing can help bring affordable equity investment to the mini-grid sector. In *the "AssetCo" model,* an investor (the 'asset company', or AssetCo) agrees to purchase a portfolio of mini-grids from a developer once certain milestones are achieved. The AssetCo, meanwhile, owns the portfolio of projects. A primary advantage of this model is that it enables the AssetCo to tap into low-cost, longer-term debt (that is not typically available to a mini-grid company) through a project finance structure (see Box 25).

Developing mini-grids through a portfolio approach will improve the bankability and risk-allocation framework, and replicability, allowing cost reduction of components and speeding up the pace of their implementation through some level of standardization. Larger and more bankable programmes combined with the appropriate risk-mitigation framework, an appropriate regulatory regime with public-sector intervention, and capital cost subsidies will help attract more private investors and lenders, in turn contributing to lower costs of capital and debt margins

Box 25 Asset companies and minigids

Cross-Boundary Energy Access (CBEA) was established in 2019 by the Cross-Boundary Group to bring in the long-term, low-cost capital that mini-grids need to scale. CBEA invests long-term equity and debt through a project finance structure to purchase mini-grid projects. Once a developer has constructed the grid, the assets are transferred from the company's balance sheet to a company created specifically to hold the assets, the so-called Asset Company (the AssetCo). All contracts, permits, and equipment are owned by the AssetCo (100% owned by CBEA). As far as possible, the revenues, risks, and costs are fixed and allocated through long-term contracts between the AssetCo, Developer, and Operator (the company that operates and maintains the mini-grids once purchased by the AssetCo). The AssetCo then pays the Operator to operate and maintain the grid as stipulated in the Operating Services Agreement (OSA); the Developer and the Operator can be the same company. To achieve scale, CBEA aggregated multiple AssetCos into a single investment platform – a HoldCo - that is large enough to raise equity and mezzanine debt from investors. Thus CBEA has been able to raise capital on 1o+ year tenors.

CBEA's first transaction on this basis was with PowerGen Renewable Energy and the Renewable Energy Performance Platform (REPP) in Tanzania. CBEA committed USD 5.5m to purchase 60 mini-grids as PowerGen constructs them, after which PowerGen steps into a long-term OSA. In Nigeria, CBEA and Engie Energy Access have signed a project finance agreement to build USD 60 million of minigrids. ENGIE has developed a pipeline of mini-grids to build over the next four years and will provide long-term operations and maintain services CBEA will finance all of the development and construction activities and will own the projects. CBEA will own the projects and provide the private capital needed for the development and construction activities, alongside grants provided by Nigeria's REA and the World Bank (see also Box 40)



Source: *Open Sourcing Infrastructure Finance for Mini-Grids*, CBEA (2020)

Box 26 Financial support programme in Bangladesh

I In Bangladesh, mini-grids are developed by private investors who may apply to the Infrastructure Development Company Limited (IDCOL) for funds. IDCOL does due diligence on a proposal. To begin, it consults with the Rural Electrification Board to check on when the main grid is likely to serve the proposed site. IDCOL also undertakes reviews of other factors affecting project viability, including potential customers' willingness to pay and the validity of cost estimates.

IDCOL finances and supports renewable energy and energy access projects in Bangladesh using a variety of financial tools. It has provided USD 7 million to support 27 mini grids totaling 5 MW, ranging between 100-250 kW (with about 400-1000 connections per grid). Funds for the solar minigrid programme have been provided by the World Bank, KfW, GPOBA, JICA, USAID, ADB and DFID. IDCOL provides a grant of 50% of the capital costs of minigrids and loans for another 30%. The loan is for 10 years, with a two-year grace period. The interest rate is 6% per year, which is below market interest rates (about 12-14%). Under the IDCOL financing structure, power is sold on a per-unit basis at a maximum price, which is currently around 30 BDT per kWh (about USD 0.40/kWh) the tariff at which sponsors could expect a return on equity of around 13% to 15%, the same equity IRR on which IDCOL investments are currently modelled, based on the cost of USD 4500/kW of the minigrid). Tariffs can be adjusted every two years.

Despite careful and detailed consumer surveys and expected load analysis—customer uptake was lower than predicted. After three years of operation, the financials under the IDCOL package showed that only two out of seven mini-grids reached their expected level of demand. Uptake lags were particularly striking among larger mini-grids (>200 kilowatts-peak) at which productive energy use was expected to account for 40–60% of demand. Daytime productive energy users were not connecting as planned, and in some cases, larger nighttime customers were saturating plant capacity more quickly than expected. Higher investment in addition to low demand and underutilization of the plant exposed these mini-grids to negative cash flows and risks. To increase the uptake of productive uses of electricity, IDCOL launched customer awareness campaigns and training for developers and operators. IDCOL introduced daytime loads via time-of-use packages and financing conversion packages ($120–$400, depending on industry and load). IDCOL provided assistance to have farmers convert from diesel p[pumps for irrigation to mini grid-powered irrigation, which can greatly increase utilization rates.

Source: *Solar Mini-Grids, Business Model Brief – Bangladesh (VividEconomics, 2019),* Minigrids for a Half a Billion People, World Bank/ ESMAP (2022).

Equity crowdfunding is a way of allowing a large number of people to invest in a mini-grid. The connection between the developer and investors is through online platforms that have been established to channel equity into a variety of investments. However, mini-grids owners or developers appear to have little experience with this model.

Socially-oriented capital comes come from (local) investors who are interested in commercially supporting mini-grids but who also recognize the social rationale for mini-grids. Sometimes, the investors can be the anchor load for the grid or a group of local business people.

Carbon funds in Africa provide upfront payments for the carbon-emission reductions the project will generate over its lifetime. These payments can count as equity toward a bank's equity requirements for loans.

Debt financing

Commercial debt, particularly from local financiers, is not readily available because of the local mini-grid sector's lack of a track record, or, if it is available, the terms are not financially attractive. One common intervention in government-supported projects is the creation of an **up-front 'two-step' credit line**, whereby the government makes its funds available to participating financial institutions (PFIs) at the time the loan is issued to the mini-grid developer. Often, the government gets funds from development partners, such as the World Bank or regional development banks. The government selects local lenders who are interested in financing mini-grids and meet some operational financial criteria. The government on-lends these funds, usually through a financial intermediary, to participating PFIs in local currency or provides grants. The loans to the PFIs have a long tenor (see, for example, the Myanmar case in Box 23).

Grants are funds provided with no expectation of repayment. *Concessional loans*, or soft loans, have to be repaid but at more generous terms than market loans. These generally include below-market *interest rates*, *grace periods* in which the *loan* recipient is not required to make debt payments for several years or a combination of low-interest rates/grace periods. While the ideal design of an up-front credit line would call for interest rates that are close to the prevailing interest rates in the country, in many cases, mini-grid developers find these interest rates too high and ask for "soft loans" at reduced interest rates. The availability of free or cheap capital in the form of a grant or concessional loan can be a huge boon to *mini-grid* project developers facing financing challenges. While there are several sources of grants and concessional financing, the funds are limited, and competition can be considerable. Some limit or restrict the countries in which they can be used, or they require a portion of funds to be spent on equipment or services from donor countries. Grants sometimes have significant reporting and other administrative requirements, including extensive social and environmental assessments, which cost money in the form of added staff time and transactional costs.

To be viable, mini-grid projects and developers need a complete financial package consisting of equity, grants, concessional debt, and commercial debt, accompanied by risk-sharing mechanisms. The government and its development partners should actively support private-sector mini-grids by facilitating debt and equity investment and risk sharing through private-sector investors, alongside subsidies and results-based grants paid directly to the mini-grid developers. The sector is now showing some early signs of maturing with a slow but increasing number of later-stage investors, such as strategic investors and commercial debt providers, Currently, most of the private capital supporting the growth of the sector is venture capital. But to scale, mini-grids need to unlock infrastructure capital from the natural long-term holders of infrastructure assets: pension funds, infrastructure funds, and insurance funds.

Project-based financing and minigrid portfolios

In renewable energy, project finance is often associated with larger projects, particularly those that sell electricity to the grid under power purchase agreements (PPAs). Project-based financing uses the project's projected cash flows as the basis for loans. Traditional financing, on the other hand, is based on the overall finances (balance sheets) of a project sponsor or developer, and it requires collateral. Project-based financing doesn't require cash collateral, so it is appealing for village-scale mini-grids. However, transaction costs (i.e., fixing and allocating costs and revenue over a long period, establishing contracts, arranging the financing and setting up the 'special-purpose vehicle') of project-based financing are high. Thus project-based financing requires a USD 5-10 million size, way above the typical investment of a mini-grid (USD 200-500,000). The relatively small size and scale of many mini-grid or related PUE projects make it hugely expensive to go through the project finance cycle.

Mezzanine financing

Mezzanine finance is a hybrid of debt and equity financing, in which funds provided as a loan can be converted by the lender to equity if the borrower does not repay. payments to mezzanine financiers are made after project operating costs, conventional (senior) debt, and required reserve balances are determined. There appears to be little or no experience with this type of financing for mini-grids in developing countries.

Risk mitigation

Another option is to introduce some risk-sharing guarantees, under which an independent third party shares the commercial risk with private finance initiatives. The third party could be a development partner or an interested. These schemes ease the financial risks private finance initiatives and equity investors face in their fear of high losses. The losses may be from a single mini-grid developer or a pool of minigrids (with pooling generally considered a more workable option).

To mitigate the demand risks (in addition to measures taken during the planning, design, and operations of the mini-grid) financial mechanisms include minimum revenue guarantees, loss sharing, and subordinated debt:

- In a *first-loss guarantee scheme*, the third party agrees to bear the first tranche of loss. If losses extend beyond the first tranche, the private finance initiative has to bear them. The definition of where the first tranche ends varies, depending on local financial conditions. First-loss schemes are a useful approach from an investment portfolio perspective, for them to work, the investor must have sufficient volume or deal flow to spread risk across a large investment base[34] (see Box 23 for an example)

[34] Other loss-sharing mechanisms are the *pari passu guarantee scheme*, in which the guarantor and the private finance initiative share

Box 27 Off-grid rural electrification in Zambia

Zambia has an estimated population of approximately 19.3 million people (in 2022), the majority of whom (54.7%) live in rural areas. Zambia's installed capacity stood at about 3,011 megawatts (MW) in 2020. About 11% comes from coal, 7% from diesel/fuel oil, 3% from solar and 80% is based on large hydropower. The electrification rate was 42% in 2019 for the overall population, of which 36% are connected to the main grid and 6% are off-grid (mostly solar lanterns, rechargeable batteries, and solar home systems). The rural electrification rate recently increased from just 5% in 2015 to close to 12% in 2019 (of which 4% were grid-connected and 8% off-grid). The Rural Electrification Agency (REA) is tasked with developing and implementing a plan to electrify rural areas. Aided by the World Bank, a new National Electrification Strategy is being developed. Least-cost geospatial planning (supported by USAID and World Bank) gives estimates of the magnitude in terms of size and cost. To achieve universal access in 2030, about 25.3 million people will need to be provided with electricity, including the 36% already electrified with 13-20% to be provided by grid extension and densification, 8-19% through minigrids, and 25-40% with stand-alone (solar PV and other) options. The cost of grid extension and extension would be about USD 3.57 billion in the coming decade, of which about USD 0.80 billion for grid expansion and extension (about USD 350 per connection for densification and USD 1200 for extension), USD 2.12 billion for minigrid (at about USD 2200 per connection) and USD 0.64 billion for off-grid solutions (at USD 400 per household). This means a whopping USD 350 million a year, in the same order as ZESCO's revenues in 2017 (USD 409 million). The amount currently invested in minigrids, of a couple of million USD a year for non-grid options is far short of the amount needed.

Several companies sell small PV systems (< 10-30 W with LED light, radio and phone charging, costing about USD 70-200) as an alternative between solar lanterns and more expensive larger solar home systems (30-200 W or larger, costing about USD 300-500). PAYGO schemes are on the increase, allowing mobile phone payments.

A Minigrid Regulatory framework was developed by the Electricity Regulation Board (ERB) and the EU-financed IAREP project, in consultation with various private and public sector stakeholders, in 2018, allows differentiating regarding permits, technical requirements and tariff-setting between MGs based on size and complexity: a) MGs with size < 100 kW have 'very light-handed' regulation, b) and MGs sized between 100 kW-1 MW will have 'light-handed' regulations.
Supported by donor funding, a number of private developers are developing minigrids, operated and financed by these developers, or in a public-private partnership with REA. Recently, the Swedish SIDA has financed the 'Beyond the Grid Fund for Zambia'; operated by REEEP, the fund operated from 2016-2020, with a maximum funding level of EUR 20 million that supported the minigrid companies (Standard Microgrid), solar PV companies (Vitalite, Fenix/Engie) and clean stoves companies (Emerging Cooking Solutions).

The EU-supported IAREP project issued a Call for Proposal (about EUR 25 million available to support about max 45-50% of CAPEX) in two lots, one for proposals with REA (in public-private partnership) and another lot for developer-identified proposals (submitted by CBEA, Standard Microgrid, Engie Africa) and others.

During 2017-2024, the World Bank implemented the "Electricity Service Access Project (ESAP) with a WB contribution of USD 26.5 million has had an off-grid component with activities on or last-mile connections, private sector support, off-grid electrification and national electrification planning. WB has supported REA with the Off-Grid Smart Subsidy Program (OGESSP, expecting to benefit solar mini-grids) It is expected that the subsidy will cover the viability gap (the difference between the cost of providing connection and what consumers are willing/able to pay for it), and is likely to consist of an upfront part and a performance-based part. In addition, there is USD 3.4 million and the Development Bank of Zambia (DBZ) with setting up an Off-Grid Loan Facility (USD 2.5 million) to provide working capital for solar companies (including locally registered solar system importers, wholesalers, distributors, and retailers) and long-term loans to finance eligible borrowers, including solar PayGo companies and mini-grid developers. The hope is that with DBZ lending as an example, this will attract commercial banks to enter the off-grid market. Under the UNDP/GEf Africa Minigrids initiative, there is a budget of USD 1.36 million, of which about USD 0.65 million is to provide support up to about 45% of CAPEX in minigrid pilots. One type of activity will be working with ZCF's solar maize mill programme, and using the systems to build small microgrids for the surrounding community, adding battery storage, system reconfiguration and the distribution network.

Source: Project document Z*ambia Minigrids project* (UNDP/GEF); *Preparation of a Least-Cost Geospatial Electrification Plan for Grid and Off-Grid Rollout in Zambia,* World Bank-Engie Impact; *Geospatial model for Zambia* (April 2018), USAID. Zambia electrification cost estimates elaborated by the author, based on data provided in these studies.

losses proportionally. The private finance initiative shares the loss right from the start. This scheme may therefore be less attractive to private financiers than is the first-loss scheme. In *a last-loss guarantee scheme*, the private finance initiative bears the first tranche of losses, with the guarantor absorbing any further losses. This scheme may be the least attractive to private financiers.

Box 28 Off-grid rural electrification in Nigeria

The rural electrification rate currently stands at 34% out of a rural population of 99 million (and 85% of the 115 million urban people). According to Nigeria's National Renewable Energy Action Plan (NREAP 2015-2030), there will be about 120.5 million people living in rural areas in 2030. Of these, 95% should be served by electricity in 2030, of which 80% connected to the grid, 10% by renewable energy minigrids and by 5% by stand-alone systems. In other words, about 3.6 million rural households would be served by solar and pico-hydro systems (60 MW in total), and 10,000 minigrids (about 5400 MW). By 2019, Nigeria had about 50 mini-grid projects (about 2.8 MW). The Rural Electrification Agency (REA) and the Rural Electrification Fund (REF) provide support and finance for off-grid energy systems. REA's main role is to promote rural electrification, coordinate programmes, and administer the REF. REA has formulated the Offf Grid Electrification Strategy. In 2017, the Nigerian Electricity Regulatory Commission (NERC) published the Regulation for Mini-Grids, providing a streamlined regulatory environment for the development of private sector-driven mini-grids. Isolated or off-grid mini-grids have been defined by Nigerian regulators as falling into two specific size categories: sub-100kW and 100kW–1MW. NERC developed a web-based tool to streamline the mini-grid registration process for developers and released a downloadable simplified Excel-based model to help developers determine what cost-reflective tariffs to charge end-users. Odyssey created an official web-based NEP hub that enables an efficient project evaluation process and data-driven decision-making. The Rural Electrification Agency (REA) has been tasked with developing the Nigerian off-grid power market

Mini-grid developers can benefit from capital subsidies or grants, or to a lesser extent, the provision of concessional loans. A preferred mode of grant disbursement is through result-based financing (RBF) which is used under both the Nigeria Electrification Project (NEP) and the REF. The REF-supported projects must have a minimum 30% proportion of renewables, which may stem from any renewable energy technology on both isolated and interconnected mini-grids. REF grants are available to successful developers of systems of a generation capacity <1 MW, in each lot (geopolitical zones in Nigeria). The grant amount per connection is USD 500 for residential customers and USD 600 for commercial and productive users, with a minimum investment size of USD 10,000 and a maximum of USD 300,000 per project, or 75% of the total capital costs. The current programmes build on experience of previous well-executed programmes under the GIZ-supported NESP, including the Mini-Grid Acceleration Scheme (MAS) and Interconnected Mini-Grid Acceleration Scheme (IMAS). These partially included up-front grants. The programmes gave a boost to local developers, who now have a strong presence vis-à-vis international developers. In 2018, the WB committed USD 350 million to the NEP, with AfDB dedicating a further USD 200 million. The funds include USD 29 million for technical assistance REA now implements the following programmes:

- Solar minigrids, supported by a) minimum subsidy tender (WB & AFdb) with a total of USD 71 million, targeting pre-identified 350 communities. Sites competitively tendered to determine the grant amount. Sites were selected through geospatial analysis to screen and prioritise high-potential sites, followed by validation to ensure they are fully off-grid, mapping of village infrastructure, and site surveys to collect data on customer segmentation and estimated consumption. This information is available to the bidders along with at least one suggested optimal mini-grid design for each site; b) under the Performance-Based Grants, developers are required to identify and validate their own sites/communities and receive a fixed grant amount of USD 350 per connection, with a minimum total grant of USD 10,000 per mini-grid. The grant is available on a first-come-first-served basis to eligible projects which include solar and solar hybrid systems with generation capacity <1 MW. Once the mini-grid is constructed and customers have been connected, the grant is disbursed after REA has verified that customers are connected and receiving satisfactory service.
- A Result Based Financing for Productive Appliances and Equipment component is also delivered under the NEP. This USD 20 million window from AfDB incentivises solar home system companies and mini-grid developers to supply energy efficient productive use appliances, and all mini-grid projects, including those developed under the NEP, are eligible to apply for this support. This scheme does not cover the cost of appliances but rather the incremental costs of integrating this line of service, like transport, marketing, end-user financing, installation, training, repairs, replacements etc at a fixed grant of USD 350 per connection. As with other result-based schemes under NEP, claims are verified after installation before grants are disbursed.
- The USD 60 million is allocated to the Output-Based Fund for households and MSMEs (for standalone solar systems). This fund will provide fixed incentive grants of up to 60% of the costs of the system to the grantees, per each eligible system installed and verified. However, 20% of the grant received can be used to reduce the cost of the end-user product price.

Commercial banks have thus far been largely absent from Nigeria's mini-grid market. In 2020, the Central Bank of Nigeria also issued a framework for the implementation of a Solar Connection Facility to provide long-term low-interest credit facilities to enterprises in the solar value chain which have been pre-qualified by the NEP. This includes mini-grid developers who can receive term loans for civil works, project expansion, equipment purchases etc. amounting to a maximum of 70% of the project cost. The tenor for such loans is set at 7 years with up to a 2-year moratorium, at 10% interest Initially, Nigeria took a public-private-partnership (PPP) split-asset model approach (see Box 32), though we now see a fully private owner-operator model. Still, all the Nigerian mini-grid projects have been subsidised by government and donor organisations to ensure lower tariffs and promote affordable access to power. Most minigrid projects today are situated in densely populated agrarian communities, typically with a population of around 2,500 distributed among 300–500 households. Tariffs range from USD 0.34-.86/kWh in 16-100 kW (solar) mini-gid systems as compared to USD 0.71/kWh in diesel-powered minigrids.

Source: Nigeria estimates based on NREAP electrification target, with current electrification rates (from World Bank data); State of the Global Minigrids Market (2020, SE4ALL), *Success in Rural Electrification, Regulatory Case Studies,* GET.Transform; https://nep.rea.gov.ng/;

Box 29 Off-grid rural electrification in East-Africa

Kenya

The recently published 2021 – 2030 Least Cost Power Development Plan (LCPDP) highlights the Government's intention to prioritize the development of geothermal, wind and solar energy plants as well as solar-fed mini-grids for rural electrification. In 2021,, the electrification rate was 77% (with 97% urban and 68% rural electrification; urban share in population was 29% in 2021). T The Rural Electrification Fund and Renewable Energy Corporation (REREC), previously REA, is responsible for rural electrification efforts (feasibility studies, development and operation) and renewable energy at large. The Ministry of Energy develops policies and regulations and oversees the Energy & Petroleum Regulatory Authority (EPRA), which implements policies and regulationsand conducts due diligence into off-grid companies so as to determine whether they can qualify for Kenya Revenue Authority tax exemptions. EPRA has developed the draft Energy (Mini-Grid) Regulations, 2021, intended to provide a clear regulatory regime for mini-grid development to support the growth of this electrification segment. initially by allowing smaller projects to operate with relatively little regulatory oversight and more recently through programmes like the Kenya Off-Grid Solar Project (KOSAP). This programme focuses on the least developed parts of the country and is designed to provide electricity to 27,000 households working with private companies on a PPP basis. K with three components: a) minigrids (implemented by the utility KPLC)These companies will build and operate the grids, but will not own them, b) stand-alone systems and clean cooking for households (SNV and SunFunder) and c) stand-alone systems for communities (KPLC and REREC). KOSAP is supported by the Dutch SNV and SunFunder (providing debt financing to solar companies in Component 2). As of May 2020 there were at least 307 mini-grids in varying stages of development, 121 under KOSAP, 53 by the Rural Electrification and Renewable Energy Corporation (REREC) supported by donor funding and 133 privately-developed mini-grids. Major operating companies include but are not limited to Azuri Technologies, BBOXX, Chloride Exide, d.light, Davis and Shirtliff, FuturePump, EcoZoom, Jua Energy, Kensen Ltd, Little Sun, M-Kopa, Mobisol, Orb Energy, Rafode Ltd, SolarNow and SunCulture. The Kenya Off-Grid Solar project (KOSAP)

Kenya has one of the largest off-grid solar markets in the world. In 2019, 1,969,483 solar home systems and pico-solar products were sold by companies affiliated with GOGLA and Lighting Global in Kenya, up from 1,269,063 in 2018. In 2019, 47% of these products were sold on a PAYGO basis, up from 41% in 2018. Major operating companies include but are not limited to Azuri Technologies, BBOXX, Chloride Exide, d.light, Davis and Shirtliff, FuturePump, EcoZoom, Jua Energy, Kensen Ltd, Little Sun, M-Kopa, Mobisol, Orb Energy, Rafode Ltd, SolarNow and SunCulture.

Tanzania

The Rural Energy Agency (REA) is an autonomous body under the Ministry of Energy and Minerals and was established in 2008 to oversee the implementation of electrification projects in rural areas of mainland Tanzania, using the Rural Energy Fund (REF). Both REA and REF are governed by the Rural Energy Board (REB). The REF is funded by international donor agencies, DFIs and the government via the annual budget and from commercial generation levies. It also provides financing to fund rural energy projects in the form of a) grants for feasibility studies up to USD 100,000 or 80% of the study cost, b) grants of USD 500 per household connection to distribution grids or mini-grids, or a maximum of 80% of the project's transmission and distribution costs; and c) construction loans up to 85% for <3MW generation projects (70% for projects greater than 3MW). Alongside Kenya, Tanzania played host to much of the early development of the mini-grid industry.. This was facilitated by supportive policymaking, streamlined licensing for multiple projects and exemption from tariff review for projects below 1 MW. The regukator EWURA has has set relatively clear regulations around mini-grids Developers can propose to EWURA a specific retail tariff structure (e.g., a flat tariff, time-adjusted tariff, or a combination of the two) for mini-grid projects below 100kW (Very Small Power Producers or VSPPs). However, if 15% of the households served by the mini-grid petition EWURA, the regulator undertakes a tariff review and can adjust. 100kW-1MW mini-grids (SPPs) receive fixed tariffs for electricity, regardless of whether they sell to isolated grid or to the main grid). There is a mini-grid portal online (at www.mini-grids.go.tz/en) for prospective developers to access resources such as GIS maps of existing grid infrastructure and details of how to apply for licences and financing. However, this portal had not been updated in a few years, whiole regulatory change impacting the agreed-upon tariffs have uncertainty into the mini-grid Tanzanian market and a slowdown in mini-grid market development.

By 2020, there were were an estimated 210 installed mini-grids, with an aggregate installed capacity of 232 MW, thus accounting for 15% of the countries total capacity of 1,461MW. There are about nine developers active in the market with Jumeme and PowerGen as the two largest in terms of the number of mini-grids installed. Jumeme aims tio bui,ld 300 minigrids with EU funding. PowerGen plans to expand its portfolio further with a project financing deal it secured with CrossBoundary Energy Access (CBEA) and other financiers in 2019 (agreement with the Renewable Energy Performance Platform (REPP), managed by Camco Clean Energy, to finance an initial debt investment of USD 5.5 million to build 60 mini-grids in Tanzania). Engie Energy Access (mySol) has 16 minigrids and 6 more in the pipeline. Other companies active are ACRA, Devergy, Ensol, CEFA, Redavia, VirungaPower, Husk Powering. The off-grid solar market in Tanzania has been growing steadily over the past two years,. According to GOGLA< o 263,927 units. In 2019, 32% of these products were sold on a PAYGO basis, down from 52% in 2018. The remaining share of products were sold as cash transfers. Operating companies include American Engineering Group, Azuri Technologies, d.light, Enda Solar, Greenlight Planet, Jaza Energy, Little Sun, M-Kopa, Mobisol, Sikubora Solar, Simusolar, Solaris Tanzania, Solar Sisters, Trend Solar, Rex Energy and ZOLA Electric.

Sources: www. GET-Invest.eu (market information); *State of the Global Minigrids Market* (SE4All, Minigrids Platform, BNEF; 2020)

Off-grid rural electrification in East-Africa (cont'd)

Rwanda

The 2018/19 – 2023/24 Energy Sector Strategic Plan and National Electrification Plan have provisions for off-grid connections as part of the government's aim to electrify 100% households by 2024 and universal electricity access by 2030, with 48% dedicated to off-grid projects. By mid-2018, about 300,000 households in off-grid areas had access to electricity through mini grids and solar home systems, of which about 3,200 to minigrids. The RURA regulations cover isolated grids below 1 MW and specify that those below 50 kW are exempt from licensing. Although the regulations are currently ambiguous regarding whether the tariff and grid arrival compensation provisions apply to exempted mini-grids, developers of isolated grids can charge cost-reflective tariffs with a reasonable margin. RURA does maintain the authority to review the reasonableness of the tariff. In the case of grid arrival, licensees have three options: (i) relocate assets, (ii) sell assets to the main grid (REG), or (iii) become a small power producer and/or a distributor of electricity purchased from the main grid. Currently, mini-grids require significant grant suppor, usually 40-70% of capital expenditure (CAPEX), to be viable, and subsidies are expected to be needed in the short- to medium-term. all financing for mini-grids in Rwanda comes from development partners or DFIs in the form of either grants or debt:

- EnDev Results-based Fiancing (RBF) provides grants of up to 70 percent CAPEX for solar or hydropower mini-grids upon commissioning. Approved projects receive significant technical assistance, including on the business model and technical design;
- Energy4Impact (E4I) provides technical assistance and upfront grants (unlike RBF through EnDev) for CAPEX to approved mini-grids. E4I currently has a pipeline of 10 pico-hydro and solar projects. E4I provides support in the form of business advisory services and financing of productive-use appliances. It supports (small) local businesses through its Scaling Up Off- Grid Energy in Rwanda (SOGER) program by providing training in business management (including pricing, record keeping, customer service, and marketing) and partial grants for equipment.
- The World Bank supported setting up the Renewable Energy Fund in 2017, a USD 49 million fund managed by the Rwanda Development Bank. It consists of various windows: 1) On-lending through SACCOs (Savings and Credit Cooperatives) to households and micro-enterprises for purchasing solar systems (Tier 1 and higher); 2) On-lending through banks (commercial and microfinance) to households and small and medium enterprises (SMEs) for the purchade and/ solar companies for the distrubuition of solar systems (with SMEs required to contribute 25% to capital cost); 3) Direct financing for mini-grid companies (up to 75% construction costs in the local currency). The REF will provide 'bridge loan' financing until grant funding from existing RBF programs (for example, EnDev) becomes available, as well as long-term financing beyond commissioning; 4) direct financing to eligible, locally registered solar companies offering Tier 1 and above solar home systems and ongoing maintenance services to its clients through delayed payment options (eigible companies will have to leverage REF financing 2:1).;l and 5) Results-based financing window (partial grants.

Some of the active mini grid companies in Rwanda include NESELTEC and RENERG (30 kW solar MGs), Absolute Energy (50 kW solar), Ecos (hydro, 11 kW), MeshPOwer (small 1-4 kW solar systems), Arc Power (solar), Huboka (Hydro) and Kabrud (Hydro). Several different technologies for stand-alone productive-use products have been tested in Rwanda, including solar egg incubation, off-grid cold storage. In addition, mini-grids are a key conduit for improving access to productive-use equipment in off-grid areas, with current mini-grids supporting irrigation and cold storage, as well as refrigerators, milling, welding, and tailoring.

Uganda

Uganda has a thriving market for solar home systems (SHS) and pico-solar solutions. By 2017, about 300,000 households were connected to at least a Tier 1 SHS and uptake seems to be growing. In 2019 alone, almost 399,285 SHS and pico-solar products were (according to GOGLA data). PAYGO accounted for 65% of sales in 2019, a 5% increase from 2018. There are over 25 companies importing and distributing a multitude of products and offering a range of related services, many of which are members of the Uganda Solar Energy Association (USEA). Examples include d.light, Fenix, Greenlight Planet (SunKing), Little Sun, M-Kopa, Rural Spark, SolarNow, Solar Links, Solar Sisters, Total, VAC Solar UK and Village Energy. The minigrid marjet has advabced less and is less mature as in neighbouring Kenya or Tanzania, maybe because of the govertnment's emphasis on grid-based power production. Active developers are Absolute Energy, Pamoja Energy, Remergy, Kirchner Solar, Engie (MySol), Equatorial Power, Winch Energy, Kalangala, WENRECO, and SunPower. Uganda has 34 installed mini-grids withan aggregated capacity of 56 MW (40% solar, 34% hydro), that serve approximately 20,000 households, less than 1% of the 7.3 million households in the country. Electrification rate in Uganda is about 45%, of which 35% in rural areas). Uganda's Rural Electrification Agency (REA) has undertaken a master planning exercise and identified opportunities to build mini-grids providing power to 62,000 households by 2029 as part of a policy aiming to achieve 60% by 2027 and 80% electrification in 2030, . However, the market has been slow to take off, largely due to a fragmented regulatory environmentand the current licensing process lacks transparency. Isolated grids in rural areas smaller than 2 MW are exempted from having to apply for a licence, and a such the mini-grid is also exempt from the regulations applicable to licenced electricity activities. However, the developer/operator must still apply to ERA for a certificate of exemption, and is expected to comply with isolated grid technical standards and isolated grid system service standards (these are not available from ERA's website). Tariffs must be in line with ERA's price schedule for rural electrification systems (around USD 0.2/kWh). There are no clear rules in Uganda for how a minigrid is to interact with the central grid in the future when the main grid gets.

Sources: www. GET-Invest.eu (market information); *State of the Global Market Minigrids* (SE4All, Minigrids Platform, BNEF; 020), *Off-Grid Solar Market Assessment Rwanda*, USAID, 2019)

Box 30 Off-grid rural electrification in Lesotho with UNDP and EU support

Lesotho does not have any indigenous resources for petroleum and also does not have any refineries, therefore it imports all its needs of petroleum fuel from South Africa. Lesotho had an electrification rate of 44.6% in 2019 (rural population, 32.6% and urban, 74.4%). Access to clean cooking methods and fuels was 40% in 2019 (rural access, 20.3% and urban, 81%). The country has an abundance of renewable energy resources. National generation capacity is limited, and the difference between demand and supply (about 212-217 GWh) is met by energy imports from South Africa and Mozambique through the Southern African Power Pool (SAPP). Extending the national grid to rural areas remains a challenge in the country which in large parts is comprised of sparsely populated areas with rugged mountains and deep valleys with small scattered villages. Lesotho has very low rates of forest cover (forest area was about 1.1% in recent years. Deforestation is a serious problem in Lesotho. Despite the resulting wood scarcity, biomass forms an important energy source in the rural household sector. Approximately 66% of households in the country use biomass for heating and cooking.

Solar home systems have been promoted by the government and development partners in the past, for example through the UNDP/GEF Lesotho Renewable Energy-Based Rural Electrification Project (LREBRE). Although some 1,500 systems were installed, a significant proportion failed after a while (due to lack of maintenance). A key component of the LREBRE project design was to introduce two financial mechanisms (a credit guarantee scheme and a performance grant scheme) designed to address the underlying financial barriers to promote a market-based approach. However, the Government increased the grant portion in its own programme from 40% to 80% and this led to consumers opting for the heavily subsidised Government scheme. Thus, the market-based approach for SHS under LREBRE had great difficulties taking off.

The European Union organized the Call for Proposals (CfP) “Energy efficient household devices, distribution, after-sales structures and Mini-grids for exploring economic growth potential in rural areas” in 2017 with the aim of contributing to the maturation and development of the off-grid energy sector in Lesotho. The CfP budget was about EUR 4 million to be matched with about 55% funding/equity provided by the proponents. About 17 concepts were presented, out of which nine were invited to present a full application and four were finally invited to enter contract negotiations. Proposals presented included a) energy service centres and kiosks (dissemination of efficient wood stoves), and b) solar PV minigrids. However, the final grant decision has only been awarded to the ‘energy centre’ proponents: a) Rural energy hubs (to Africa Clean Energy, EUR 1 million); b) Renewable energy access solutions (Positive Planet, EUR 1 million); c) RE Women Empowerment (KESI, EUR 0.35 million), and d) RE User Groups (Solar Lights, EUR 0.71 million). With debt financing support from the EU’s ElectriFI facility and a UK-based foundation and equity financing (with Lesotho Pension Fund), a solar-battery mini-grid has recently been built by OnePower at Ha Makebe selling electricity to about 200 households using the mobile money banking system M-PESA, smart meter technology and solar PV trackers

UNDP (with GEF co-financing) implemented the project “Development of Cornerstone Public Policies and Institutional Capacities to Accelerate Sustainable Energy for All Progress”, shortly referred to as SE4All project, from 2016-2022. With the help of the SE4All project, the Mini-grids Regulatory Framework was developed, covering isolated and grid-connected mini-grids. The framework distinguishes between three categories of mini-grids. Small Mini-grids (<100 kW), will be licensed in a “very light-handed manner”, Medium Mini-grids (between 100kW and 1MW) in a “light-handed” manner and Large Mini-grids (>1MW like the main grid regulations). The differentiation lies in how tariffs are regulated, what standards need to be complied with, and in the compliance and monitoring requirements for the different-sized grids. The Project also made an important contribution to having credible and up-to-date data on energy consumption utilizing a national energy survey for households with data stored in an energy database. The commercial operation of Clean Energy Centres/Energy Kiosks in Lesotho is governed by and must comply with the following legislation: Trading Enterprises Regulations 1999, Legal Notice No. 107 of 1999. This means these are not regulated as such, but must comply with basic requirements. The energy centres/kiosks typically provide an electricity charging service (charging lanterns, torches, radios, phones, batteries) and/or sell devices (such as efficient stoves, lanterns, solar home systems, supplemented by other services (e.g. cooled drinks, telecom and airtime cards). With demand for wood outpacing its supply in this deforested country, the dissemination of efficient stoves is important. Companies, such as Africa Clean Emergy and Solar Lights sell efficient biomass stoves.

One main element in SE4All was the operationalization of the Financial Support Scheme (FSS), for which a total of USD 1.2 million in GEF and UNDP funding was allocated. The FSS supports minigrids with a mix of investment grants of 50% of the cost of a feasibility study and initial investment up to a maximum of USD 60,000 per project plus a performance-based grant. The energy centres with a performance-based grant (50% max of initial cost with a disbursement of max USD 7500 per year). At the project start, it was considered to establish the FSS at a Lesotho institution, but this turned out not to be possible. Then, discussions were opened with private banks to host the FSS as a ‘responsible party’. However, private banks cannot on-grant to recipients (‘grantees’) that are private sector organisations. An agreement was, therefore, reached in early 2019 with the UNCDF (UN Capital Development Fund) to manage the FSS. After delays, a Call for Proposals resulted in the selection of seven companies to establish mini-grid systems at 10 sites and energy centres at 10 sites. As a basis for the CfP, detailed feasibility studies were carried out at the ten sites. The average proposed installed capacity of the minigrids is 64 kW at an average investment is USD 6,400 per kW (or USD 415,560 per site, receiving an initial grant of USD 60,000 and a performance-based grant of USD 30,000), with 8 out of 10 sites proposed by OnePower. Eight of the service centre proposals (each servicing between 150-300 households; 200 on average) were presented by ACE and Solar Lights (and one by KESI, the other by RSDA) at an average cost of USD 65,000.

Source: UNDP/GEF SE4A Development of Cornerstone Public Policies and Institutional Capacities to accelerate Sustainable Energy for All (SE4All) Progress (by Van den Akker, J. & Lethola, R.); European Union, Technical Assistance Facility (TAF), Report ES-0110: Assistance in the evaluation of grant applications received in the framework of the call for proposals (2017)

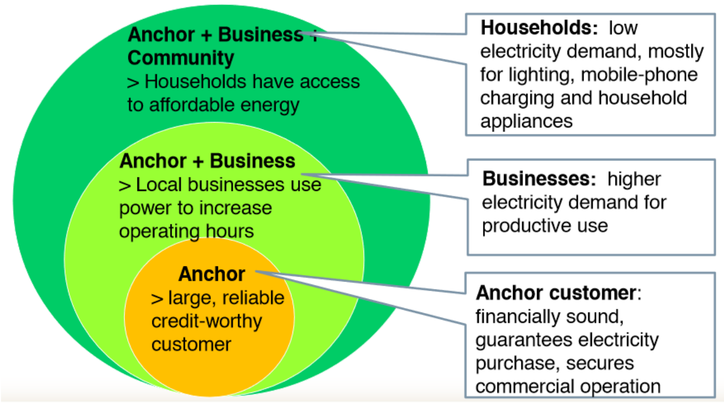
- Risk-mitigation instruments can also be designed specifically for debt providers. *Subordinated concessional loans* can be added to the debt structure to ensure that commercial lenders are repaid in priority if the demand, revenues, and hence debt-coverage ratios are lower than anticipated. In such an event, the developer will be able to defer or even write off its debt repayment to the subordinated debt portion.
- A *minimum revenue guarantee* (MRG) issued in favour of the mini-grid developer can partly reduce the demand risk and would benefit both the lenders (principal and interest) and equity indirectly. The instrument is sized to cover a percentage of annual projected revenue, and if the demand does not materialize, then the guarantee would be called

Foreign exchange risks can be mitigated by currency-hedging instruments and explicit language in contracts and license agreements that the developer can pay its investors and suppliers in foreign currency and can make these payments internationally. While there have been few significant experiences with these interventions in the mini-grid sector, they would be helpful in a large-scale mini-grid development plan.

Financing productive uses and demand stimulation

In the ABC micro-grid developer business model, which is what many developers targeted initially, focuses on larger anchor clients (see Box 31). "A" refers to anchor clients, which have large consumer loads and are responsible for a majority of the micro-grid's electricity sales. They can potentially generate more stable, predictable long-term revenues for the micro-grid, making financing easier. Examples include cell phone towers, flower farms, tourist lodges, medium-sized industries and agriculture processing activities.

Box 31 A-B-C model



Source: GIZ:

In Malawi, the Usinigini hydropower MG is an example, with coffee processing as the 'A' client. However, in Malawi mini-grids will be in remote areas that may not host large anchor clients. Also, some 'A' clients may have fewer social objectives and may insist on more competitive tariffs and often have onerous service requirements that the mini-grid may not be able to consistently fulfil.

The B refers to smaller business customers, including agricultural loads, small manufacturing loads, and commercial or retail loads. "C" stands for community customers, which are mainly private households and make up a small proportion of the micro-grid's loads. These customers typically need Tier 1 and Tier2 types of energy services (see Box 11). Up-front capital costs often prevent end-users from purchasing equipment, electric or otherwise. Most small-scale users, small businesses and smallholders lack the credit history and collateral that banks require to provide financing with reasonable terms. Instead, they prefer to borrow money informally from family, friends or a (village) savings and credit association

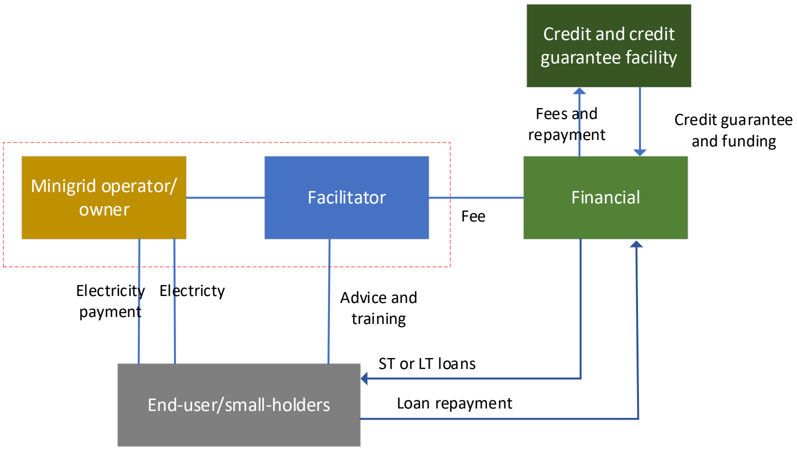
In a **facilitator model**, a facilitator enables small-scale businesses and small farmers to invest in agricultural, agro-processing or workshop equipment by serving as their education resource and connection point to finance providers. While the end-user is ultimately responsible for the credit and operational risk, the facilitator builds awareness about the investment opportunity and provides business development training to support loan applications and equipment selection. One key benefit of the Facilitator Model is that it de-risks participation by third parties to provide financing and capacity building, which enables equipment purchases and reduces the burden on the mini-grid developer. The facilitator preferably is an organisation embedded in the local community, such as a local farmer's cooperative, women's group, local NGO or local social enterprise. The mini-grid owner/operator focuses on its core business of generating and selling electricity but the mini-grid entity can also fulfil the role of facilitator.

The (private) financial institution should have experience lending to the agriculture sector and have a mandate to support financial inclusion. PFIs that are already lending to micro-enterprises and small-holders in rural areas will have a better understanding of the risks prevalent in the sector, have developed mechanisms to address these risks and be more willing to lend to small (productive) end-users. They may also need concessionary funding to reduce the blended cost of capital to affordable levels until perceived risks fall and market-rate debt becomes affordable to them. One issue is that since PUE projects/businesses are (often) both renewable energy and agriculture and industry projects, investment officers may not adequately understand both sectors. Again, the often-small size, low energy revenues and relative technical complexity of PUE projects cause many to fall through the cracks, with investment teams typically organised by sectors. This impedes access to critical debt.

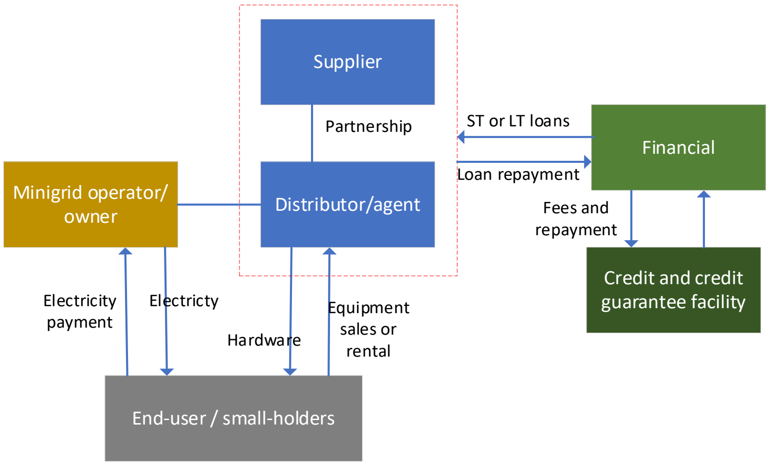
The **supplier model** follows the business model of stand-alone solar (SAS) providers that set up a distribution and sales system. Examples are power tools, agricultural machinery, household appliances, and solar-powered appliances. Thus, hardware suppliers can build market share by providing reasonably priced, reliable equipment to the end-users. However, there is a significant risk in this model for companies in terms of the volume of transactions required for viable operations which necessitates large investments and most likely a significant proportion of debt (both borrowed and lent). Also, with the concentration of grid-connected customers in (peri-)urban areas who have a greater ability to pay, it is highly unlikely such hardware distributors would pursue business in more dispersed, rural areas as the operational costs of such a sales approach (especially when providing after-sales support in remote areas) would be much higher compared to an urban-centred approach. Thus, to incentivise more existing appliance distributors to expand their sales focus into rural, 'last-mile' areas will likely require financing below commercial rates (with some grant support, if needed).

Box 32 Minigrid, PUE and financing models

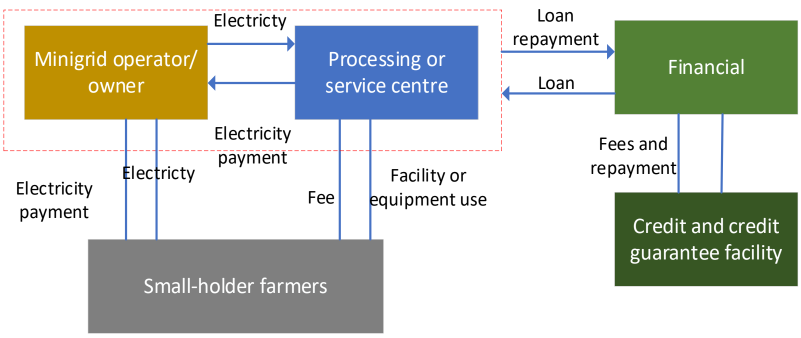
Facilitator model



Supplier model



Processing or service centre model



Source: own elaboration, based on diagrams presented in *Nigeria Power Sector Program Agricultural Productive Use Stimulation in Nigeria: Value Chain & Mini-Grid Feasibility Study* (Deloitte Consukting; USAID), 2020

In the longer term, the advantage for the supplier is that the market can develop to numerous villages, even beyond the scope of a rural electrification project or mini-grid. The lender, promoter or investor deals with one larger partner in the financial transaction (with this partner being far more credit-worthy than the hundreds of individual farmers, small cooperatives or MFIs). The kind of scale, collateral and business model this kind of actor can demonstrate to financiers is more likely (than other models) to receive guarantees. The hardware supplier model probably works best in situations where the distributor has already some local presence (sales and/or service points) in the targeted client area and in larger-scale PUE (where specialised equipment is required).

In a variant of the above, the minigrid owner/operator itself can supply hardware in their villages of operation, to stimulate demand for their power and encourage economic activity that creates impact from electrification. Alternatively, the minigrid owner/operator does not sell hardware but provides leasing services to farmers and end-users (who prefer to rent equipment rather than buy it themselves). Thus, the company can offer PUE equipment and services through existing energy agreements with households, businesses and/or institutions. Some even may integrate PUE fees into the kWh electricity tariffs. This can be offered for a definite term (with PUE equipment ownership being transferred to the end-user after a set time) or an indefinite term (with the mini-grid company providing PUE services as needed by the customer).

Thus, the mini-grid operators sometimes can act as PUE equipment distributors and after-sales service providers. From a financing point of view, a drawback is that mini-grid developers tend to secure grants and (concessional) loans to fund the construction and initial operation of a minigrid, but horizontal integration into the appliance market would require them to also take on even more working capital in addition (to set up the service centre, i.e. to fund hardware inventory and storage space). Furthermore, any actor selling appliances to rural customers will typically also have to extend credit to their customers (who usually lack the cash on hand to pay for an appliance in full). This means an otherwise well-positioned minigrid may be forced to enter multiple complicated financing arrangements and will have to interact with a constellation of stakeholders, thus operating in ecosystems of non-energy related fields (such as agriculture and processing) with a need to acquire the necessary sales and after-sales skills. This would increase management complexities and operating costs.

A third model is for larger productive uses (Tier 2 or 3). In the **processing or PUE service centre model,** the mini-grid operator-owner owns the processing centre and has a partnership with the processing/PUE service centre (that thus takes the operational aspects and credit risks of the PUE away from the mini-grid operator. The proposed solar minigrid--maize mills pilot in the Zambia activities of the UNDP/GEF Africa Minigrids is an example of this model, in which there would be a partnership of a cooperative[35] with a minigrid developer. Another example is the minigrid operator Jumeme in Tanzania which runs its own cold storage for fish freezing and runs a delivery system to connect fishermen with local markets.

The financial institutions need experience with mini-grid development as well as lending to the small-scale agricultural sector. it is important to make sure financial instruments (including disbursement mechanisms) are designed in such a way that they complement prevailing structures, increasing the chance of successful adoption. This requires close engagement with local banks, which needs to be supported by identifying viable PUE solutions and financial mechanisms which meet the needs of the potential end-user.

1.9 Public sector institutions: health facilities and energy

The Ministry of Health (MoH)) and the Ministry of Local Government Unity and Culture (MoLG) are jointly responsible for public health service delivery. At the national level, MoH is responsible for policymaking; regulating the health sector including the private sector; developing and reviewing standards, norms, and management protocols for service delivery; quality assurance; strategic planning and resource mobilization; technical support; coordinating research; and monitoring and evaluation and international representation. Below the central level, the healthcare facilities fall under 27 districts. Each district has a District Health Office (DHO), headed by a District Health Officer, who is accountable to the Principal Secretary, a District Hospital and the peripheral health units (health centres, dispensaries and village

[35] A local cooperative member of ZCF (Zambia Cooperative Federation)

clinics). The Health Sector Strategic Plan (HSSP) III (2023-2030) builds on the previous HSSP I & II, with the aim to integrate health care delivery, create a One Plan, One Budget, and One Report system, establish a sector-wide performance management system and increase domestic revenue for health.

Box 33 Overview of health faciliies

Health Facility Type	Total Facilities	Facilities on grid (2022)	Facilities off-grid (2022)	Percent Electrified
Health Post (HP)	157	65	92	41%
Health Center (HC)	786	692	94	88%
Hospital (H)	109	109	-	100%
Regional/District Vaccine Store (S)	29	29	-	100%
Totals	**1081**	**895**	**186**	**83%**

Source: *Malawi Integrated Energy Plan; Medical cold chain and vaccine distribution* (2022)

Malawi's health system is organized at four levels namely: community, primary, secondary and tertiary. At the central level, Central Hospitals provide health services at a regional level and also provide referral services to district hospitals within their region. The secondary level of care consists of district hospitals and hospitals of equivalent capacity. In addition, vaccines are kept in regional/district vaccine stores. At the primary level, health services are provided by urban and rural health centres (HC). Health centres offer outpatient and maternity services and are meant to serve a population of 10,000. At the community level, services are provided by health posts (HP) as well as village and outreach facilities and dispensaries.

An estimated 83% of health facilities in Malawi are served by ESCOM, the national utility. These facilities may benefit from on-site solar hybridization, PQS equipment replacement, and battery energy storage retrofits to increase the reliability and resiliency of vaccine storage and distribution. For the remaining 17% of health facilities, standalone solar infrastructure is necessary for off-grid cold chain infrastructure to facilitate last-mile vaccine distribution. The table in Box 35 below gives an overview of the estimation of energy and electrification needs in order to have all facilities not only supplied with a minimum required electricity but also by sources that are reliable and stable.

Box 34 Donors of off-grid electrification of health facilities

Lead implementing agency	Capital provider	HF Tier	Financing type	Financing purpose
GAVI	GAVI	1	Grant	Capex
IPCS	Power Africa Off-grid Project	1	Grant	Capex
UNDP S4H	Global Fund, Innovation Norway, UNDP	1	Grant	Capex
UNICEF	UNICEF	1	Grant	Capex
UNICEF	UNICEF, Differ Community Power	1	Grant	Capex
Zuwa Energy	Power Africa Off-grid Project	1	Grant	Capex
Community Energy Malawi, United Purpose	Government of Scotland	1	Grant	Capex
Malawi Ministry of Health	FCDO, USAID	1	Grant	Capex
Little Sun Foundation	UD[2]	1	Grant	Capex
Differ Community Power	GIZ	1	Grant	Capex & opex

Source:

Box 35 Energy needs and costs per facility

	Numbers (2022)		Expansion	Retrofit	Cost	Expansion off-grid			Cost
Type of facility	**Total**	**Grid tied**	**Grid**	**grid-PV**	**(USD)**	**Minigrid**	**SAS**	**Total**	**(USD)**
Health posts	157	65	40	105	850,500	9	43	52	648,560
Health centres	786	692	53	745	11,934,900	4	37	41	1,460,275
Hospitals	109	109		109	2,523,350				
Vaccines stores	29	29		29	2,597,211				
TOTAL					**17,905,961**				**2,108,835**
Assumptions	*Energy*	*Stand-alone for access*			*Grid-PV retrofit for cold chain stability*				
	use	*USD per*	*PV size*	*Battery*	*USD per*	*PV size*	*Battery*		
	kWh/day	facility	(kW)	size (kWh)	facility	(kW)	size (kWh)		
Health posts	6.7	14,750	3.0	13	1,590	0.3	0.55		
Health centres	20.2	37,735	7.0	42	16,020	6.0	5.0		
Hospital	31.5				23,150	10	19.7		
Vaccine stores	109				89,559	34	68.4		

T The analysis anticipates that 186 facilities (posts and health centres) will need to be added by 2030, of which 93 will have to be provided with off-grid options, i.e. minigrid or stand-alone solar (SAS) kit. The assumption is that health posts need lighting, basic power for essentials (including pre-natal and post-natal) services, microscopes and a cold storage facility. Health centres need higher amounts of electricity (lighting, outpatient and maternity services, lighting, cold chain, and medical equipment (oxygen concentrator, suction machine, incubator, nebuliser, resuscitation machine, autoclave, haematology mixer and microscopes, apart from lighting and computer. More details are also provided in the demand estimates given in section 2.10).

To ensure reliability and stability, the (mini-() grid-connected facilities may benefit from a PV-battery backup tied to the grid, of which the configuration can be smaller than the equivalent full SAS. The figures in the table deviate slightly from those mentioned in the IEP, as a higher energy consumption for health posts is assumed (6.7 instead of 0.876 kWh).

Source: own estimates based on IEP, Cold chain (2022) and energy demand estimates provided in section 2.10

The total cost of providing PV-powered energy access and cold chain resilience, according to the estimates in Box 35, is about USD 20 million, of which USD 18 million to hybridise current and planned (mini-) grid-connected health facilities with their own PV solar-battery system, and USD 2 million to provide power access with stand-alone systems. The estimates do not include the cost of connecting to the grid (or minigrid) and the cost of medical equipment.

Since 2017, UNDP has been spearheading the Solar for Health (Solar4Health)[36] initiative as a means of connecting two vital sectors – energy and health – to help countries advance universal health coverage while protecting the environment. To date, with the support of its partners, UNDP has supported the solar electrification of some 1,000 health centres and storage facilities in 15 countries, including Malawi.

Most off-grid electrification (usually at a Tier-1 level) in health facilities is provided by donors (see Box 34). One issue for ongoing sustainability is that all but one provide funding for CAPEX, but do not take into account O&M consideration. The danger then is that systems will stop functioning due to lack of maintenance, repair issues or when batteries need to be replaced. Most donor-funded installations are still done through a design, build, operate and transfer (BOT) model, where the government is the eventual owner. Some developers have operated an 'energy-as—service' (EaaS) model (with private hospitals in particular) relying on guarantees to secure commercial lending for their project finance debt. This could work for public facilities as well if the government is the ultimate off-taker. As part of a new Solar for Health programme, to be supported by the Green Climate Fund (GCF), UNDP seeks to develop and demonstrate innovative financial mechanisms (such as EaaS or other models, such as lease-back).

[36] Zimbabwe, Sudan, Zambia, South Sudan, Namibia, Liberia, Libya, Malawi, Yemen, Angola, Nepal, Uganda, Chad, Lebanon and Eswatini). The initiative is largely by the Global Fund (as well as Innovation Norway and EU Humanitarian Fund) with a budget of over USD 38 milloon

2. MODEL BUSINESS CASES MINIGRIDS AND RURAL ENERGY

2.1 Minigrid model business cases

The Model Business Cases analyses[37] the feasibility of renewable energy minigrid facilities plant supplying a hypothetical community in rural Zambia where national grid extension is not foreseen. The analysis considers the potential sale of electricity to five customer types: households (low, medium, high-income), small businesses (shops, barber shops, bars & restaurants; metal workshop; small maize mill), social services (school, clinic, community centre, worship; village water supply), and utilities (street lighting and the mini-grid's powerhouse). It is assumed that a private developer will invest in the project and be responsible for the implementation of both the plant and the distribution network and for the commercial operation of the system. The latter includes maintenance of the energy generation system and the distribution grid and connections and the sale of electricity to customers. The model has been prepared considering experiences with pre-feasibility demand and minigrid supply analysis (see, for example, the summary of characteristics of selected minigrids in Malawi (and neighbouring Zambia) given in Box 16).

Box 36 Summary table, business cases minigrids

	Cases included as example in Output 2.1 pilots								
	5. Solar 24 kW	*1. Solar* 40 kW	*2a. Solar* 60 kW small PUE	*3a. Solar* 80 kW 10% e-cooking	*2b. Hydro* 16 kW	*3b. Hydro* 17 kW 10% e-cooking	4a. Solar *Full anchor load*	4b Hydro *Full anchor load*	4b Solar *Partial anchor load*
Average annual consumption (kWh/yr/client)									
- residential	210	210	210	285	210	285	210	210	210
- social and public	1,261	1770	2391	2,121	2,391	2,121	1,993	1,993	1,993
- small commercial	1,292	1258	1527	1,531	1,527	1,531	1,322	1,322	1,527
- large PUE/water treatment	0	0	613	613	613	613	18,959	18,959	45,275
Number of clients	79	128	178	179	178	179	178	178	178
- residential	70	115	160	160	160	160	160	160	160
- social and public	4	5	5	6	5	6	6	6	6
- small commercial	5	8	12	12	12	12	11	11	12
- large PUE/water treatment	0	0	1	1	1	1	2	2	2
Investment cost	113,862	187,853	258,191	281,374	217,631	219,662	300,889	282,696	348,804
- Grant CAPEX (55-60%)	68,317	112,712	142,005	154,756	119,697	120,814	165,489	155,483	191,842
- Debt financing (20-25%)	22,772	37,571	64,548	70,343	54,408	54,915	75,222	70,674	87,201
- Equity (developer; other; 20%)	22,772	37,571	51,638	56,275	43,526	43,932	60,178	56,539	69,761
Levelised cost (LCOE; USD/kWh) w/ grant	0.416	0.411	0.402	0.368	0.371	0.313	0.324	0.340	0.364
Levelised cost (LCOE, w/o grant), USD/kWh	0.723	0.719	0.661	0.603	0.624	0.525	0.533	0.567	0.600
Annual energy consumption (kWh/yr)	26,201	43,060	64,502	93,566	77,391	93,566	574,949	574,949	154,438
Installed capacity (kW)	24	40	60	72	16	17	91	28	144
- cost per kW RE capacity	4744	4696	4303	3,908	13,560	12,831	3,306	10162	2422
Installed battery capacity (kWh)	216	302	432	518	-	-	432		432
GHG (avoided diesel generator) tCO2/yr	22.5	36.9	55.3	66.3	55.3	66.3	78.3	78.29	80.60
Lifetime emissions (20 yrs; tCO2)	449	738	1,105	1,326	1,105	1,326	1,566	1,566	1,566
Emissions (using AMG methodology)	53	87	125	138	125	138	159	159	215
Lifetime emissions (20 yrs; tCO2)	1,054	1,732	2,502	2,759	1,732	2,759	3,172	3,172	3,172
Tariff at project IRR-15%; no grant (USD/kWh)	1.083	1.082	0.993	0.904	0.861	0.726	0.800	0.787	0.900
Energy bill, households, with 55-60% grant									
Tariff at project IRR=15% (USD/kWh)	0.758	0.568	0.562	0.513	0.497	0.417	0.451	0.455	0.507
- Lower-income HH (USD/month)	6.01	4.50	4.45	4.07	4.45	4.07	3.58	3.58	4.02
- Middle-income HH (USD/month)	26.82	20.10	19.87	18.16	19.87	26.12	15.96	15.96	17.94
- Higher-income HH (USD/moth)	67.98	50.95	50.37	47.53	50.37	78.75	40.46	40.46	45.48
Description in Annex	B.7	B.2	B.3	B.4	B.3	B.4	B.6	B.6	B.6

Case	**Monthly expenditures, HH w/ and w/o e-cooking** (in USD/month)	80 kW PV
	MI HH with e-cooking	44.70
	MI HH without e- cook	31.98
	HI HH with e-cooking	78.75
	HI HH without no e-cooking	47.53
	LI HH with e-cooking	30.61
	LI HH without e-cooking	4.07

Note:LI HH actually are not assumed to cook electrically in the business cases presented, due to high cost

[37] The analysis is done using spreadsheet models kindly made available by J.H.A. van den Akker, ASCENDIS (www.ascendis.nl)

The business models are prepared based on energy demand and load assumptions gathered from IAREP surveys (Zambia), CEM survey (Sitolo solar PV MG) and other sources of information. The *Appendix* provides more details (see section 2.10). For the exchange rate USD 1 = MWK 1150 is assumed[38]. The lending bank rate is assumed to be 24% annually, assuming that in 2024 (and thereafter) the RBM policy rate[39] lending drops to 18%.

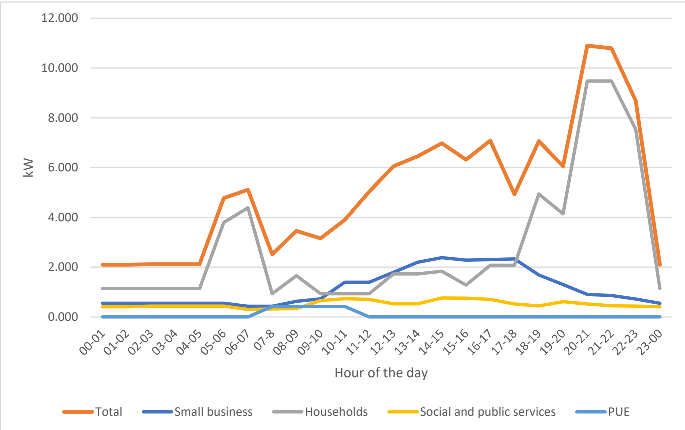
2.2 Case 1: small minigrid (40 kW solar)

In this case, we assume a demand of 120 households plus some small businesses and social services (school, health) but no larger productive uses of energy (PUE) of 118 kWh per day (that will be reached in year 5). Not all villagers will connect in the first year. Demand will start at 50% of the demand in year 5 of 107 kWh per day and then increase. Between year 5 and year 10 demand is assumed to grow at 2% annually to reach 118 kWh/day with a daily peak load of 11 kW and thereafter demand remains flat. A minigrid based on solar PV-battery generation option will deliver electricity from 100% renewable energy[40]. The system design parameters and estimated CAPEX) covers typical solar PV equipment, and associated costs including modules, inverters, mounting, battery system, cabling and various balance of plant costs. The site has a distribution network of 5.1 km.

The bulk of annual operating expenses (OPEX) are staff and administration costs such as for project managers, technicians, security guards, back-office and insurance. Parts and components for maintenance are assumed to be a percentage of the CAPEX for both the generation plant and the distribution grid In the 10th year of operations, the battery is replaced. Inverters need to be replaced after the 16th year (which is within the horizon of analysis of 20 years).

Box 37 Energy demand and load curve, minigrid 40 kW

Consumer group		Number	Total daily demand (kWh) (Year 10)	Peak power demand (kW)
	Subtotal	*115*	*66.17*	*9.48*
Households	75%	86	22.47	
	20%	23	26.75	
	5%	6	16.95	
Salon/barber		2	7.82	1.87
Shops		4	10.10	
Community/worship		1	0.92	0.36
Office		1	1.43	
Clinic	Small	1	6.69	0.35
School	Small	1	3.21	0.27
Bar/restaurant		2	9.63	0.59
Utilities		1	12.00	2.00
Small maize mill			0.00	0.00
Workshop		0	0.00	0.00
Total		*13*	*51.81*	
Large PUE		*0*	*0.00*	*0.42*
Total (rounded)		**128**	**117.97**	**11.00**



The demand in the first year is assumed to be 45% in this business case analysis and will reach 90% of maximum demand of the 128 clients by Year 5, after which demand will slowly increase to the maximum design value of 117.97 kWh per day. Thus, relative low demand in the first years is commonly occurring in minigrids taken into account in the cost-benefit analysis table presented in Box 51

38 Average over Jan-Nov 2023. At MWK 1030 on 01-01-2023, MWK 1060 on 01-07-2023 to MWK 1110 on 01-092-2023, MWK 1168 on 01-11, the exchange reate went up to about MWK 1690 after 15-11-2023. See exchange-rates.org,

39 Policy rate is the interest rate at which banks can borrow fro RBM (reflecting the country's inflation, exchange rates, credit availability). The RBM lending rate went up from 18% on 01-01-2023 to 22% in May and again 24% in September. An average policy rate of 18% is assumed in the calculations in this report. Assuming cost of 6% (funding costs 3.5%, administrative cost 1.5% and profit margin 1%), thus the bank kendig rate is 24%. A guarantee scheme provides credit risk coverage to financial intermediaries on a loan by loan basis, up to a guarantee rate, for the creation of a portfolio of new loans to energy project proponents, thus enabling to provide improved lending conditions (assumed here is reduced interest rate to 12% (=6+.8*18%), higher tenor (10 instead of 8 years) and up to 2 years of moratorium.

40 The mini-grid does not have a diesel generator. Some MG will have a diesel as backup system, but the cost of regularly procuring, transporting and storing diesel fuel and operating and maintaining a diesel generator is not included in the assessment.

Box 38 Minigrid solar PV capacity and battery configuration, Case 1 (village, no large PUE)

Base data, PV system				
PV system	40	kW	Unit cost	0.40
Peak sun hours	4.25	per day	Solar panels	16,000
System efficiency and degrad	0.92		Unit cost battery	100
Sesasonal correction	1.15		Battery	30,240
Degradation (oversizing factor)	1.15			302.4
Demand	43,060	kWh/yr	PV structures	4,000
Daily energy demand	117973	Wh/day	Unit cost inverters	360
Max power demand	11000	VA	Inverter	13,200
System requirements	2731	Ah/day	Cabling, protection, etc	4,000
Battery needs (900 Ah@6V)			Civil works, site	25,000
- at 1.45 days storage DOD=.6	6600	Ah/day		
Number of batteries	56		Protection, grounding, ect.	4,000
Network	5.1	km	Spare parts	0
Network MV in locality	0	km	**Total cost**	**96,440**
LV/MV substation (USD 6000 each)	0			
Inverter	37	kVA	Installation (at 7%)	6751
Voltage level	48	VDC	**Cost per kW**	**2,580**
Night time fraction	60%		Cost per customer	753
Usable energy	0.60			
Battery sizing factor	1.57			

	Solar	Energy (kWh/month)	
Month	**kWh/kW$_p$**	**Demand**	**Supply**
Jan	3.63	3,657	696
Feb	3.84	3,303	737
Mar	4.10	3,657	1,442
Apr	4.07	3,539	2,998
May	4.21	3,539	4,042
Jun	4.12	3,539	3,952
Jul	4.13	3,657	4,100
Aug	4.59	3,657	4,557
Sep	5.01	3,539	4,810
Oct	4.91	3,657	4,714
Nov	4.51	3,539	3,466
Dec	3.90	3,657	1,621
Average	**4.25**	42,942	**37,135**
Seasonal correction		1.15	

$$\textbf{Solar PV Capacity for a Solar PV Battery system (kW)}$$
$$= \text{Daily electricity consumption in (kWh)} \times \mathit{Seasonal\ Multiplier}\ (1.15) \div \left(1 - \mathit{Losses\ Factor}\ (8\%)\right)$$
$$\div\ \mathit{Daily\ peak\ sun\ hours}\ (\mathit{hours}) \times (1 + \mathit{Solar\ PV\ Oversizing\ Factor}$$

$$\textbf{Battery Capacity for a Solar PV} - \textbf{Battery system(kWh)}$$
$$= \text{Average daily electricity consumption in Year 3 (kWh)} \times \mathit{Night\ time\ fraction}\ (\%)$$
$$\times\ \mathit{Night\ time\ demand\ to\ be\ met\ by\ battery}\ (\%) \div (\mathit{Usable\ Energy}\ (60\%)) \times (1 + \mathit{Battery\ Oversizing\ Factor})$$

All electricity produced by the mini-grid is assumed to be sold to customers. An average tariff (USD/kWh) is assumed across all customer types so as not to make the analysis presented in this section too complicated. In reality, the tariff would likely be differentiated per end-user category. Mini-grids usually charge different tariffs subject to regulatory approval. Some tariffs may be monthly service fees (in the low-demand category) or based on consumption. Also, it is assumed that there is no connection charge.

In principle, cost-reflective tariffs may be proposed by developers. In practice, the tariff definition will depend on a trade-off interplay between subsidy level (lowering investment cost), the end-user's ability or willingness to pay (ATP/WTP) and the developer's desired return on investment. The model uses a combination of generic and country-specific inputs to calculate the Levelized Cost of Electricity (LCOE) in US$/kWh for the minigrid. The LCOE is the price that would have to be charged for the electricity to allow for cost recovery of all costs (CAPEX, OPEX) over a 20-year timeframe.

Estimation of subsidy level

The subsidy level is determined by looking at investment costs on their impact on the tariff vis-à-vis the ability or willingness to pay (as discussed in Box 25.

(a/b) No grant is available

The LCOE of the 40 kW solar minigrid is USD 0.719/kWh. If no investment subsidy is provided, even lower-income households (assumed to be 75% of all households) would have to pay about USD 6.21-8.57 a month (tariff at USD 0.784-1.082/kWh, giving a project IRR of 9-15%). The social discount rate is assumed to be 9%. This is above the ATP/WTP range. Lower-income households are the largest group of clients and are most likely to reject grid connections if their energy payments are above their WTP/ATP. Low participation (due to complaints about the fairness of tariffs and lack of awareness of energy use), especially in the initial years, can be an issue in minigrids.

(c/d 60% grant funding (for minigrid projects < 50 kW)

The LCOE is USD 0.411 per kWh. If a 60% investment grant is provided, low-income monthly payment drops to USD 3.55-4.50 per month (tariff at USD 0.448-0.568/kWh, giving a project IRR of 9-15%). This is more within the range of ATP/WTP.

Box 39 Solar PV minigrid CAPEX, OPEX and LCOE with tariff and subsidy optimization, Case 1

Solar PV generation		
Size	**40**	kW
Economic lifetime	20	yr
Demand	43,060	kWh/yr
Max production	43,182	kWh/yr
Total cost, solar PV	103,191	USD
O&M, insurance	4.0%	
Replacement batteries (after 10 yrs)	30,240	USD
Distribution and wiring system		
Unit cost	8,000	USD
Length LV distribution system	5.1	km
Unit cost	15,000	USD
Length MV lines	0.0	km
Subtotal cost	40,960	USD
HH metering & wiring USD/client 150	19200	USD
Total cost	60,160	USD
O&M, insurance	4.0%	
Transport, customs and logistics 15%	24,503	USD

Lifecycle cost per unit of kWh		
Discount rate	9%	
Investment cost per kW	4696	USD/kW
Investment, solar mini-grid	**187,853**	**USD**
Annualised cost of investment	23,891	USD/yr
Operation and maintenance (O&M)	6,534	USD/yr
Total annual cost	**30,425**	
LCOE, solar PV mini-grid	*0.719*	*USD/kWh*
Capital subsidy	60%	
Grant support	**112,712**	USD
Discount rate	9%	
Investment, solar mini-grid	75,141	USD
Annualised cost of investment	11,544	USD/yr
Operation and maintenance (O&M)	6,534	USD/yr
Total annual cost	**18,078**	**USD/yr**
LCOE, solar PV	*0.411*	*USD/kWh*

Investment cost (USD/client)	**1468**
Breakdown investment cost (USD/kW)	**4696**
- Site, civil works	625
- Generation	930
- Storage	1086
- Distribution	1504
- Other	781

The table below gives the implications of different tariffs for the monthly payments of different household groups.

NO GRANT		**Monthly payment**		
TARIFF LEVEL FOR NPV=0			USD	MWK
Tariff (USD/kWh)	0.7839	LL HH	6.21	7143
Benefits (Revenues - costs)		MM HH	27.73	31891
		HI HH	70.29	80838
NO GRANT + margin		**Monthly payment**		
TARIFF LEVEL FOR IRR=15%			USD	ZMW
Tariff (USD/kWh)	1.0816	LL HH	8.57	9856
Benefits (Revenues - costs)		MM HH	38.26	44002
		HI HH	96.99	111537
COSTS AFTER GRANT	40%	**Monthly payment**		
TARIFF LEVEL FOR NPV=0			USD	ZMW
Tariff (USD/kWh)	0.4484	LL HH	3.55	4086
Benefits (Revenues - costs)		MM HH	15.86	18240
		HI HH	40.21	46236
COSTS AFTER GRANT	40.00%	**Monthly payment**		
TARIFF LEVEL FOR IRR=15%			USD	ZMW
Tariff (USD/kWh)	0.5682	LL HH	4.50	5178
Benefits (Revenues - costs)		MM HH	20.10	23115
		HI HH	50.95	58593

						Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
Capital Cost			USD			187,853	0	0	0	0	0	0	0	0	0	30,240	0	0	0	0	0	13,200	0	0	0	0
O&M Cost			USD				6,534	6,534	6,534	6,534	6,534	6,534	6,534	6,534	6,534	6,534	6,534	6,534	6,534	6,534	6,534	6,534	6,534	6,534	6,534	6,534
Consumption MG (kWh/yr)							19,462	27,246	31,138	35,031	38,923	39,717	40,528	41,355	42,199	43,060	43,060	43,060	43,060	43,060	43,060	43,060	43,060	43,060	43,060	43,060
Consumption							19,462	27,246	31,138	35,031	38,923	39,717	40,528	41,355	42,199	43,060	43,060	43,060	43,060	43,060	43,060	43,060	43,060	43,060	43,060	43,060
Consumption large PUE(kWh/yr)							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO GRANT																										
TARIFF LEVEL FOR NPV=0	Tariff	0.7839	USD/kWh				0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
	Revenues MG		USD million				15,256	21,359	24,410	27,462	30,513	31,136	31,771	32,419	33,081	33,756	33,756	33,756	33,756	33,756	33,756	33,756	33,756	33,756	33,756	33,756
Benefits (Revenues - costs)	Disc rate	9%		NPV	0	-187,853	8,722	14,825	17,876	20,928	23,979	24,602	25,237	25,885	26,547	-3,018	27,222	27,222	27,222	27,222	27,222	27,222	14,022	27,222	27,222	27,222
				IRR	9%																					
NO GRANT + margin																										
TARIFF LEVEL FOR IRR=15%	Tariff	1.0816	USD/kWh				1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
	Revenues MG		USD million				21,050	29,470	33,680	37,890	42,100	42,960	43,836	44,731	45,644	46,575	46,575	46,575	46,575	46,575	46,575	46,575	46,575	46,575	46,575	46,575
Benefits (Revenues - costs)	Disc rate	9%		NPV	91,743	-187,853	14,516	22,936	27,146	31,356	35,566	36,426	37,302	38,197	39,110	9,801	40,041	40,041	40,041	40,041	40,041	40,041	26,841	40,041	40,041	40,041
				IRR	15%																					
COSTS AFTER GRANT	40%																									
TARIFF LEVEL FOR NPV=0	Tariff	0.4484	EUR/kWh				0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
	Revenues MG		USD million				8,726	12,217	13,962	15,707	17,452	17,808	18,172	18,543	18,921	19,307	19,307	19,307	19,307	19,307	19,307	19,307	19,307	19,307	19,307	19,307
Benefits (Revenues - costs)	Disc rate	9%		NPV	0	-75,141	2,192	5,683	7,428	9,173	10,918	11,274	11,638	12,009	12,387	-17,467	12,773	12,773	12,773	12,773	12,773	12,773	-427	12,773	12,773	12,773
				IRR	9%																					
COSTS AFTER GRANT	40%																									
TARIFF LEVEL FOR IRR=15%	Tariff	0.5682	USD/kWh				0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
	Revenues		USD million				11,058	15,481	17,693	19,905	22,116	22,568	23,028	23,498	23,978	24,467	24,467	24,467	24,467	24,467	24,467	24,467	24,467	24,467	24,467	24,467
Benefits (Revenues - costs)	Disc rate	9%		NPV	36,928	-75,141	4,524	8,947	11,159	13,371	15,582	16,034	16,494	16,964	17,444	-12,307	17,933	17,933	17,933	17,933	17,933	17,933	4,733	17,933	17,933	17,933
				IRR	15%																					

Box 40 40 kW solar PV minigrid financial indicators (no grant)

70% debt financing, prevailing interest rate

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cashflow projections																					
Capital expenditures	-188																				
Earnings EBITDA	-188	15	23	27	31	36	36	37	38	39	10	40	40	40	40	40	40	27	40	40	40
pre-tax NPV 92																					
IRR 15%																					
payback (yrs) 6.5																					
Depreciation		-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	0	0	0	0	0
Earnings EBIT (before interest and tax)		2	10	15	19	23	24	25	26	27	-3	28	28	28	28	28	40	27	40	40	40
Cost of finance		0	-32	-29	-25	-21	-15	-8	0	0	0	0	0	0	0	0	0	0	0	0	0
Earnings before taxes		2	-21	-14	-6	2	9	16	26	27	-3	28	28	28	28	28	40	27	40	40	40
Tax		0	0	0	0	0	-1	-2	-4	-4	0	-4	-4	-4	-4	-4	-6	-4	-6	-6	-6
Net income		2	-21	-14	-6	2	7	14	22	23	-3	23	23	23	23	23	34	23	34	34	34
Plus:																					
Depreciation and interest		13	44	41	38	33	28	21	13	13	13	13	13	13	13	13	0	0	0	0	0
Cash flow (after tax)	-188	15	23	27	31	36	35	35	34	35	10	36	36	36	36	36	34	23	34	34	34
IRR 12.7%																					

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Financing activities																					
Equity	56																				
Soft loan	0			0	0	0	0	0	0	0	0		0								
Bank loan	131		-44	-44	-44	-44	-44	-44													
Change in cash	0	15	-21	-16	-12	-8	-8	-9	34	35	10	36	36	36	36	36	34	23	34	34	34
Cumulative cash balance	0	15	-6	-22	-35	-43	-51	-60	-25	10	20	55	91	127	163	199	233	256	290	324	358

Financing requirement

	Amount (USD 000)	Annual repayment	Share	Interest	Grace period	Repay period
Grant	0		0.0%			
Equity	56		30.0%			
Soft loan	0	0.00	0.0%	12.0%	2	8
Local loan	131	-43.54	70.0%	24.0%	1	6

Corporate tax rate	15%	
Minigrid power tariff	1.082	$/kWh

70% debt financing, soft loan

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cashflow projections																					
Capital expenditures	-188																				
Earnings EBITDA	-188	15	23	27	31	36	36	37	38	39	10	40	40	40	40	40	40	27	40	40	40
pre-tax NPV 92																					
IRR 15%																					
payback (yrs) 6.5																					
Depreciation		-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	0	0	0	0	0
Earnings EBIT (before interest and tax)		2	10	15	19	23	24	25	26	27	-3	28	28	28	28	28	40	27	40	40	40
Cost of finance		0	0	-16	-14	-13	-11	-10	-8	-5	-3	0	0	0	0	0	0	0	0	0	0
Earnings before taxes		2	10	-1	4	10	12	15	18	21	-6	28	28	28	28	28	40	27	40	40	40
Tax		0	0	0	0	0	-2	-2	-3	-3	0	-4	-4	-4	-4	-4	-6	-4	-6	-6	-6
Net income		2	10	-1	4	10	11	13	15	18	-6	23	23	23	23	23	34	23	34	34	34
Plus:																					
Depreciation and interest		13	13	28	27	26	24	22	20	18	15	13	13	13	13	13	0	0	0	0	0
Cash flow (after tax)	-188	15	23	27	31	36	35	35	35	36	10	36	36	36	36	36	34	23	34	34	34
IRR 12.7%																					

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Financing activities																					
Equity	56																				
Soft loan	131			-26	-26	-26	-26	-26	-26	-26	-26		0								
Bank loan	0		0	0	0	0	0	0													
Change in cash	0	15	23	1	5	9	8	9	9	9	-17	36	36	36	36	36	34	23	34	34	34
Cumulative cash balance	0	15	37	38	43	52	60	69	78	87	71	106	142	178	214	250	284	307	341	375	409

Financing requirement

	Amount (USD 000)	Annual repayment	Share	Interest	Grace period	Repay period
Grant	0		0.0%			
Equity	56		30.0%			
Soft loan	131	-26.47	70.0%	12.0%	2	8
Local loan	0	0.00	0.0%	24.0%	1	6

Corporate tax rate	15%	
Minigrid power tariff	1.082	$/kWh

Another issue is financing. In case there is no grant financing, the developer needs to provide 100% or get debt financing. Few developers will be able to provide 100% equity. Box 40 presents the scenario in which the developer provides 30% equity (with 70% debt financing at 28% bank lending rate). The table shows that the project would have a severe cash balance problem with having to pay back at the prevailing high interest rate. With ‘soft loan’ conditions (reduced interest rate at 12%, higher tenor and moratorium), the example shows a positive cash balance. Still, with no grant support for the CAPEX, the minigrid would have to charge an average of USD 1.1 per kWh, which is beyond what many households would be able or willing to pay. The third case is the same 40 kW solar minigrid, but receiving a 60% CAPEX subsidy as well as a soft loan (12% interest rate.). Box 40 presents the case of 60% grant, 20% equity and 20% debt financing, assuming the end-user is charged USD 0.568 USD/kWh. With a commercial loan, the annual cash balance would be precarious, but the annual cash balance is positive with a soft loan.

Box 41 40 kW solar PV minigrid financial indicators (with 60% CAPEX subsidy)

20% debt financing, prevailing interest rate

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cashflow projections																					
Capital expenditures	-75																				
Earnings EBITDA	-75	5	9	11	13	16	16	16	17	17.4	-12	18	18	18	18	18	18	5	18	18	18
pre-tax NPV 37																					
IRR 15.0%																					
payback (yrs) 6																					
Depreciation		-5	-5	-5	-5	-5	-5	-5	-5	-5.0	-5	-5	-5	-5	-5	-5	0	0	0	0	0
Earnings EBIT (before interest and tax)		0	4	6	8	11	11	11	12	12.4	-17	13	13	13	13	13	18	5	18	18	18
Cost of finance (interest expenses)		0	-9	-8	-7	-6	-4	-2	0	0.0	0	0	0	0	0	0	0	0	0	0	0
Earnings before taxes		0	-5	-2	1	5	7	9	12	12.4	-17	13	13	13	13	13	18	5	18	18	18
Tax		0	0	0	0	-1	-1	-1	-2	-1.9	0	-2	-2	-2	-2	-2	-3	-1	-3	-3	-3
Net income		0	-5	-2	1	4	6	8	10	10.6	-17	11	11	11	11	11	15	4	15	15	15
Plus:																					
Depreciation and interest		5	14	13	12	11	9	7	5	5	5	5	5	5	5	5	0	0	0	0	0
Cash flow (after tax)	-75	5	9	11	13	15	15	15	15	16	-12	16	16	16	16	16	15	4	15	15	15
IRR 13.9%																					

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Financing activities																					
Equity	38																				
Soft loan	0			0	0	0	0	0	0	0	0	0	0								
Loan	38		-12	-12	-12	-12	-12	-12	0	0											
Change in cash	0	5	-3	-1	1	2	3	3	15	16	-12	16	16	16	16	16	15	4	15	15	15
Cumulative cash balance	0	5	1	0	1	3	6	8	23	39	27	43	59	75	91	107	122	126	141	156	172

Financing requirement

	Amount (USD 000)	Annual repayment	Share	Interest	Grace period	Repay period
Grant	113		60.0%			
Equity	38		20.0%			
Soft loan	0	0.00	0.0%	12.0%	2	8
Loan	38	-12.44	20.0%	24.0%	1	6

Corporate tax rate	15%	
Electricity tariff	0.568	$/kWh

20% debt financing, soft loan

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cashflow projections																					
Capital expenditures	-75																				
Earnings EBITDA	-75	5	9	11	13	16	16	16	17	17.4	-12	18	18	18	18	18	18	5	18	18	18
pre-tax NPV 37																					
IRR 15.0%																					
payback (yrs) 6																					
Depreciation		-5	-5	-5	-5	-5	-5	-5	-5	-5.0	-5	-5	-5	-5	-5	-5	0	0	0	0	0
Earnings EBIT (before interest and tax)		0	4	6	8	11	11	11	12	12.4	-17	13	13	13	13	13	18	5	18	18	18
Cost of finance (interest expenses)		0	0	-5	-4	-4	-3	-3	-2	-1.5	-1	0	0	0	0	0	0	0	0	0	0
Earnings before taxes		0	4	2	4	7	8	9	10	10.9	-18	13	13	13	13	13	18	5	18	18	18
Tax		0	-1	0	-1	-1	-1	-1	-1	-1.6	0	-2	-2	-2	-2	-2	-3	-1	-3	-3	-3
Net income		0	3	1	4	6	7	7	8	9.3	-18	11	11	11	11	11	15	4	15	15	15
Plus:																					
Depreciation and interest		5	5	10	9	9	8	8	7	7	6	5	5	5	5	5	0	0	0	0	0
Cash flow (after tax)	-75	5	8	11	13	15	15	15	15	16	-12	16	16	16	16	16	15	4	15	15	15
IRR 13.7%																					

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Financing activities																					
Equity	38																				
Soft loan	38			-8	-8	-8	-8	-8	-8	-8	-8	0	0								
Loan	0		0	0	0	0	0	0	0	0											
Change in cash	0	5	8	3	5	7	7	8	8	8	-20	16	16	16	16	16	15	4	15	15	15
Cumulative cash balance	0	5	13	16	21	28	36	43	51	60	40	56	72	88	104	120	135	139	154	169	185

Financing requirement

	Amount (USD 000)	Annual repayment	Share	Interest	Grace period	Repay period
Grant	113		60.0%			
Equity	38		20.0%			
Soft loan	38	-7.56	20.0%	12.0%	2	8
Loan	0	0.00	0.0%	24.0%	1	6

Corporate tax rate	15%	
Electricity tariff	0.568	$/kWh

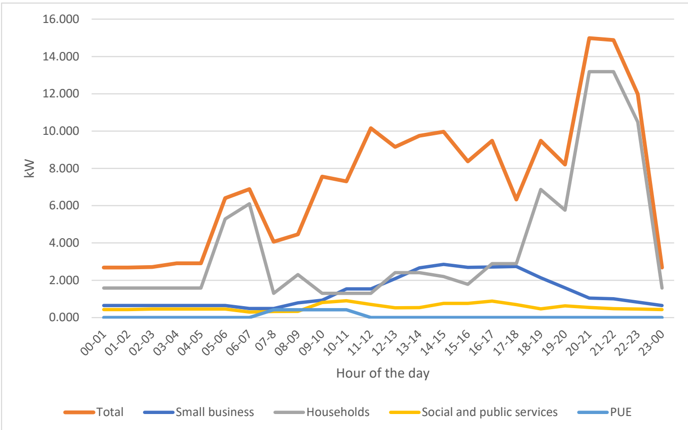
The business case presented is for a small minigrid (solar < 50 kW) which receives a 60% investment subsidy, that would allow a small profit margin for the developer with end-user tariffs in the range of ATP/WTP of lower-income households. If the developer/proponent cannot fully provide the equity, a 'soft' loan will be needed. In the example, soft loans give a positive cash balance with high commercial bank lending rates the cash balance in the first years would be small or negative).

2.3 Case 2: minigrids with small PUE (60 kW solar; 16 kW hydro)

The second case assumes a demand equivalent of 160 households by year 5 of the MG implementation) plus small businesses and social services (school, health) and small PUE (small businesses, a small metal workshop, village water pump and treatment, and a small maize mill). Not all villagers will connect in the first year. Demand will start at 50% of the projected demand in year 5 of 158 kWh per day and then increase to 179 kWh/day by year 10 (between year 5 and year 10 demand is assumed to grow at 2% annually to 179 kWh/day with a daily peak load of 36 kW and thereafter demand remains flat. The site has a distribution network of 8.6 km, a distance which represents the relatively low population density in man. Two types of minigrids are studied in this business case to supply the projected demand. A 60 kW PV minigrid based on a solar PV-battery generation option will deliver electricity from 100% renewable energy. The system design parameters and estimated CAPEX) cover typical solar PV equipment, and associated costs including modules, inverters, mounting, battery system, cabling and various balance of plant costs. Alternatively, the power is supplied by a 16 kW hydropower facility[41].

Box 42 Energy demand and load curve, 80 kW solar, 16 kW hydro minigrid

Consumer group		Number	Total daily demand (kWh) (Year 10)	Peak power demand (kW)
Households (w/o electric cooking)	Subtotal	160	92.06	13.18
	75%	120	31.26	
	20%	32	37.22	
	5%	8	23.58	
Salon/barber		2	7.82	2.34
Shops		6	15.16	
Community/worship		2	1.83	0.54
Office		1	1.43	
Clinic	Small	1	6.69	0.35
School	Small	1	3.21	0.27
Bar/restaurant		2	9.63	0.59
Utilities		1	19.60	3.00
Small maize mill		1	10.39	2.59
Workshop		1	7.22	1.15
Total		*18*	*82.98*	
Other PUE		1	1.68	0.42
Total (rounded)		**179**	**176.72**	**15.00**



The demand in the first year is assumed to be 45% in this business case analysis and will reach 90% of maximum demand by Year 5, after which demand will slowly increase to the maximum design value of 176.7 kWh per day in year 10. The relative low demand in is takenn into account in the cost-benefit analysis tables presented in Box 51

The bulk of annual operating expenses (OPEX) are staff and administration costs such as for project managers, technicians, security guards, back-office and insurance. Parts and components for maintenance are assumed to be a percentage of the CAPEX for both the generation plant and the distribution grid In the 10th year of operations, the battery is replaced. Inverters need to be replaced after the 16th year (which is within the horizon of analysis of 20 years).

All electricity produced by the mini-grid is assumed to be sold to customers. An average tariff (USD/kWh) is assumed across all customer types so as not to make the analysis presented in this section too complicated. In reality, the tariff would likely be differentiated per end-user category. Mini-grids usually charge different tariffs subject to regulatory approval. Some tariffs may be monthly service fees (in the low-demand category) or based on actual consumption. Also, it is assumed that there is no initial connection charge.

In principle, cost-reflective tariffs may be proposed by developers. In practice, the tariff definition will depend on a trade-off interplay between subsidy level (lowering investment cost), the end-users ability or willingness to pay

[41] Assuming pipe losses of about 7%, a 16 kW facility is neeed to provide the expected peak power demand of 15 kW. This assumes that river flow in the driest month is sufficient given the height difference of the water. For example, assuming an efficiency of 75% and a head of 100 metres, a minimal flow of 0.022 m^3/s is needed. At a lower head, a larger flow is needed.

Box 43 Minigrid solar PV capacity and battery configuration, Case 2 (60 kW solar minigrid)

Base data, PV system					
PV system	60	kW	Unit cost	0.40	per Wp
Peak sun hours	4.25	per day	Solar panels	24,000	USD
System efficiency and degrad	0.92		Unit cost battery	100	USD/kWh
Sesasonal correction	1.15		Battery	43,200	USD
Degradation (oversizing factor)	1.15			432	kWh
Demand	64,502	kWh/yr	PV structures	6,000	
Daily energy demand	176717	Wh/day	Unit cost inverters	360	USD/kVA
Max power demand	15000	VA	Inverter	18,000	USD
System requirements	4091	Ah/day	Cabling, protection, etc	5,000	USD
Battery needs (900 Ah@6V)			Civil works, site	30,000	USD
- at 1.35 days storage DOD=.6	9204	Ah/day			
Number of batteries	80		Protection, grounding, ect.	5,000	USD
Network	7.2	km	Spare parts	0	
Network MV in locality	0	km	**Total cost**	**131,200**	**USD**
LV/MV substation (USD 6000 each)	0				
Inverter	50	kVA	Installation (at 7%)	9184	
Voltage level	48	VDC	**Cost per kW**	**2,340**	**USD/kW**
Night time fraction	54%		Cost per customer	737	USD/kW
Usable energy	0.60				
Battery sizing factor	1.70				

	Solar	Energy (kWh/month)	
Month	**kWh/kW$_p$**	**Demand**	**Supply**
Jan	3.63	3,657	696
Feb	3.84	3,303	737
Mar	4.10	3,657	1,442
Apr	4.07	3,539	2,998
May	4.21	3,539	4,042
Jun	4.12	3,539	3,952
Jul	4.13	3,657	4,100
Aug	4.59	3,657	4,557
Sep	5.01	3,539	4,810
Oct	4.91	3,657	4,714
Nov	4.51	3,539	3,466
Dec	3.90	3,657	1,621
Average	**4.25**	42,942	**37,135**
Seasonal correction		1.15	

$$\textbf{Solar PV Capacity for a Solar PV Battery system (kW)} = \text{Daily electricity consumption in (kWh)} \times \textit{Seasonal Multiplier}\ (1.15) \div \left(1 - \textit{Losses Factor}\ (8\%)\right) \div \textit{Daily peak sun hours}\ (\textit{hours}) \times (1 + \textit{Solar PV Oversizing Factor}$$

$$\textbf{Battery Capacity for a Solar PV} - \textbf{Battery system(kWh)} = \text{Average daily electricity consumption in Year 3 (kWh)} \times \textit{Night time fraction}\ (\%) \times \textit{Night time demand to be met by battery}\ (\%) \div (\textit{Usable Energy}\ (60\%)) \times (1 + \textit{Battery Oversizing Factor})$$

The solar data are taken from *Solar Resource Atlas,* World Bank/ESMAP (2018) and are average data for three measuring stations in Malawi (North, Central and South). For Mzuzu, average output kWh/kWp is 4.20, for Kasungu, 4.44 and Chileka 4.18

(ATP/WTP) and the developer's desired return on investment. The model uses a combination of generic and country-specific inputs to calculate the Levelized Cost of Electricity (LCOE) in US$/kWh for the minigrid. The LCOE is the price that would have to be charged for the electricity to allow for cost recovery of all costs (CAPEX, OPEX) over a 20-year timeframe.

Estimation of subsidy level

The subsidy level is determined by looking at investment costs on their impact on the tariff vis-à-vis the ability or willingness to pay (see Box 25). The grant portion is slightly smaller than in case 1 (60%) due to better economies of scale of the large system (LCOE of USD 0.661/kWh in this case vs. USD 0.719/kWh in case 1).

(a/b) No grant is available

If no investment subsidy is provided, even lower-income households (assumed to be 75% of all households) would have to pay about USD 5.71-7.87 a month (tariff at USD 0.720-0.994/kWh, giving a project IRR of 9-15%). The social discount rate is assumed to be 9%. This is above the ATP/WTP range. Lower-income households are the largest group of clients and are most likely to reject grid connections if their energy payments are above their WTP/ATP. Low participation (due to complaints about the fairness of tariffs and lack of awareness of energy use), especially in the initial years, can be an issue in minigrids.

(c/d) 55% grant funding (for minigrid projects < 50 kW)

With the subsidy, the LCOE is USD 0.402 per kWh (compared with the LCOE of USD 0.441/kWh of the 40 kW minigrid, case 1). If a 55% investment grant is provided, low-income monthly payment drops to USD 3.47-4.465 per month (tariff at USD 0.438-0.562/kWh, giving a project IRR of 9-15%). This is more within the range of ATP/WTP.

The business case also looks at the option that a 16 kW provides the demand of the same 160-household village. Key features of a hydropower site such as hydrology and civil works layout, cannot be defined. It is assumed that there are no site-specific limitations to obtaining the required power output and energy production to supply the mini-grid. This means that the power output will be as required from the demand forecasting and the scheme can provide the required power output all year round, which is a real case would mean that the design flow is lower than the minimum flow available in the river or stream every hydrological year.

Box 44 60 kW solar PV minigrid CAPEX, OPEX and LCOE with grant and without grant suport

Solar PV generation		
Size	**60**	kW
Economic lifetime	20	yr
Demand	64,502	kWh/yr
Max production	64,773	kWh/yr
Total cost, solar PV	140,384	USD
O&M, insurance	4.0%	
Replacement batteries (after 10 yrs)	43,200	USD
Distribution and wiring system		
Unit cost	8,000	USD
Length LV distribution system	7.2	km
Unit cost	15,000	USD
Length MV lines	0.0	km
Subtotal cost	57,280	USD
HH metering & wiring USD/client 150	26850	USD
Total cost	84,130	USD
O&M, insurance	4.0%	
Transport, customs and logistics 15%	33,677	USD

Lifecycle cost per unit of kWh		
Discount rate	9%	
Investment cost per kW	4303	USD/kW
Investment, solar mini-grid	**258,191**	**USD**
Annualised cost of investment	33,016	USD/yr
Operation and maintenance (O&M)	8,981	USD/yr
Total annual cost	**41,997**	
LCOE, solar PV mini-grid	*0.661*	*USD/kWh*
Capital subsidy	55%	
Grant support	**142,005**	USD
Discount rate	9%	
Investment, solar mini-grid	116,186	USD
Annualised cost of investment	17,460	USD/yr
Operation and maintenance (O&M)	8,981	USD/yr
Total annual cost	**26,441**	**USD/yr**
LCOE, solar PV	*0.402*	*USD/kWh*

Investment cost (USD/client)	**1442**
Breakdown investment cost (USD/kW)	**4303**
- Site, civil works	500
- Generation	867
- Storage	1020
- Distribution	1402
- Other	714

The table below gives the implications of different tariffs for the monthly payments of different household groups.

NO GRANT		**Monthly payment**		
TARIFF LEVEL FOR NPV=0			USD	MWK
Tariff (USD/kWh)	0.7202	LL HH	5.71	6563
Benefits (Revenues - costs)		MM HH	25.48	29300
		HI HH	64.58	74270
NO GRANT + margin		**Monthly payment**		
TARIFF LEVEL FOR IRR=15%			USD	ZMW
Tariff (USD/kWh)	0.9935	LL HH	7.87	9053
Benefits (Revenues - costs)		MM HH	35.14	40415
		HI HH	89.08	102445
COSTS AFTER GRANT	45%	**Monthly payment**		
TARIFF LEVEL FOR NPV=0			USD	ZMW
Tariff (USD/kWh)	0.4382	LL HH	3.47	3992
Benefits (Revenues - costs)		MM HH	15.50	17824
		HI HH	39.29	45182
COSTS AFTER GRANT	45.00%	**Monthly payment**		
TARIFF LEVEL FOR IRR=15%			USD	ZMW
Tariff (USD/kWh)	0.5618	LL HH	4.45	5119
Benefits (Revenues - costs)		MM HH	19.87	22854
		HI HH	50.37	57930

				Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
Capital Cost			USD	258,191	0	0	0	0	0	0	0	0	0	43,200	0	0	0	0	0	18,000	0	0	0	0
O&M Cost			USD		8,981	8,981	8,981	8,981	8,981	8,981	8,981	8,981	8,981	8,981	8,981	8,981	8,981	8,981	8,981	8,981	8,981	8,981	8,981	8,981
Consumption MG (kWh/yr)					28,875	41,038	46,813	52,588	58,363	59,542	60,745	61,972	63,224	64,502	64,502	64,502	64,502	64,502	64,502	64,502	64,502	64,502	64,502	64,502
Consumption HH and small PUE					28,875	40,425	46,200	51,975	57,750	58,929	60,131	61,359	62,611	63,889	63,889	63,889	63,889	63,889	63,889	63,889	63,889	63,889	63,889	63,889
Consumption larger PUE					0	613.2	613.2	613.2	613.2	613.2	613.2	613.2	613.2	613.2	613.2	613.2	613.2	613.2	613	613	613	613	613	613
NO GRANT																								
TARIFF LEVEL FOR NPV=0	Tariff	0.7202	USD/kWh		0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
	Revenues MG		USD million		20,797	29,557	33,717	37,876	42,035	42,884	43,751	44,634	45,536	46,457	46,457	46,457	46,457	46,457	46,457	46,457	46,457	46,457	46,457	46,457
Benefits (Revenues - costs)	Disc rate	9%	NPV 0	-258,191	11,816	20,577	24,736	28,896	33,055	33,904	34,770	35,654	36,556	-5,724	37,476	37,476	37,476	37,476	37,476	37,476	19,476	37,476	37,476	37,476
			IRR 9%																					
NO GRANT + margin																								
TARIFF LEVEL FOR IRR=15%	Tariff	0.9935	USD/kWh		0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
	Revenues MG		USD million		28,687	40,770	46,508	52,245	57,982	59,153	60,348	61,567	62,811	64,081	64,081	64,081	64,081	64,081	64,081	64,081	64,081	64,081	64,081	64,081
Benefits (Revenues - costs)	Disc rate	9%	NPV 126,193	-258,191	19,706	31,790	37,527	43,264	49,002	50,173	51,367	52,587	53,831	11,900	55,100	55,100	55,100	55,100	55,100	55,100	37,100	55,100	55,100	55,100
			IRR 15%																					
COSTS AFTER GRANT		45%																						
TARIFF LEVEL FOR NPV=0	Tariff	0.4382	EUR/kWh		0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44
	Revenues MG		USD million		12,652	17,981	20,511	23,042	25,572	26,089	26,615	27,153	27,702	28,262	28,262	28,262	28,262	28,262	28,262	28,262	28,262	28,262	28,262	28,262
Benefits (Revenues - costs)	Disc rate	9%	NPV 0	-116,186	3,671	9,001	11,531	14,061	16,592	17,108	17,635	18,173	18,721	-23,919	19,281	19,281	19,281	19,281	19,281	19,281	1,281	19,281	19,281	19,281
			IRR 9%																					
COSTS AFTER GRANT		45%																						
TARIFF LEVEL FOR IRR=15%	Tariff	0.5618	USD/kWh		0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56
	Revenues		USD million		16,222	23,055	26,299	29,543	32,788	33,450	34,125	34,815	35,518	36,236	36,236	36,236	36,236	36,236	36,236	36,236	36,236	36,236	36,236	36,236
Benefits (Revenues - costs)	Disc rate	9%	NPV 57,098	-116,186	7,241	14,074	17,318	20,563	23,807	24,469	25,145	25,834	26,538	-15,945	27,255	27,255	27,255	27,255	27,255	27,255	9,255	27,255	27,255	27,255

Box 45 CAPEX and OPEX, 16 kW micro hydropower facility

Hydropower (unit cost figures)	USD	USD/kW
Site preparation and infrastruct (road)	2,087	130
Civil works (inlet, forebay, penstocks, building)	55,680	1,600
Substation	11,235	700
Electromechanical equipment	28,088	1,750
Installation and supervison	8,025	500
TOTAL	**105,114**	**6,549**

Data based onm data published by IRENA and GET.Invest and other sources

Investment and operating costs for the hydropower plant and for the distribution network are provided in Box 45. Considering the size and likely remote location of the plant, a relatively high CAPEX is assumed (for civil works, the penstock, turbine, generator, powerhouse and substation, and installation). The installation is expected to need a substantial overhaul in year 16 of its operations (which is included as an element in the estimation of the LCOE). The annual OPEX for the hydropower plant is assumed at 4% of CAPEX plus 4% insurance cost. Cost assumptions for the distribution network are the same as for the solar minigrid case (8.6 km; see Box 50). The main mini-grid system parameters, CAPEX, OPEX, LCOE and are summarised in Box 45**.**

The subsidy level is determined by looking at investment costs on their impact on the tariff vis-à-vis the ability or willingness to pay, and, as in the solar mini-grid equivalent, is assumed to be 55%. The table on the left in Box 46 presents four cases:

(a/b) No grant is available

The LCOE is USD 0.624/kWh (about the same as the equivalent solar PV minigrid). If no investment subsidy is provided, even lower-income households would have to pay about USD 5.0-6.8 a month (tariff at USD 0.632-0.861/kWh, giving a project IRR of 9-15%). The social discount rate is assumed to be 9%. This is above the ATP/WTP range (given in Box 40). Lower-income households are the largest group of clients and are most likely to reject grid connection, if their energy payments are above their WTP/ATP. Low participation, especially in the initial years, will negatively affect the revenue stream of a minigrid (this is reflected in the analysis in Box 44 and Box 46 with lower energy consumption in the first 5-10 years as the system can potentially deliver)

(c/d 55% grant funding.

The LCOE is USD 0.371 per kWh. If a 55% investment grant is provided, the monthly payment of lower-income households (75% of the population in the minigrid-served area) drops to USD 3.12-4.45 per month (tariff at USD 0.394-0.497/kWh, giving a project IRR of 9-15%). This is more within the range of ATP/WTP.

A micro-hydro mini-grid or portfolio of sites is highly dependent on the characteristics of the site(s) and community (or communities) in question and should be taken only after a detailed assessment combining technical and socio-economic analysis, taking into consideration the location (including site characteristics and hydrology), the initial and anticipated future load, the number of larger consumers and, customer ability to pay and expectations for the level.

As, in case 1, we look at debt financing options for the 60 kW solar minigrid system (the corresponding analysis for the 16 kW hydropower minigrid would give quite similar results and is not presented here). The first case is a straight commercial venture with no grant, equity of 30% and 70% bank loan. Such a venture would not be successful. The high tariffs needed (USD 0.993 per kWh on average) would shy away customers (that would consume less or cancel their connection, thus diminishing revenues and leading to negative results). At the prevailing high interest of bank lending (28% is assumed here), the annual repayment would lead to a negative cash balance for several years, thus forcing the mini-grid operator to charge even higher tariffs or stop operations. Minigrids cannot be purely commercial ventures. With a 55% grant on CAPEX and a soft loan, the minigrid operation would have positive, acceptable results. Box 47 shows the financial situation assuming a soft bank loan covering 25% of CAPEX (at an interest rate of 12%). The LCOE of case 2 (60 kW minigrid), USD 0.661/kWh is smaller than case 1 (40 kW), USD 0.719/kWh due to economies of scale effects and the addition of small but substantial PUE (a small mill). In case 2, without the addition of the small mill as PUE, the initial investment in solar capacity would be somewhat smaller (USD 255,000 instead of USD 259,000) than in case 1, but its LCOE would be higher (USD 0.696/kWh) The calculations confirm the arguments presented in the Box 17) that PUE additions (outside peak demand time) help to increase the load utilisation factor resulting in LCOEs.

The business case presented is of a small minigrid with PUE (60 kW solar PV minigrid or 16 kW hydropower mini-grid) with a 55% investment subsidy, which would allow a small profit margin for the developer and affordable end-user tariffs (in the range of ATP/WTP of lower-income households). For developers that are not able to provide 45% of financing with equity (their own or third-party), **debt financing (with soft loans)** would be needed

Box 46 16 kW hydropower minigrid CAPEX, OPEX and LCOE with and without grant support

Hydropower generation			
Size		**16**	kW
Economic lifetime		20	yrs
Max production		126,538	
Load utilization		51%	
Demand		64,502	kWh/yr
Total cost, hydropower generation		105,114	USD
O&M, insurance		6.0%	
Distribution and wiring system			
Unit cost		8,000	USD
Length LV distribution system		7.2	km
Unit cost		15,000	USD/km
Length MV lines		0	km
Subtotal cost		57,280	USD
HH metering & wiring	USD/client 150	26850	
Total cost		84,130	
O&M cost		4.0%	
Transport, customs and logistics	15%	28,387	USD
Overhaul (year 16)	50%	52557	
Lifecycle cost per unit of kWh			
Discount rate		9%	
Investment cost per kW		13560	
Investment, hydropower minigrid		**217,631**	USD
Annualised cost of investment		23,841	USD/yr
Operation and maintenance (O&M)		9,672	USD/yr
Total annual cost		**33,513**	
LCOE, hydropower mini-grid		*0.624*	*USD/kWh*
Capital subsidy		55%	
Grant support		**119,697**	
Discount rate		9%	
Investment, hydropower minigrid		97,934	USD
Annualised cost of investment		10,728	USD/yr
Operation and maintenance (O&M)		9,672	USD/yr
Total annual cost		**20,400**	**USD**
LCOE, hydropower plant		*0.371*	*USD/kWh*

The table below gives the implications of different tariffs for the monthly payments of different household groups.

NO GRANT		**Monthly payment, no grant**		
TARIFF LEVEL FOR NPV=0			USD	MWK
Tariff (USD/kWh)	0.6318	LL HH	5.01	5757
Benefits (Revenues - costs)		MM HH	25.48	29300
		HI HH	56.65	65152
NO GRANT + margin		**Monthly payment, no grant**		
TARIFF LEVEL FOR IRR=18%			USD	ZMW
Tariff (USD/kWh)	0.8608	LL HH	6.82	7844
Benefits (Revenues - costs)		MM HH	35.14	40415
		HI HH	77.19	88765
COSTS AFTER GRNAT	45%	**Monthly payment, grant 55%**		
TARIFF LEVEL FOR NPV=0			USD	ZMW
Tariff (USD/kWh)	0.3940	LL HH	3.12	3591
Benefits (Revenues - costs)		MM HH	15.50	17824
		Monthly payment, grai	35.33	40634
GRANT + profit margin	45%	**Monthly payment, grant+margin**		
TARIFF LEVEL FOR IRR=15%			USD	ZMW
Tariff (USD/kWh)	0.4968	LL HH	4.45	5119
Benefits (Revenues - costs)		MM HH	19.87	22854
		HI HH	50.37	57930

		Year 0	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Capital Cost	USD	**217,631**	0	0	0	0	0	0	0	0	0	0
O&M Cost	USD		9,672	9,672	9,672	9,672	9,672	9,672	9,672	9,672	9,672	9,672
Consumption MG (kWh/yr)			28,875	41,038	46,813	52,588	58,363	59,542	60,745	61,972	63,224	64,502
Consumption HH and small PUE			28,875	40,425	46,200	51,975	57,750	58,929	60,131	61,359	62,611	63,889
Consumption larger PUE			0	613.2	613.2	613.2	613.2	613.2	613.2	613.2	613.2	613.2
NO GRANT												
TARIFF LEVEL FOR NPV=0	Tariff 0.6318 USD/kWh		0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63
	Revenues MG USD million		18,244	25,929	29,578	33,226	36,875	37,620	38,380	39,155	39,946	40,753
Benefits (Revenues - costs)	Disc rate 9% NPV 0	-217,631	8,572	16,257	19,905	23,554	27,203	27,948	28,708	29,483	30,274	31,081
	IRR 9%											
NO GRANT + margin	0%											
TARIFF LEVEL FOR IRR=18%	Tariff 0.8608 USD/kWh		0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
	Revenues MG USD million		24,856	35,326	40,297	45,268	50,240	51,254	52,289	53,346	54,424	55,524
Benefits (Revenues - costs)	Disc rate 9% NPV 105,758	-217,631	15,184	25,654	30,625	35,596	40,568	41,582	42,617	43,674	44,752	45,852
	IRR 15%											
COSTS AFTER GRANT	45%											
TARIFF LEVEL FOR NPV=0	Tariff 0.3940 EUR/kWh		0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
	Revenues MG USD million		11,378	16,171	18,447	20,722	22,998	23,462	23,936	24,420	24,913	25,417
Benefits (Revenues - costs)	Disc rate 9% NPV 0	-97,934	1,706	6,499	8,775	11,050	13,326	13,790	14,264	14,748	15,241	15,745
	IRR 9%											
COSTS AFTER GRANT	45%											
TARIFF LEVEL FOR IRR=18%	Tariff 0.4968 USD/kWh		0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Revenues USD million		14,344	20,386	23,255	26,124	28,992	29,578	30,175	30,785	31,407	32,042
Benefits (Revenues - costs)	Disc rate 9% NPV 47,435	-97,934	4,672	10,714	13,583	16,452	19,320	19,906	20,503	21,113	21,735	22,370
	IRR 15%											

		Year 11	**Year 12**	**Year 13**	**Year 14**	**Year 15**	**Year 16**	**Year 17**	**Year 18**	**Year 19**	**Year 20**
Capital Cost	USD	0	0	0	0	0	52,557	0	0	0	0
O&M Cost	USD	9,672	9,672	9,672	9,672	9,672	9,672	9,672	9,672	9,672	9,672
Consumption MG (kWh/yr)		64,502	64,502	64,502	64,502	64,502	64,502	64,502	64,502	64,502	64,502
Consumption HH and small PUE		63,889	63,889	63,889	63,889	63,889	63,889	63,889	63,889	63,889	63,889
Consumption larger PUE		613.2	613.2	613.2	613.2	613	613	613	613	613	613
NO GRANT											
TARIFF LEVEL FOR NPV=0	Tariff 0.6318 USD/kWh	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63
	Revenues MG USD million	40,753	40,753	40,753	40,753	40,753	40,753	40,753	40,753	40,753	40,753
Benefits (Revenues - costs)	Disc rate 9% NPV 0	31,081	31,081	31,081	31,081	31,081	31,081	-21,476	31,081	31,081	31,081
	IRR 9%										
NO GRANT + margin	0%										
TARIFF LEVEL FOR IRR=18%	Tariff 0.8608 USD/kWh	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
	Revenues MG USD million	55,524	55,524	55,524	55,524	55,524	55,524	55,524	55,524	55,524	55,524
Benefits (Revenues - costs)	Disc rate 9% NPV 105,758	45,852	45,852	45,852	45,852	45,852	45,852	-6,705	45,852	45,852	45,852
	IRR 15%										
COSTS AFTER GRANT	45%										
TARIFF LEVEL FOR NPV=0	Tariff 0.3940 EUR/kWh	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
	Revenues MG USD million	25,417	25,417	25,417	25,417	25,417	25,417	25,417	25,417	25,417	25,417
Benefits (Revenues - costs)	Disc rate 9% NPV 0	15,745	15,745	15,745	15,745	15,745	15,745	-36,812	15,745	15,745	15,745
	IRR 9%										
COSTS AFTER GRANT	45%										
TARIFF LEVEL FOR IRR=18%	Tariff 0.4968 USD/kWh	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Revenues USD million	32,042	32,042	32,042	32,042	32,042	32,042	32,042	32,042	32,042	32,042
Benefits (Revenues - costs)	Disc rate 9% NPV 47,435	22,370	22,370	22,370	22,370	22,370	22,370	-30,187	22,370	22,370	22,370
	IRR 15%										

Box 47 60 kW solar PV minigrid financial indicators (case 2)

Without grant support, high tariff and 70% commercial debt financing

Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cashflow projections (pre-financing)																						
Capital expenditures		-258																				
Earnings EBITDA		-258	20	32	38	43	49	50	51	53	54	12	55	55	55	55	55	55	37	55	55	55
pre-tax NPV	126																					
IRR	15%																					
payback (yrs)	6.5																					
Depreciation			-17	-17	-17	-17	-17	-17	-17	-17	-17	-17	-17	-17	-17	-17	-17	0	0	0	0	0
Earnings EBIT (before interest and tax)			2	15	20	26	32	33	34	35	37	-5	38	38	38	38	38	55	37	55	55	55
Cost of finance				-43	-39	-35	-28	-21	-12	0	0	0	0	0	0	0	0	0	0	0	0	0
Earnings before taxes			2	-29	-19	-8	3	12	23	35	37	-5	38	38	38	38	38	55	37	55	55	55
Tax			0	0	0	0	-1	-2	-3	-5	-5	0	-6	-6	-6	-6	-6	-8	-6	-8	-8	-8
Net income			2	-29	-19	-8	3	10	19	30	31	-5	32	32	32	32	32	47	32	47	47	47
Plus:																						
Depreciation and interest			17	61	57	52	46	38	29	17	17	17	17	17	17	17	17	0	0	0	0	0
Cash flow (after tax)		-258	19	32	38	43	49	48	48	47	48	12	49	49	49	49	49	47	32	47	47	47
IRR	12.7%																					

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Financing activities																					
Equity and grant	77																				
Soft loan	0			0	0	0	0	0	0	0	0										
Bank loan	181		-60	-60	-60	-60	-60	-60		0											
Change in cash	0	19	-28	-22	-17	-11	-11	-12	47	48	12	49	49	49	49	49	47	32	47	47	47
Cumulative cash balance	0	19	-9	-31	-48	-59	-70	-82	-35	13	25	75	124	174	223	272	319	351	398	444	491

Financing requirement

	Amount (USD 000)	Annual repayment	Share	Interest	Grace period	Repay period
Grant	0		0.0%			
Equity	77		30.0%			
Soft loan	0	0.00	0.0%	12.0%	2	8
Local loan	181	-59.84	70.0%	24.0%	1	6

Corporate tax rate	15%	
Minigrid power tariff	0.993	$/kWh

With 55% CAPEX grant support and soft loan

Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cashflow projections (pre-financing)																						
Capital expenditures		-116																				
Earnings EBITDA		-116	7	14	17	21	24	24	25	26	27	-16	27	27	27	27	27	27	9	27	27	27
pre-tax NPV	57																					
IRR	15.0%																					
payback (yrs)	6																					
Depreciation			-8	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8	0	0	0	0	0
Earnings EBIT (before interest and tax)			-1	6	10	13	16	17	17	18	19	-24	20	20	20	20	20	27	9	27	27	27
Cost of finance				0	-8	-7	-6	-6	-5	-4	-3	-1	0	0	0	0	0	0	0	0	0	0
Earnings before taxes			-1	6	2	6	10	11	13	14	16	-25	20	20	20	20	20	27	9	27	27	27
Tax			0	-1	0	-1	-1	-2	-2	-2	-2	0	-3	-3	-3	-3	-3	-4	-1	-4	-4	-4
Net income			-1	5	2	5	8	9	11	12	14	-25	17	17	17	17	17	23	8	23	23	23
Plus:																						
Depreciation and interest			8	8	15	15	14	13	12	11	10	9	8	8	8	8	8	0	0	0	0	0
Cash flow (after tax)		-116	7	13	17	20	22	23	23	24	24	-16	24	24	24	24	24	23	8	23	23	23
IRR	13.8%																					

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Financing activities																					
Equity	52																				
Soft loan	65			-13	-13	-13	-13	-13	-13	-13	-13	0	0	0	0	0	0	0	0	0	0
Bank loan	0		0	0	0	0	0	0	0	0											
Change in cash	0	7	13	4	7	9	10	10	11	11	-29	24	24	24	24	24	23	8	23	23	23
Cumulative cash balance	0	7	20	24	31	40	50	61	71	82	53	78	102	126	151	175	198	206	229	252	276

Financing requirement

	Amount (USD 000)	Annual repayment	Share	Interest	Grace period	Repay period
Grant	142		55.0%			
Equity	52		20.0%			
Soft loan	65	-12.99	25.0%	12.0%	2	8
Local loan	0	0.00	0.0%	24.0%	1	6

Corporate tax rate	15%	
Minigrid power tariff	0.562	$/kWh

Comparison with notional diesel minigrid

An interesting exercise is a comparison with a notional minigrid powered by a 15 kW diesel generator to provide electricity to the village of Case 2 (see Box 48). At current diesel prices (about USD 1.5/litre in main cities and higher in remote areas), the LCOE would be USD 0.69/kWh, somewhat higher even than the non-subsidised equivalent hydropower (16 kW) or solar PV minigrid (60 kW) of USD 0.624-0.661/kWh respectively. To this can be added, that diesel supply to remote areas can be unreliable, so a 100% renewable energy minigrid can compete with a diesel-powered mini-grid, at least, in the above-sketched examples.

2.4 Case 3: electric cooking and minigrids

Many microgrid customers still rely on costly, time-intensive and unsafe biomass fuels to cook daily meals. Electric cooking is often perceived to be prohibitively expensive given the high tariff rates charged by most minigrids or will drain the minigrid beyond its peak power capacity. Electric pressure cookers (EPC) have the potential to change this paradigm and offer a unique opportunity for customers to use minigrid electricity, thereby boosting the sales of power. With more revenue from customers, the grid operator can hereby slightly lower power tariffs.

Box 48 Diesel minigrid financial indicators

Diesel generator MHP			
Economic life		15	
Size		15.00	kW
Load utilization factor		49%	
Investment		4,800	
Generator efficiency		34%	
Electricity demand		65	MWh/yr
Diesel consumption		19,739	litre
Price of diesel (cities)		1.5	USD/litre
Price of diesel (remote area)		1.65	USD/litre
Capital cost, diesel		4,800	USD
Preparation and infrastructure		900	USD
Cost diesel generator		*5,700*	*USD*
Distribution and wiring		*84,130*	
Transport and logistics		*4,492*	USD
Total cost diesel mini-grid		**94,322**	
Diesel cost		32,569	USD/yr
O&M	10%	480	USD/yr
Annualised capital cost		11,701	USD/yr
Total annual cost		44,750	USD/yr
LCOE		*0.69*	*USD/kWh*
Avoided GHG emissions per village			
CO_2 content, diesel		2.8	$kgCO_2$/litre
Avoided GHG emission		55.27	tCO2/yr

The Business case looks at the same village as in Case 2 with 160 households and some small PUE (179 clients in total) but adds the use of a HE (high-efficiency) cooker by 10% of the clients (for an average 2 hours a day). The case assumes that an 850 W HE cooker is used by 1/3 of the middle-income households (25% of households) and a 1 kW HE cooker by the high-income households (5% of households) plus the local restaurant/bar. The figures are average, so can also be interpreted as meaning that more households use the cooker for 1 hour a day. There are many parameters to vary in the model, such as the number of households participating, hour of the day (coinciding or not with peak load), impact of the total system peak load and day/night use. Energy consumption in the grid system will increase (in comparison with the case without HE cooking, see section 2.4 and details of assumption in the *Appendix*, section 2.10). Thus, somewhat larger solar PV (and battery capacity) will be needed to accommodate this additional energy demand. However, with electric cooking limited to 10% of the clients and with appropriate demand-side management (assuming that peak demand hardly increases if e-cooking is done outside mean peak consumption time) the needed expansion of the PV system remains limited and may not be needed in the case of the hydropower. A much larger increase use of e-cooking by households will imply not only a higher energy consumption but also an increase in the peak power demand of the system (as not all cooking will be outside peak hours or if the cooking creates a power demand higher than the peaks without e-cooking). This would require an expansion of solar PV or hydropower installed capacity. Indicators of the case are presented in Box 50.

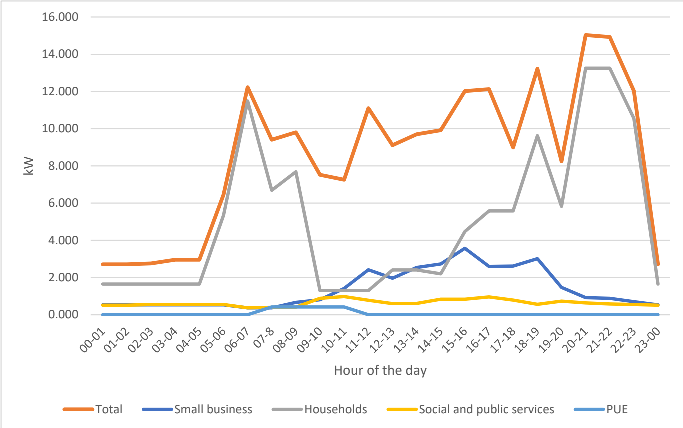
Box 49 Average household expenditure, solar minigrid with limited e-cooking

NO GRANT + IRR=15%		
Tariff (USD/kWh)	0.9039	
With electric cooking		
	USD	MWK
LL HH	53.90	24362
MM HH	78.72	90524
HI HH	138.68	159484
Without electric cooking		
	USD	MWK
LL HH	7.16	8237
MM HH	31.98	36772
HI HH	83.69	96247
COST with GRANT 45% + IRR=15%		
Tariff (USD/kWh)	0.5133	
With electric cooking		
	USD	MWK
LL HH	30.61	13834
MM HH	44.70	51405
HI HH	78.75	90565
Without electric cooking		
	USD	MWK
LL HH	4.07	4677
MM HH	18.16	20882
HI HH	47.53	54655

On a household level, the impact of electric cooking on household expenditures would be dramatic. Even in the case of investment subsidy (55%, and assuming a margin for the developer, IRR=15%), a lower-income household would see its monthly electricity bill jump from USD 4.07 to USD 30.61, probably not realistic (compare with the experiences of e-cooking trial in Mulanje, see Box 19). Hence, it is assumed in Case 3 that lower-income households will not cook electrically and the 10% of households that do cook electrically are limited to the higher-income households and some of the middle-income households. Even for middle-income and higher-income households the monthly expenditure would significantly increase; in Case 3, from USD 18.16 to USD 44.7 (MI HH) and from USD 47.53 to USD 78.75 (HI HH). In conclusion, unless a rural household currently already buys fuels for cooking (roadside firewood or charcoal purchase instead of free wood collection), electric cooking will imply a substantial increase in expenditures. To this cost, the purchase price of a HE cooker (around USD 110) must be added. In reality, a household will probably start with stacking of fuels (a combination of using firewood, charcoal, electric cooking) rather than shift 100% to a more expensive cooking method.

Box 50 Impact of 10% electric cooking on energy demand and load curve of a small-sized minigrid (case 3)

Consumer group		Number	Total daily demand (kWh) (Year 10)	Peak power demand (kW)
Households (with electric cooking)	Subtotal	160	125.15	13.25
	75%	120	31.26	
	20%	32	53.54	
	5%	8	40.35	
Salon/barber		2	7.82	2.34
Shops		6	15.16	
Community/worship		2	1.83	0.54
Office		1	1.43	
Clinic	Small	1	8.79	0.45
School	Small	1	3.21	0.27
Bar/restaurant		2	9.75	1.45
Utilities		1	19.60	3.00
Small maize mill		1	10.39	2.59
Workshop		1	7.22	1.15
Total		*18*	*85.20*	
Larger PUE		*1*	*1.68*	*0.42*
Total (rounded)		**179**	**212.03**	**16.00**



Hydropower generation		**Solar PV generation**	
Size	**17** kW	Size	**72** kW
Economic lifetime	20 yrs	Economic lifetime	20 yr
Max production	134,974	Demand	77,391 kWh/yr
Load utilization	57%	Max production	77,728 kWh/yr
Demand	77,391 kWh/yr	Total cost, solar PV	160,543 USD
Total cost, hydropower generation	106,880 USD	O&M, insurance	4.0%
O&M, insurance	6.0%	Replacement batteries (after 10 yrs)	51,840 USD
Distribution and wiring system		**Distribution and wiring system**	
Unit cost	8,000 USD	Unit cost	8,000 USD
Length LV distribution system	7.2 km	Length LV distribution system	7.2 km
Unit cost	15,000 USD/km	Unit cost	15,000 USD
Length MV lines	0 km	Length MV lines	0.0 km
Subtotal cost	57,280 USD	Subtotal cost	57,280 USD
HH metering & wiring USD/client 150	26850	HH metering & wiring USD/client 150	26850 USD
Total cost	84,130	Total cost	84,130 USD
O&M cost	4.0%	O&M, insurance	4.0%
Transport, customs and logistics 15%	28,652 USD	**Transport, customs and logistics** 15%	36,701 USD
Overhaul (year 16) 50%	53440		
Lifecycle cost per unit of kWh		**Lifecycle cost per unit of kWh**	
Discount rate	9%	Discount rate	9%
Investment cost per kW	12831	Investment cost per kW	3908 USD/kW
Investment, hydropower minigrid	**219,662** USD	**Investment, solar mini-grid**	**281,374 USD**
Annualised cost of investment	24,063 USD/yr	Annualised cost of investment	36,502 USD/yr
Operation and maintenance (O&M)	9,778 USD/yr	Operation and maintenance (O&M)	9,787 USD/yr
Total annual cost	**33,841**	**Total annual cost**	**46,289**
LCOE, hydropower mini-grid	*0.525 USD/kWh*	*LCOE, solar PV mini-grid*	*0.603 USD/kWh*
Capital subsidy	55%	Capital subsidy	55%
Grant support	**120,814**	**Grant support**	**154,756** USD
Discount rate	9%	Discount rate	9%
Investment, hydropower minigrid	98,848 USD	**Investment, solar mini-grid**	126,618 USD
Annualised cost of investment	10,828 USD/yr	Annualised cost of investment	19,549 USD/yr
Operation and maintenance (O&M)	9,778 USD/yr	Operation and maintenance (O&M)	9,787 USD/yr
Total annual cost	**20,606 USD**	**Total annual cost**	**29,336 USD/yr**
LCOE, hydropower plant	*0.313 USD/kWh*	*LCOE, solar PV*	*0.368 USD/kWh*

Base data, PV system			
PV system	72 kW	Unit cost	0.40 per Wp
Peak sun hours	4.25 per day	Solar panels	28,800 USD
System efficiency and degrad	0.92	Unit cost battery	100 USD/kWh
Sesasonal correction	1.15	Battery	51,840 USD
Degradation (oversizing factor)	1.15		518.4 kWh
Demand	77,391 kWh/yr	PV structures	7,200
Daily energy demand	212029 Wh/day	Unit cost inverters	360 USD/kVA
Max power demand	16000 VA	Inverter	19,200 USD
System requirements	4908 Ah/day	Cabling, protection, etc	5,500 USD
Battery needs (900 Ah@6V) - at 1.3 days storage DOD=.6	10634 Ah/day	Civil works, site	32,000 USD
Number of batteries	96	Protection, grounding, ect.	5,500 USD
Network	7.2 km	Spare parts	0
Network MV in locality	0 km	**Total cost**	**150,040 USD**
LV/MV substation (USD 6000 each)	0		
Inverter	53 kVA	Installation (at 7%)	10503
Voltage level	48 VDC	**Cost per kW**	**2,230 USD/kW**
Night time fraction	52%	Cost per customer	843 USD/kW
Usable energy	0.60		
Battery sizing factor	1.80		

Tariffs solar PV minigrid

NO GRANT + margin	
TARIFF LEVEL FOR IRR=15%	
Tariff (USD/kWh)	0.9039
COSTS AFTER GRANT	45%
TARIFF LEVEL FOR IRR=15%	
Tariff (USD/kWh)	0.5133

Tariffs hydropower MG

NO GRANT + margin	
TARIFF LEVEL FOR IRR=15%	
Tariff (USD/kWh)	0.7256
COSTS AFTER GRANT	
TARIFF LEVEL FOR IRR=15%	
Tariff (USD/kWh)	0.4172

2.5 Demand stimulation

Impact of demand stimulation

Demand stimulation has a positive effect on the system tariff, as indicated in Box 51 for the model village of 160 households (served by a 17 kW hydropower or 60 kW solar minigrid; Case 2). The columns on the right under each technology give the energy demand situation as in case 2 but without the demand of the small maize mill. The columns on the left present the situation in which a small maize mill is added (tus equal energy demand as described in Case 2) and electric cooking (in 10% of households and in one of the two bars). We assume the maize mill operation and electric cooking take place outside peak hours so that the max peak demand (16 kW) stays the same. Thus, the size of the mini-hydro facility stays the same, while a higher load utilization (51% instead of 45%), implies a LCOE which is 25% lower. In case of the solar PV, the capacity of the solar system needs to be expanded to capture the additional solar energy needed, but still, the better load utilisation implies its LCOE is lower (by 15%) as well. If such demand stimulation implies higher peak power demand, the impact on load utilisation will be less. The investment cost will increase, but better economies of scale will often imply a lower LCOE nonetheless.

Box 51 Impact of demand stimulation

	Micro hydro		Solar PV	
	w/ cook+mill	without	w/ cook+mill	without
LCOE (USD/kWh)	17 kW	17 kW	72 kW	57 kW
No grant	0.525	0.668	0.603	0.710
Grant 55%	0.313	0.398	0.368	0.432

Impact of adding e-cooking (in 10% of households) and with or without small maize mill (2.5 kW, case 2) to small minigrid systems

Profitability of small electric mill versus diesel-powered mill

An interesting question how profitable it is for the small mill owner to connect to the minigrid versus powering the facility with a diesel engine. Box 52 describes the case of a small mill powered by a diesel engine (3.5 HP) or an equivalent electric motor (2.5 kW) powered by minigrid electricity or an equivalent solar mill (stand-alone solar PV)

The example shows that the mill connected to the minigrid has comparable energy cost (assuming the minigrid, 60 kW solar or 16 kW hydro, receiving a 55% grant as described in Business Case 2). In this example, if the electricity costs more than USD 0.545 per kWh the mill would be more expensive to operate with electricity.

Even at higher energy costs, electric motor-driven mills can be preferable to diesel-driven mills because they can be easier to operate and more reliable. They require less maintenance, are easier to start, and have environmental benefits. They also never run out of fuel and reduce labour by removing the time and cost of travelling to purchase diesel fuel.

Many millers already have diesel-powered mills, and they may well decide to convert their

Box 52 Benefits and costs of milling service by diesel and electricity-powered small mill

Base data						
Amount milled (per hour)		90	kg per hour			
Average daily operation		4	hours/day			
Number of days operating		300	days / year			
Amount milled per year		108	ton maize milled/yr			
Energy data						
Size of the diesel		3.5	HP diesel			
Equivalent size of electr motor		2.5	kW electric mill			
Electr consumption per year		3000	kWh/yr			
Diesel consumption		0.747	liter per hour			
		896	liters per year			
Diesel price		1.65	USD per litre			
Diesel cost per year		1478	USD/yr			
Annual non-fuel O&M cost		156	O&M			
Total operating (fuel and non-fuel)		1634	Total cost			
Breakeven tariff diesel equivalence		0.545	USD/kWh			
Minigrid - See Case 2		*Hydro*	*PV*			
		16 kW	*60 kW*			
No grant MG		0.861	0.994	USD/kWh		
55% CAPE) Sub 55%		0.497	0.562	USD/kWh		
Cost-benefit small maize mill			w/ 55% CAPEX grant			
	Dedza	*Diesel*	*Solar MG*	*Hydro MG*	*Solar mill*	
Size engine'mill	*study*	*3.5 HP*	*2.5 kW*	*2.5 kW*	*2.5 kW*	
Useful life (yrs)		12	12	12	12	yrs
Investment cost mill		830	830	830	20000	USD
Service fee of the mill		0.05	0.05	0.05	0.05	$/kg maize
Service		5400	5400	5400	5400	USD/year
Energy		1634	1491	1686		USD/year
Non-fuel O&M	200-3600	936	936	936	936	USD/year
OPEX	400-7200	2570	2427	2622	936	USD/year
Annualized CAPEX		116	116	116	2793	USD/year
Revenue	350-9100	5400	5400	5400	5400	USD/year
Net revenue		2714	2857	2857	1671	USD/year

mill to electric motors rather than purchase a brand-new electric mill. However, there are a few challenges with retrofitting a mill for an electric motor. One example is that selecting an appropriate electric motor can be complex as it must conform to certain standards and specifications to avoid the risk of damaging the mill and potentially the mini-grid. In contrast, many electric mills have already been designed to meet certain technical, safety, and efficiency requirements. The example in the Box gives a rough indication only of profitability, which will highly depend on the cost (and availability) of diesel (in the case of the diesel mill), the actual minigrid tariff charged, and, ultimately, on the service fee charged by the mill (a charge USD 0.05 per kg of maize has been assumed here). The column on the right in the Box shows how the results of the analysis correspond with the findings of a study on maize milling in the Dezda area[42].

If a grid or mini-grid connection is not possible, solar mills are available (coming complete with solar panels, inverter, and AC motor). Currently, very few such mills have been installed due to high investment costs. In the example of the box, payback time would be over 10 years[43].

The profitability of a mill, diesel or electric, ultimately depends on the price of the grains, droughts and pests affecting food production and income generation, equipment breakdowns, and of course, the cost of electricity or fuel. The cost-benefit analysis in Box 52 shows the services-for-a-fee model, in which clients present the product to be milled. Another sales model is that the facility purchases (or produces) raw commodities such as maize kernels, milling them and selling them as flour.

2.6 Case 4: minigrids with anchor loads

The case describes the situation of a Case 2 type of minigrid with a large anchor load, such as a 20 kW coffee processing or 20 kW maize milling facility. In this case, the PUE has become the dominant energy use, assuming it is located in the same village as Case 2 (160 households). One has to be careful, though, with statements that large anchor loads will make the minigrids more feasible. This will depend on whether the load is operational throughout the year or only part of the year. For example, many agro-processing facilities will only work in or after the harvest period. Similarly, irrigation schemes will on have an energy demand during certain months of the year.

The case of the 20 kW maize mill anchor load is presented in Box 53. In comparison with Case 2, the tariffs calculated are lower than the tariffs charged in the equivalent minigrids without the 20 kW anchor load. However, the effect is limited somewhat by the annual operational days of the maize mill, which is assumed to be 300 days (out of 365 maximum). This affects the revenue stream and thus tariffs have to be somewhat higher than the case in which the anchor load is operational for the full year. The impact is more pronounced in the case of the solar minigrid (favoured by a higher relative proportion of demand during the day when the sun shines). With the anchor load, the LCOE of even a 100% unsubsidised hydro or solar minigrid becomes comparable with that of a diesel-fueled minigrid, hovering around USD 0.50-0.55 per kWh.

With a slightly better economy of scale, rather than lower tariffs, another consideration is lowering the CAPEX subsidy level. The calculations presented in the table of the Box assume a slightly lower CAPEX investment grant for the minigrid (50% in comparison with 55% in Case 2).

Box 54 gives the case of another anchor load, that of a 30 kW coffee processing facility[44]. However, the facility operates operates only part of the year (200 days). This implies that in the remaining days of the year, most of the mini-grid's power capacity will be idle and relatively low revenue streams. Thus, the facility will not have the same economies of scale advantage as the case with the large maize mill (operating 300 days a year). In this case, a hybrid diesel-mini grid facility would be recommended, in particular, in the case of the solar minigrid. The use of software, such as Homer, will help to find the exact configuration.

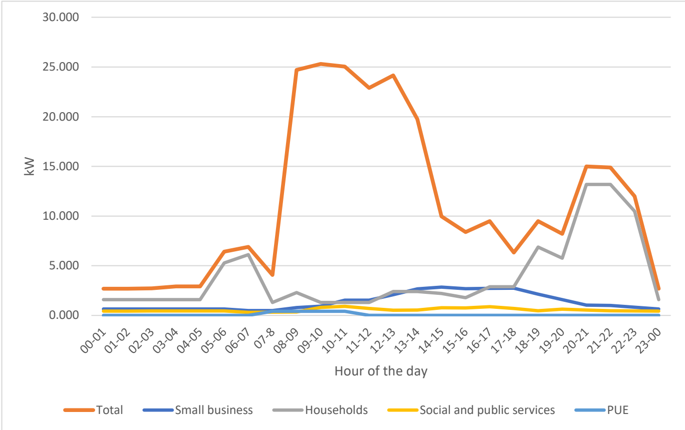
42 *Productive Use of Solar PV in Rural Malawi: Feasibility Studies*, University of Strathclyde/CEM (2017)

43 Based on info in the above-mentioned study; 1.1 kW solar mill, USD USD 8860, 7.5 kW solar mill, USD 29,100

44 The machinery will process about 290 kg per hour. An area of 202 hectares can produce 283 tons per year. Processing operations are 120 days in a year or 2.36 tons a day.

Box 53 Case 4, minigrid with large anchor load (20 kW maize mill, 300 days/yr)

Power rating (W)	Number per end-user	Total power (W)	Daily usage (hrs)	Daily demand (kWh/HH)	Power demand kW
10	2	20	12	0.240	0.02
4	6	24	6	0.14	0.02
75	4	300	6	1.80	0.30
20000	1	20000	5	100.00	20.00
5	2	10	2	0.02	0.01
				102.204	**20.35**



Diesel generator MHP		
Economic life	15	
Size	26.00	kW
Load utilization factor	0%	
Investment	4,800	
Generator efficiency	34%	
Electricity demand	91	MWh/yr
Diesel consumption	27,961	litre
Price of diesel (cities)	1.5	USD/litre
Price of diesel (remote area)	1.65	USD/litre
Capital cost, diesel	4,800	USD
Preparation and infrastructure	1,560	USD
Cost diesel generator	*6,360*	*USD*
Distribution and wiring	*84,130*	
Transport and logistics	*4,525*	USD
Total cost diesel mini-grid	**95,015**	
Diesel cost	46,136	USD/yr
O&M 10%	480	USD/yr
Annualised capital cost	3,708	USD/yr
Total annual cost	50,325	USD/yr
LCOE	*0.55*	*USD/kWh*
Avoided GHG emissions per village		
CO_2 content, diesel	2.8	$kgCO_2$/litre
Avoided GHG emission	78.29	tCO2/yr

Tariff solar minigrid	*Anchor 55% grant*	*Without anchor (case 2)*	*Anchor 50% grant*
NO GRANT + margin			
TARIFF LEVEL FOR IRR=15%			
Tariff (USD/kWh)	0.8003	0.9935	0.8003
COSTS AFTER GRANT	45.00%	45.00%	50.00%
TARIFF LEVEL FOR IRR=15%			
Tariff (USD/kWh)	0.4512	0.5618	0.4834

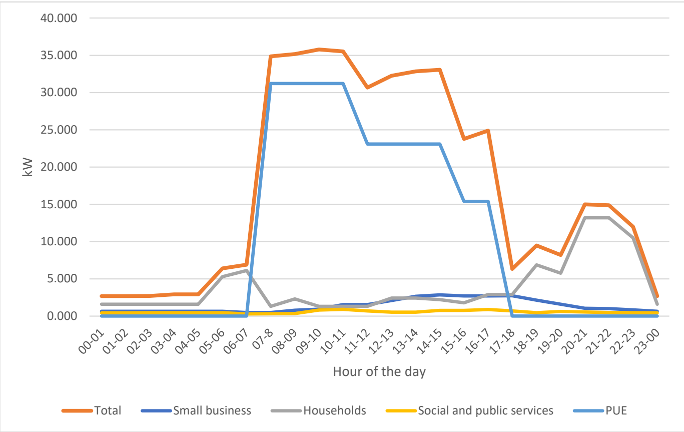
Tariff hydropower minigrid			
NO GRANT + margin			
TARIFF LEVEL FOR IRR=18%			
Tariff (USD/kWh)	0.7870	0.8608	0.7870
GRANT + profit margin	45%	45%	50.00%
TARIFF LEVEL FOR IRR=15%			
Tariff (USD/kWh)	0.4554	0.4968	0.4869

Hydropower generation			
Size		**28**	kW
Economic lifetime		20	yrs
Max production		219,333	
Load utilization		45%	
Demand		98,015	kWh/yr
Total cost, hydropower generation		161,692	USD
O&M, insurance		6.0%	
Distribution and wiring system			
Unit cost		8,000	USD
Length LV distribution system		7.2	km
Unit cost		15,000	USD/km
Length MV lines		0	km
Subtotal cost		57,280	USD
HH metering & wiring	USD/client 150	26850	
Total cost		84,130	
O&M cost		4.0%	
Transport, customs and logistics	15%	36,873	USD
Overhaul (year 16)	50%	80846.14	
Lifecycle cost per unit of kWh			
Discount rate		9%	
Investment cost per kW		10162	
Investment, hydropower minigrid		**282,696**	USD
Annualised cost of investment		30,968	USD/yr
Operation and maintenance (O&M)		13,067	USD/yr
Total annual cost		**44,035**	
LCOE, hydropower mini-grid		*0.567*	*USD/kWh*
Capital subsidy		55%	
Grant support		**155,483**	
Discount rate		9%	
Investment, hydropower minigrid		127,213	USD
Annualised cost of investment		13,936	USD/yr
Operation and maintenance (O&M)		13,067	USD/yr
Total annual cost		**27,002**	**USD**
LCOE, hydropower plant		*0.340*	*USD/kWh*

Solar PV generation			
Size		**91**	kW
Economic lifetime		20	yr
Demand		98,015	kWh/yr
Max production		98,239	kWh/yr
Total cost, solar PV		177,513	USD
O&M, insurance		4.0%	
Replacement batteries (after 10 yrs)		43,200	USD
Distribution and wiring system			
Unit cost		8,000	USD
Length LV distribution system		7.2	km
Unit cost		15,000	USD
Length MV lines		0.0	km
Subtotal cost		57,280	USD
HH metering & wiring	USD/client 150	26850	USD
Total cost		84,130	USD
O&M, insurance		4.0%	
Transport, customs and logistics	15%	39,246	USD
Lifecycle cost per unit of kWh			
Discount rate		9%	
Investment cost per kW		3306	USD/kW
Investment, solar mini-grid		**300,889**	**USD**
Annualised cost of investment		37,694	USD/yr
Operation and maintenance (O&M)		10,466	USD/yr
Total annual cost		**48,160**	
LCOE, solar PV mini-grid		*0.533*	*USD/kWh*
Capital subsidy		55%	
Grant support		**165,489**	USD
Discount rate		9%	
Investment, solar mini-grid		135,400	USD
Annualised cost of investment		19,565	USD/yr
Operation and maintenance (O&M)		10,466	USD/yr
Total annual cost		**30,031**	**USD/yr**
LCOE, solar PV		*0.324*	*USD/kWh*

Box 54 Case 4, minigrid with large anchor load (30 kW coffee processing, 210 days/yr)

Coffee processing	Power rating (W)	Number per end-user	Total power (W)	Daily usage (hrs)	Daily demand (kWh/HH)	Power demand kW
Coffee washing/refining						
Huller, Peeler	30100	1	30100.0	8	240.80	30.100
Lights, computer	700	1	700.0	8	5.60	0.700
Outdoor light	10	1	10	12	0.12	0.010
Total					246.52	



Diesel generator MHP		
Economic life	15	
Size	36.00	kW
Load utilization factor	0%	
Investment	4,800	
Generator efficiency	34%	
Electricity demand	94	MWh/yr
Diesel consumption	28,787	litre
Price of diesel (cities)	1.5	USD/litre
Price of diesel (remote area)	1.65	USD/litre
Capital cost, diesel	4,800	USD
Preparation and infrastructure	2,160	USD
Cost diesel generator	*6,960*	*USD*
Distribution and wiring	*84,600*	
Transport and logistics	*4,578*	USD
Total cost diesel mini-grid	**96,138**	
Diesel cost	47,499	USD/yr
O&M 10%	480	USD/yr
Annualised capital cost	1,483	USD/yr
Total annual cost	49,462	USD/yr
LCOE	*0.53*	*USD/kWh*
Avoided GHG emissions per village		
CO_2 content, diesel	2.8	$kgCO_2$/litre
Avoided GHG emission	80.60	tCO2/yr

Tariff solar minigrid

	Anchor 55% grant	*Without anchor (case 2)*
NO GRANT + margin		
TARIFF LEVEL FOR IRR=15%		
Tariff (USD/kWh)	0.9002	0.9935
COSTS AFTER GRANT	45.00%	45.00%
TARIFF LEVEL FOR IRR=15%		
Tariff (USD/kWh)	0.5072	0.5618

Tariff hydropower minigrid

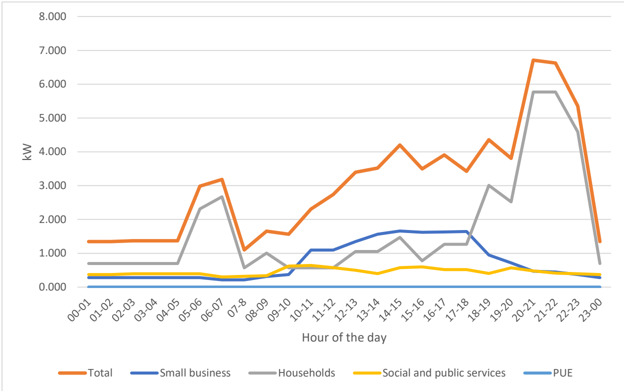
NO GRANT + margin		
TARIFF LEVEL FOR IRR=18%		
Tariff (USD/kWh)	0.9170	0.8608
GRANT + profit margin	45%	45%
TARIFF LEVEL FOR IRR=15%		
Tariff (USD/kWh)	0.5377	0.4968

Hydropower generation		**Solar PV generation**	
Size	**39** kW	Size	**144** kW
Economic lifetime	20 yrs	Economic lifetime	20 yr
Max production	303,692	Demand	154,438 kWh/yr
Load utilization	51%	Max production	155,456 kWh/yr
Demand	154,438 kWh/yr	Total cost, solar PV	218,708 USD
Total cost, hydropower generation	210,420 USD	O&M, insurance	4.0%
O&M, insurance	6.0%	Replacement batteries (after 10 yrs)	43,200 USD
Distribution and wiring system		**Distribution and wiring system**	
Unit cost	8,000 USD	Unit cost	8,000 USD
Length LV distribution system	7.2 km	Length LV distribution system	7.2 km
Unit cost	15,000 USD/km	Unit cost	15,000 USD
Length MV lines	0 km	Length MV lines	0.0 km
Subtotal cost	57,600 USD	Subtotal cost	57,600 USD
HH metering & wiring USD/client 150	27000	HH metering & wiring USD/client 150	27000 USD
Total cost	84,600	Total cost	84,600 USD
O&M cost	4.0%	O&M, insurance	4.0%
Transport, customs and logistics 15%	44,253 USD	**Transport, customs and logistics** 15%	45,496 USD
Overhaul (year 16) 50%	105210.04		
Lifecycle cost per unit of kWh		**Lifecycle cost per unit of kWh**	
Discount rate	9%	Discount rate	9%
Investment cost per kW	8808	Investment cost per kW	2422 USD/kW
Investment, hydropower minigrid	**339,273** USD	**Investment, solar mini-grid**	**348,804 USD**
Annualised cost of investment	37,166 USD/yr	Annualised cost of investment	42,943 USD/yr
Operation and maintenance (O&M)	16,009 USD/yr	Operation and maintenance (O&M)	12,132 USD/yr
Total annual cost	**53,175**	**Total annual cost**	**55,075**
LCOE, hydropower mini-grid	*0.665 USD/kWh*	*LCOE, solar PV mini-grid*	*0.600 USD/kWh*
Capital subsidy	55%	Capital subsidy	55%
Grant support	**186,600**	**Grant support**	**191,842** USD
Discount rate	9%	Discount rate	9%
Investment, hydropower minigrid	152,673 USD	**Investment, solar mini-grid**	156,962 USD
Annualised cost of investment	16,725 USD/yr	Annualised cost of investment	21,927 USD/yr
Operation and maintenance (O&M)	16,009 USD/yr	Operation and maintenance (O&M)	12,132 USD/yr
Total annual cost	**32,734 USD**	**Total annual cost**	**34,059 USD/yr**
LCOE, hydropower plant	*0.400 USD/kWh*	*LCOE, solar PV*	*0.364 USD/kWh*

2.7 Case 5: solar minigrid 24 kW

Box 55 Solar PV minigrid (24 kW) and equivalent hydropower minigrid

Consumer group		Number	Total daily demand (kWh) (Year 10)	Peak power demand (kW)
Households	*Subtotal*	*70*	*40.28*	*5.77*
	75%	53	13.68	
	20%	14	16.28	
	5%	4	10.32	
Salon/barber		2	7.82	1.41
Shops		2	5.05	
Community/worship		1	0.92	0.18
Office		0	0.00	
Clinic	Small	1	6.69	0.35
School	Small	1	3.21	0.27
Bar/restaurant		1	4.82	0.30
Utilities		1	3.00	0.50
Small maize mill			0.00	0.00
Workshop		0	0.00	0.00
Total		*9*	*31.51*	
Large PUE		*0*	*0.00*	*0.00*
Total (rounded)		**79**	**71.78**	**7.00**



Hydropower generation			**Solar PV generation**		
Size	7	kW	Size	**24**	kW
Economic lifetime	20	yrs	Economic lifetime	20	yr
Max production	59,051		Demand	26,201	kWh/yr
Load utilization	44%		Max production	26,603	kWh/yr
Demand	26,201	kWh/yr	Total cost, solar PV	72,760	USD
Total cost, hydropower generation	57,413	USD	O&M, insurance	4.0%	
O&M, insurance	6.0%		Replacement batteries (after 10 yrs)	21,600	USD
Distribution and wiring system			**Distribution and wiring system**		
Unit cost	8,000	USD	Unit cost	8,000	USD
Length LV distribution system	1.8	km	Length LV distribution system	1.8	km
Unit cost	15,000	USD/km	Unit cost	15,000	USD
Length MV lines	0	km	Length MV lines	0.0	km
Subtotal cost	14,400	USD	Subtotal cost	14,400	USD
HH metering & wiring USD/client 150	11850		HH metering & wiring USD/client 150	11850	USD
Total cost	26,250		Total cost	26,250	USD
O&M cost	4.0%		O&M, insurance	4.0%	
Transport, customs and logistics 15%	12,549	USD	**Transport, customs and logistics** 15%	14,852	USD
Overhaul (year 16) 50%	28706.275				
Lifecycle cost per unit of kWh			**Lifecycle cost per unit of kWh**		
Discount rate	9%		Discount rate	9%	
Investment cost per kW	12845		Investment cost per kW	4744	USD/kW
Investment, hydropower minigrid	**96,212**	USD	**Investment, solar mini-grid**	**113,862**	**USD**
Annualised cost of investment	10,540	USD/yr	Annualised cost of investment	14,839	USD/yr
Operation and maintenance (O&M)	4,495	USD/yr	Operation and maintenance (O&M)	3,960	USD/yr
Total annual cost	**15,034**		**Total annual cost**	**18,800**	
LCOE, hydropower mini-grid	*0.689*	*USD/kWh*	*LCOE, solar PV mini-grid*	*0.723*	*USD/kWh*
Capital subsidy	60%		Capital subsidy	60%	
Grant support	**57,727**		**Grant support**	**68,317**	USD
Discount rate	9%		Discount rate	9%	
Investment, hydropower minigrid	38,485	USD	**Investment, solar mini-grid**	45,545	USD
Annualised cost of investment	4,216	USD/yr	Annualised cost of investment	7,355	USD/yr
Operation and maintenance (O&M)	4,495	USD/yr	Operation and maintenance (O&M)	3,960	USD/yr
Total annual cost	**8,711**	**USD**	**Total annual cost**	**11,316**	**USD/yr**
LCOE, hydropower plant	*0.389*	*USD/kWh*	*LCOE, solar PV*	*0.416*	*USD/kWh*

Tariffs solar PV minigrid

NO GRANT		**Monthly payment**		
TARIFF LEVEL FOR NPV=0			USD	MWK
Tariff (USD/kWh)	0.7881	LL HH	6.24	7181
Benefits (Revenues - costs)		MM HH	27.88	32060
		HI HH	70.67	81268
NO GRANT + margin		**Monthly payment**		
TARIFF LEVEL FOR IRR=15%			USD	ZMW
Tariff (USD/kWh)	1.0834	LL HH	8.58	9872
Benefits (Revenues - costs)		MM HH	38.32	44072
		HI HH	97.14	111716
COSTS AFTER GRANT	40%	**Monthly payment**		
TARIFF LEVEL FOR NPV=0			USD	ZMW
Tariff (USD/kWh)	0.4539	LL HH	3.60	4136
Benefits (Revenues - costs)		MM HH	16.05	18463
		HI HH	40.70	46800
COSTS AFTER GRANT	40.00%	**Monthly payment**		
TARIFF LEVEL FOR IRR=15%			USD	ZMW
Tariff (USD/kWh)	0.7581	LL HH	6.01	6908
Benefits (Revenues - costs)		MM HH	26.82	30841
		HI HH	67.98	78177

Tariffs hydropower minigrid

NO GRANT		**Monthly payment, no subsidy**		
TARIFF LEVEL FOR NPV=0			USD	ZMW
Tariff (USD/kWh)	0.5858	LL HH	4.64	70
Benefits (Revenues - costs)		MM HH	27.88	418
		HI HH	52.53	788
GRANT REA/GEF 50%		**Monthly payment, grant = 50%**		
TARIFF LEVEL FOR IRR=18%			USD	ZMW
Tariff (USD/kWh)	0.7975	LL HH	6.32	95
Benefits (Revenues - costs)		MM HH	38.32	575
		HI HH	71.51	1073
GRANT REA/GEF 25%		**Monthly payment, grant = 50%**		
TARIFF LEVEL FOR NPV=0			USD	ZMW
Tariff (USD/kWh)	0.3462	LL HH	2.74	41
Benefits (Revenues - costs)		MM HH	16.05	241
		HI HH	31.04	466
GRANT REA + profit margin		**Monthly payment, business case**		
TARIFF LEVEL FOR IRR=18%			USD	ZMW
Tariff (USD/kWh)	0.4313	LL HH	6.01	90
Benefits (Revenues - costs)		MM HH	26.82	402
		HI HH	67.98	1020

2.8 Case 6: solar irrigation

Irrigation is the controlled application of water for agricultural purposes through man-made systems to supply water requirements not satisfied by rainfall. Crop irrigation means that farmers can grow crops when outside the rainy season, meaning they can extend the growing season and bring in a greater income. This case looks at the costs and benefits of smallholder irrigation with different pumping options (solar PV pumping and diesel pumping).

Number of farmers	10	
Maxium water need	162.7	m3/day
Dynamic head	24	meters
Efficiency	80%	
Working hours (peak)	5	hours/day
	13.26	kWh/day pea
Power	2.7	kW

Crop cultivation differs per type of farmer and per region. The case does not pretend to represent the situation of the average but serves to illustrate the profitability of irrigation and the feasibility of pumping options. For this case, a scheme is assumed in which 10 farmers cooperate to irrigate 0.6 acres of crop land. To determine the water pump size, it is necessary to estimate the total water needs of the different crops cultivated. The assumed dynamic head of the irrigation system is 24 metres (m). Each member irrigates 0.2 acres of maize (out of the 0.8 acres the farmer uses for maize cultivation), 0.1 acre of rice, 0.1 acres of sorghum, 0.1 acre of wheat and 0.1 acre of soybeans. The irrigation allows the members to plant these crops two times a year instead of one. All crops have an average growing time and the cropping density is set to normal spacing. The irrigation scheme is flooded through piped supply with an estimated total efficiency of 80%. During the rainy season, there is no irrigation need; the maximum daily water needed by the 10 farmers is highest in July (163 m^3/day). Considering the pump operates 5 hours/day, the size of the pump is roughly 2.7 kW.

Box 56 compares the cost of an electric pump (powered by a minigrid with the same size as described in Business Case 2) and an equivalent diesel pump and stand-alone solar pump. As expected, solar pumps require higher upfront investment while incurring the lowest operating costs. The levelized cost of energy (LCOE, annualised CAPEX and annual fuel and non-fuel cost) is also highest for solar PV pumping (but compares to that of diesel pumps in this example, if a 50% CAPEXC subsidy is provided). At an average tariff of USD 0.52 per kW (around which the tariff of the 60 kW solar and 16 kW hydropower minigrid hover) and assuming a 55% subsidy on the minigrid's investment cost), connecting to the minigrid has a slightly higher LCOE than employing a diesel pump.

The data are to give a rough indication of the profitability of farmers (from a village as described in Case 2) choosing to irrigate with pumps. The economic performance will depend on variables, such as plot size, water need of the crops cultivated, diesel price, tariffs charged in the minigrid or cost of solar pumps. A more detailed sensitivity analysis can shed more light on the viability and critical role of these variables in water pumping.

The purpose of irrigation-fed cultivation is to be able to sell more crops and generate more income. In this Business Case 6, a farmer's income from crops (increased crop sales minus cost of added inputs, such as fertilizer, and energy cost) is estimated to increase by one-and-a-half[45]. However, with the initial investment costs (CAPEX for the borehole and pump system) several times the annual income from rain-fed cultivation, it will be difficult for the average small-holding farmer to participate in the above-sketched irrigation system without having access to financing facilities that can provide loans at favourable conditions (in terms of collateral requirements, tenor and interest rate). For this reason, it is proposed in the RURED programme to include a soft loan scheme to enable farmers to acquire a (subsidised) solar water pump.

[45] This assums that the average from rain-fed crop cultivation is an average USD 160 per year (average plot isize is 1.35 hectare which produces crops for own consumption by the farmer's family and sales to the market. Additional income from irrigated plots is USD 189 per year in the example. The net benefits can be estimated by substracting the annual costs (annualized CAPEX minus fuel and non-fuel OPEX) from the net income, ranging between USD 24 (unsubsidized solar pump), to USD 83 (minigrid electricity at USD 0.525/kWh) to USD 95-105 (diesel pump and subsidized solar pump), i.e. an income increase of 15%, 52% and 59-66% respectively. Data on farmer's incomes are based on farm gate prices (see Ministry of Agricuklture for 2019-20 and 2020-23 and compared with income data from other sources, for example, EASE project surveys in Dedza area (see e.g. *Feasibility study for a solar PV microgrid in Malawi*. In: 2018 53rd International Universities Power Engineering Conference (UPEC). , *The impact of investment in smallholder irrigation schemes on irrigation expansion and crop productivity in Malawi* (in: African Journal of Agricultural and Resource Economics Volume 11 Number 2 pages 141-153); *Quiet Rise of Medium-sacle Farms in Malawi* (in: Land 2016, 5, 19; doi:10.3390/land5030019)

Box 56 Crop cultivation schedule and water need estimation

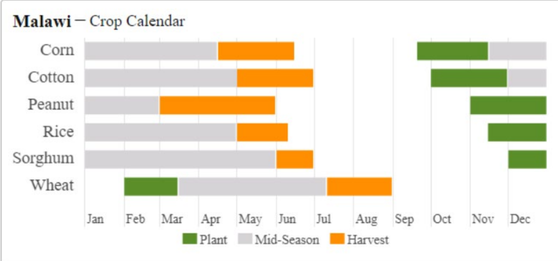
		J	F	M	A	M	J	J	A	S	O	N	D	
	Month	J	F	M	A	M	J	J	A	S	O	N	D	
	Daily mean temp (°C)	23	23	22	21	19	17	17	18	21	24	24	23	
	Rainfall (mm/month)	262	234	169	64	11	4	4	2	4	13	70	216	
	Eto (mm/month)	110	97	109	102	99	87	93	115	146	169	147	117	
Calculation water needs for irrigation														
Maize	ETcr	121	31	0	16	61	102	104	36	0	28	92	138	mm/month
	Irrigation need	0	0	0	0	100	196	200	68	0	30	44	0	mm/month
	0.2 acre	0.0	0.0	0.0	0.0	2.6	5.3	5.2	1.8	0.0	0.8	1.2	0.0	m3/day
Rice	ETcr	131	116	124	39	57	94	110	138	163	52	82	126	mm/month
	Irrigation need	0	0	0	0	92	180	212	272	318	78	24	0	mm/month
	0.1 acre	0.0	0.0	0.0	0.0	1.2	2.4	2.8	3.6	4.3	1.0	0.3	0.0	m3/day
Sorghum	ETcr	90	97	90	8	29	75	115	118	9	0	0	40	mm/month
	Irrigation need	0	0	0	0	36	142	222	232	10	0	0	0	mm/month
	0.1 acre	0.0	0.0	0.0	0.0	0.5	1.9	2.9	3.0	0.1	0.0	0.0	0.0	m3/day
Soybean	ETcr	111	109	24	0	22	62	107	75	0	0	0	53	mm/month
	Irrigation need	0	0	0	0	22	116	206	146	0	0	0	0	mm/month
	0.1	0.0	0.0	0.0	0.0	0.3	1.6	2.7	1.9	0.0	0.0	0.0	0.0	m3/day
Wheat	ETcr	126	99	24	0	37	91	107	113	24	0	53	121	mm/month
	Irrigation neeed	0	0	0	0	52	174	206	222	40	0	0	0	mm/month
	0.1 acre	0	0	0	0	0.7	2.3	2.7	2.9	0.5	0	0	0	m3/day
TOTAL NEED														
Irrigated	0.243 ha	0.0	0.0	0.0	0.0	5.2	13.5	16.3	13.2	5.0	1.8	1.5	0.0	m3/day
Energy	1385 kWh/yr	0	0	0	0	107	331	411	332	121	46	37	0	kWh/month
Water	1731 m3/yr													

Costs and revenues of 2.6 kW water pump fort irrigation

		Diesel pump		Solar pump No grant	Solar pump 50% subsidy		Minigrid 55% grant
Input data							
CAPEX (USD)		2300		10200	5100		1971
Period of analysis (yrs)		12		12	12		12
Energy need (kWh/yr)		1385		1385	1385		1385
Fuel equivalent		160	liter/yr				
Price		1.65	USD/liter	0	0	USD/kWh	0.52
Cost (USD/yr)		264					720
Estimation of costs of pumps							
Annualised CAPEX (USD/yr)		321		1424	712		275
Non-fuel O&M	10%	230	2%	204	204	2%	39.41
OPEX (fuel and non-fuel)		494		204			760
Total annual cost (USD/yr)		815		1628	916		1035
Cost (USD/m3)		0.471		0.941	0.529		0.598
Other cost (borehole, etc.)		2013		2013	2013		2013
Annualised other costs		221		221	221		221
Annualised other cost/farmer		22.1		22.1	22.1		22.1
Total costs of irrigation (USD/yr)							
Total annual irrigation scheme		837		1650	938		1057
Total annual cost per farmer		83.7		165.0	93.8		105.7
Benefits							
Additional income (USD/yr)		188.8		188.8	188.8		188.8
Net benefit after energy cost		105.0		23.7	95.0		83.1
Increase income from crops		66%		15%	59%		52%
Pump+borehole CAPEX (USD)		4313		12213	7113		3984
CAPEX per farmer (USD)		431		1221	711		398
Revenue-OPEX (USD/yr)		154		183	183		127
Payback period (yrs)		2.8		6.7	3.9		3.1

Source: analysis uis based on information from *Techno-economic feasibility of Energy Hubs located in rural communities in Malawi,* University of Strathclyde (2019), *Productive Use of Solar PV in Rural Malawi,* U. of Strathclyde/CEM (2017), farm gate prices (website, Ministry of Agriculture), *National Census Agriculture and Livestock* (2006/07), *Indentifying Investment Priorities for Malawian Agriculture,* by, Benfica, R. & Thurlow, J. (presentation, 2017). CAPEX and OPEX cost based on GET.Invest data (Solar PV pumping for small-scale irrigation schemes) and internet search on cost of pumps. Social discount rate is 9%.

The data on evapotranspiration (Eto) and crop evapotranspiration (ETCr) are obtained from https://aquastat.fao.org/climate-information-tool/ (for Central Region). The ETCr 9 [in mm.month] is related to ETo by applying a coefficient for each crop (ETcr=ETo.Kc). Irrigation need follows from (rainfall – ETCr)/IReff, where IReff is the efficiency of furrow irrigation (50%). By convention 1 mm/month equals 10 m³/hectare



Income from crop cultivation, average smallholder

	Average acreage	Production (kg/yr)	Sales Sold (kg/yr)	Sales USD/yr
Maize	0.8	670.5	125	62
Rice	0.1	103.3		
Groundnuts	0.15	71.6	64	51
Soybeans	0.2	70.0	64	51
Sorghum	0.1	43.1	30	24
Other				30
TOTAL	1.35			218
Costs				58
Income from crops				160

Income from additional irrigated crop cultivation

Production	Production kg/ha	Price MWK/kg	Price USD/kg	Irrigated fields Prod. (kg)	Irrigated fields Sales ($)
Maize	2071	500	0.498	167.6	83.4
Rice	2552.5	500	0.498	103.3	51.4
Sorghum	1065	400	0.398	43.1	17.2
Wheat	1060	550	0.547	42.9	23.5
Soybeans	865	800	0.796	35.0	27.9
		Total'(USD/yr)			203.3
		Extra costs (fertilizer, etc)			14.5
		Income from irrigation (USD/yr)			188.8

Average rural incomes are about USD 450-860/yr (2017/2021 data). A smallholder may earn USD 180-215 from crop cultivation. The smallholder family may combine with one or more from the following activities, livestock sales ($ 40/yr), tree crops ($ 30/yr, labour (USD 45), cottage enterprise (USD 145) or fisheries (USD 495). Tobacco cultivators may earn USD 500/yr. Sugarcane workers on average USD 65/yr. Data compiled from *The Quiet Rise of Medium-Scale Farms in Malawi,* Anseew, et.al. in: Land (2016, 5, 19); *Diversity of Sources of Income for Smallholder Farming Communities in Malawi: Importance for Improved Livelihood,* by Bhatti et.al., in: Sustainability 2021, 13, 9599.

2.9 Case 7: energy kiosk and service centres

In the Integrated Energy Plan (Electrification, 2021), minigrids provide 343,000 connections with 831,000 households to be provided stand-alone solar solutions (SAS). Solar service centres (or solar kiosks) form a suitable method when minigrids are not available and the commercial business models to disseminate SAS are not sufficient to reach poorer households. This section[46] describes the costs and benefits of setting up such a solar kiosk, either linked to the minigrid, to serve households that are too far or can otherwise not be connected to the minigrid, or as an independent facility to serve surrounding local communities.

The service centres can be operated as an extension of the minigrid operation or the service centre operates may enter a partnership with the minigrid managing entity, or the centre can operate in an area without minigrid (solar kiosk; powered by its own solar PV). The service centre/kiosk may be owned by the local community, social enterprise or private sector. The service centre owner may directly operate the service centre/kiosk or recruit a local entrepreneur (accountable to the community/owner) to act as a sole trader (who can retain part or all of the profits as agreed). The energy service centre/kiosk may act in partnership with one or more hardware suppliers and micro-finance providers or act in a facilitating role (see description in Box 32)

Box 57 Price of selected solar products sold in Malawi

		Price (USD)	PYAG price (USD)		
			Price	Period	interest
Portable products	Solar lantern	11			
Sun King	6W, 3 lamps +2USB	87			
Connect	6W, 4+lamps+radio+2 USB	141			
Zuwa Kw	10 W+4 lamps+torch+radio+3Ah batt	207	247	1.5 yr	19%
	Idem, 6 lamps	223	281	1.5 yr	26%
Solar home systems (with TV)					
Machreza	55 W+4 LED, `19"TV, USV+dec+12 Ah bat	622	777	1.5 yr	25%
Solar Works	40W+4 LED +24"TV	535	669	1.5 yr	25%
	50W+4 LED+36"TV	790	988	1.5 yr	25%
Larger solar PV systems	265 W+inverter+battery	915			
	idem, plus installation, service	1125	.		
	4*100 W+1kVA/12 V inv+200 Ah bat	1181			
	530 Wp	1772			
	idem, plus installation	1985			
	4*265 W panels +2KVA/24 V in+200 Ah	2270			

Based on https://solar-works.mw/solar-life
http://www.mphamvu-now.info/home-solar-systems/

Stand-alone PV systems (incl. installation, wiring)		
Size (kW)	265	530
Cost per client (USD)	558	1083
Cost per kW	2106	2043
Monthly payments per client (USD)	15.5	30.1
Period of payment (yrs)	3	3

A summary example of possible business activities, expenditures and income of such service centre (kiosk) is presented in Box 58, The system is assumed to be powered by a 1 kW solar PV-battery system. The kiosk will service at least 600 households. Price assumptions of solar systems are based on the sales price of solar products sold in Malawi (see Box 57). The centre/kiosk offers the following main services offered are a) sale and rental of portable solar products (PSP) that the consumer can pay over two years (at a 10% interest rate), b) mobile phone charging, c) sale of battery kits and battery charging, d) sale of electrical components. The centre further may participate in two RURED-supported project activities: a) installation of 265 and 530 kW solar PV systems (for those that want a certain level of energy but cannot be connected to a grid or mini-grid) and b) installation of solar pumps (as described in the previous Case 5). The 265-530 kW solar systems will receive a 50% grant (if bought through the centre/kiosk). These are leased to the client for a 4-year period, during which the kiosk will provide maintenance services and assist in the replacement of the batteries in year 4 of operation (batteries are assumed here to be 100% financed by RURED in this example). The systems are repaid over a 4-year period (at a 10% annual interest rate) and the client will own the system after 5 years. The subsidy level is chosen such that, every month, households that opt for the 265-530 kW system will pay slightly more than middle-higher income households connected to a mini-grid[47]. Regarding batteries (solar and other), the assumption is that a battery recollection system will be put in place to avoid these being dumped in the environment after their useful life.

[46] The Case is based on experience of the SOGERV project in Malawi (*Sustainability of Solar PV Energy Kiosks for Off- Grid Energy Access: Malawi Case Study*, by Frame, D. et.al., conference paper; Oct 2018) and solar kiosks in Malawi) and Lesotho (see UNDP/GEF project *Development of Cornerstone Public Policies and Institutional Capacities to accelerate Sustainable Energy for All (SE4All)*, Mid-Term Evaluation report, by Van den Akker, J. and Lethola, R.)

[47] Afterr 4 years they will have repaid the system. Compare with the monthly payments in the minigrid systems, see Box …, Box…. The power the 265 kW system provides will be less than the middle-income in the minigrids example and the 530 kW more than the enrgy consumption of a minigrid middle-income household but below the consumption of a MG higher-income household

Box 58 Case 7: business analysis of an energy service centre (kiosk))

	TOTAL	Yr1	Yr2	Yr3	Yr4	Yr5	Yr6	Yr 7
Number of products sold								
Sales and PAYG								
50 W SHS+TV	12				4	4	4	
Portable systems	490	120	120	120	40	50	50	
Battery kit	40	10	10	10	10			
EE woodstoves	80	10	10	20	20	20		
Projects								
530 W solar PV	15	6	6	3	0			
265 W solar PV	24	9	9	6	0			
Solar pumps		0	0	1	2	2		
Costs of stocking and restocking								
	Yr0	Yr1	Yr2	Yr3	Yr4	Yr5	Yr6	
530 W	5,325	5,325	2,663	0				
265 W	4,118	4,118	2,745	0				
50 W	0	0	0	2,400	2,400	2,400		
PSP	15,000	15,000	15,000	5,000	6,250	6,250		
Battery kit	1200	1200	1200	1200				
Electric components	885	885	885	885	885	885	885	
Stock of solar and PSP	26,528	*26,528*	*22,493*	*9,485*	*9,535*	*9,535*	*885*	
Stock EE stoves	25	25	50	50	50	50		
Stock pump	0	0	5,100	10,200	10,200			
Stock 530/265 W batteries					16035	10365		
Installation/construction; annual operation and maintenance								
Kiosk 1kW	15,000							
Storage space	5,000							
Project development	8,650							
O&M; labour		1,532	1,532	1,532	1,532	1,021	1,021	1,021
Kiosk system battery replace							6,500	
O&M service; battery replace						9,435	9,435	5,190
Total costs	**55,203**	**28,085**	**29,175**	**21,267**	**21,317**	**10,606**	**8,406**	**1,021**
Grant 50%	**27,601**				16,035	10,365		
Annual income from sales								
530 W		2,166	4,331	5,414	3,248	1,083		
265 W		1,674	3,349	4,465	2,791	1,025		
50 W					1,464	2,928	2,928	1,464
PSP		7,700	16,100	16,800	11,200	6,300	7,625	3,813
Battery kit		1,300	1,300	1,300	1,300			
Electric components		1,140	1,140	1,140	1,140	1,140	1,140	1,140
Sales - solar & electric		*13,980*	*26,220*	*29,119*	*21,143*	*12,476*	*11,693*	*6,417*
Sales EE stoves		*28*	*56*	*56*	*56*	*56*		
Sales - pump		*0*	*0*	*6,222*	*11,424*	12,444		
Phone charging		180	180	180	180	180	180	180
Charging batteries		60	60	60	60	60	60	60
Sales & service	0	**14,248**	**26,516**	**35,637**	**32,863**	**25,216**	**11,933**	**6,657**
Net income	**-27,601**	**-13,837**	**-2,659**	**14,370**	**27,581**	**24,974**	**3,527**	**5,635**
NPV 8,733								
IRR 15%								

Base data; assumptions

Type of product	Cost (USD)
Portable (PSP)	
Solar lantern	1
Lantern+lamps+UB 6W	90
Idem+radio+torch 10W	200
Larger solar	
SHS TV+LEDs	600
265 W solar PV	915
530 W solar PV	1,775
Other	
Solar pump (50% grant)	5,100
Battery kit + light+USB	120
EE woodstove	3.6

Kiosk O&M costs'	USD
Salaries	82
Trsp	60
Maintenace	556
Other	834
TOTAL	1532
Social discount rate	9%
PAYG solar products	
Margin on sales	10%
Interest in PAYG	20%
Period in PAYG (yrs)	2

Year		**0**	**1**	**2**	**3**	**4**	**5**	**6**	
Cashflow projections (pre-financing)									
Capital expenditures		-27,601							
Earnings EBITDA		-27,601	-13,837	-2,659	14,370	27,581	24,974	3,527	5,635
pre-tax NP	8,733								
IRR	14.7%								
payback (yı	3								
Depreciation			-4,600	-4,600	-4,600	-4,600	-4,600	-4,600	-4,600
Earnings EBIT (before interest and tax)			-18,437	-7,259	9,770	22,981	20,374	-1,074	1,035
Cost of finance			0	0	-3,600	-3,600	-3,600	-3,600	0
Earnings before taxes			-18,437	-7,259	6,170	19,381	16,774	-4,674	1,035
Tax			0	0	-925	-2,907	-2,516	0	-155
Net income			-18,437	-7,259	5,244	16,474	14,258	-4,674	880
Plus:									
Depreciation and interest			4,600	4,600	8,200	8,200	8,200	8,200	4,600
Cash flow (after tax)		-27,601	-13,837	-2,659	13,444	24,674	22,458	3,527	5,480
IRR	12.1%								

Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	
Financing activities								
Equity	17,601							
Soft loan	30,000			-9,877	-9,877	-9,877	-9,877	
Bank loan	0		0	0	0			
Change in cash	20,000	-13,837	-2,659	3,567	14,797	12,581	-6,350	5,480
Cumulative cash balance	20,000	6,163	3,505	7,072	21,869	34,450	28,099	33,579

Financing requirement — Corporate tax rate 15%

	Amount (USD 000)	Annual repayment	Share	Interest	Grace period	Repay period
Grant	54001		53.1%			
Equity	17601		17.3%			
Soft loan	30000	-9,877.03	29.5%	12.0%	2	4
Local loan	0	0.00	0.0%	28.0%	1	3

Total investment year 1: USD 55,203. Total investment (yr1 and yr2 + battery replacemnts yers 5-7: USD 101,603

For the business operation to be viable, subsidized start-up capital is required; a grant of 50% is assumed (as indicated in the Box), partly covering the installation and construction cost and to purchase stock for the first and part of the second year. In addition, a sustainable business will require equipment replacement (particularly batteries). To be able to have sufficient cash reserves, a loan is needed to have a small cash reserve in the first years of operation. As in Buisiness Cases, profitability will depend on many variables, in this case, the ability to sell portable and larger solar products. The timeline of sales (PSP) project sales (stand-alone solar and solar pumps) focuses on the first 5 years of the facility (i.e., coinciding with the proposed implementation period of the RURED programme with the first year to install/construct the facility after RURED's Call for Proposals, and four years of operation). The level of sales of portable solar products will decline as most households in the vicinity will have one or more solar products after some time. Thus, the energy service may have to expand its area of coverage to villages further away or add other services or products (e.g. selling of energy-efficient agricultural, agro-processing, cold storage or other equipment), or participate in new donor-funded projects.

2.10 Appendix: energy demand assumptions

End-users are classified into different types, each of which has different demand categories:

- Households, subdivided into low, medium and high-income households,
- Small businesses (shops, barber shops, restaurants &bars)
- Institutions (schools, rural health centres, worship, offices)
- Other (street lighting; powerhouse)

End-users have a typical daily energy consumption in kilowatt-hour per day (kWh/day) and load profile (hourly power demand in watts (W), throughout the day). The daily energy consumption is modelled by making assumptions on the type of appliances used, the power rating of the appliance (wattage), number of appliances and their usage over a 24-hour period. The load for each appliance was aggregated for each hour of the day. The tables below show the model energy demand for each household category, their appliances and the average time of use per day.
At the village or site level, the energy consumption and total hourly load can be calculated by multiplying by the number of end-users per category and aggregating the demand for all the category types. Seasonal demand variation can be

Without e-cooking

Appliance	Power rating (W)	Number per end-user	Total power (W)	Daily usage (hrs)	Daily demand (kWh/HH)	Power demand kW
Lights	6	3	18	6	0.11	0.018
Radio	5	1	5	6	0.03	0.005
TV+DVD	75	0.5	37.5	3	0.11	0.038
Phone charger	5	1	5	2	0.01	0.005
Total					**0.2605**	**0.066**

Household - Type 2

Appliance	Power rating (W)	Number per end-user	Total power (W)	Daily usage (hrs)	Daily demand (kWh)	Power demand kW
Outdoor light	6	1	6	12	0.072	0.006
Lights	6	6	36	6	0.216	0.036
Radio	5	1	5	6	0.030	0.005
TV+DVD	75	1	75	3	0.225	0.075
Phone charger	5	2	10	2	0.020	0.010
HE cooker	850	0	0	2	-	0.000
Small refrigerator	50	1	50	12	0.600	0.050
Total					**1.163**	**0.135**

Household - Type 3

Appliance	Power rating (W)	Number per end-user	Total power (W)	Daily usage (hrs)	Daily demand (kWh)	Power demand kW
Outdoor light	6	2	12	12	0.144	0.012
Lights	6	8	48	6	0.288	0.048
Radio	12	0.5	6	6	0.036	0.006
TV/Satellite/DVD	125	1	125	3	0.375	0.125
Music system	75	0.5	37.5	6	0.225	0.038
Fan	30	2	60	6	0.360	0.060
HE cooker	1000	0	0	2	-	0.000
Refrigerator	125	1	125	12	1.500	0.125
Phone charging	5	2	10	2	0.020	0.010
Total					**2.948**	**0.424**

With e-cooking

Household - Type 1

Appliance	Power rating (W)	Number per end-user	Total power (W)	Daily usage (hrs)	Daily demand (kWh/HH)	Power demand kW
Lights	6	3	18	6	0.11	0.018
Radio	5	1	5	6	0.03	0.005
TV+DVD	75	0.5	37.5	3	0.11	0.038
Phone charger	5	1	5	2	0.01	0.005
Total					**0.2605**	

Household - Type 2

Appliance	Power rating (W)	Number per end-user	Total power (W)	Daily usage (hrs)	Daily demand (kWh)	Power demand kW
Outdoor light	6	1	6	12	0.072	0.006
Lights	6	6	36	6	0.216	0.036
Radio	5	1	5	6	0.030	0.005
TV+DVD	75	1	75	3	0.225	0.075
Phone charger	5	2	10	2	0.020	0.010
HE cooker	850	0.3	255	2	0.510	0.255
Small refrigerator	50	1	50	12	0.600	0.050
Total					**1.673**	

Household - Type 3

Appliance	Power rating (W)	Number per end-user	Total power (W)	Daily usage (hrs)	Daily demand (kWh)	Power demand kW
Outdoor light	10	2	20	12	0.240	0.020
Lights	6	8	48	6	0.288	0.048
Radio	12	0.5	6	6	0.036	0.006
TV/Satellite/DVD	125	1	125	3	0.375	0.125
Music system	75	0.5	37.5	6	0.225	0.038
Fan	30	2	60	6	0.360	0.060
HE cooker	1000	1	1000	2	2.000	1.000
Refrigerator	125	1	125	12	1.500	0.125
Phone charging	5	2	10	2	0.020	0.010
Total					**5.044**	

important, in particular in the case of some productive uses. However, in the modelling, it is assumed that such seasonal fluctuation in energy demand can be levelled out:[48]

- Lower- income households living in one or two-roomed mainly grass-thatched houses use lighting, phone chargers and radio/TV with daily consumption of 261 Wh. These would be connected using a ready-board with insulated cables running from sockets on the ready-board to the respective rooms.
- Medium-income households live in mainly grass-thatched or iron-sheet roofs with three to five rooms and are assumed to use lighting, radio/TV, phone chargers with some households using a small refrigerator. Connections would also be by ready-board, with insulated cables running from sockets on the ready-board to the respective rooms. Expected daily consumption is 1,163 Wh.
- High-income rural end-users live mainly in iron sheet roofed houses and include among others, the rural health workers', school teachers' and government department/ institutional staff houses. They are assumed to use the same appliances as medium-income households, although some of these with a higher wattage. Expected daily consumption would be 2,948 Wh. It should be noted that the definition of low, middle and high income in the case studies may not be according to Malawian statistical income definitions but according to expected energy consumption level.

Village businesses are small grocery shops that use lighting, radio, refrigeration, barber shops (lighting, clipping or shaving), restaurants and bars (lighting, music system, phone charging, and refrigeration).

The rural health posts need a basic set of health services, including obstetric care, immunizations, basic emergency treatment and simple medical devices. For more advanced medical diagnosis, treatment, and surgery the patients would have to go to the district hospital, which is often far away. Given the long distance to district health facilities, it is important that some basic disease diagnosis and treatment can be done by medical staff at the clinic. Without electricity, even basic medical devices, such as a powered microscope or oxygen concentrator or small fridge for vaccine storage, cannot function. A basic load profile for a rural facility includes security lighting, indoor lighting, a microscope, a computer and a printer, an oxygen

Shops/small commercial/tailor

Appliance	Power rating (W)	Number per shop	Total power (W)	Daily usage (hrs)	Daily demand (kWh)	Max power kW
Outdoor light	10	2	20	12	0.240	0.02
Indoor lights	6	3	18	12	0.216	0.02
Fan	30	2	60	6	0.360	0.06
Radio/Music/TV	75	1	75	8	0.600	0.08
Refrigerator (small)	50	0.5	25	12	0.300	0.03
Refrigerator	150	0.25	37.5	12	0.450	0.04
Sewing machine	200	0.25	50	4	0.200	0.05
Phone charger	10	2	20	8	0.160	0.02
Total					**2.53**	**0.31**

Barber shop

Appliance	Power rating (W)	Number per shop	Total power (W)	Daily usage (hrs)	Daily demand (kWh)	Max power kW
Outdoor light	10	1	10	12	0.120	0.01
Indoor lights	6	1	6	12	0.072	0.01
Fan	30	1	30	6	0.180	0.03
Radio/TV	15	1	50	8	0.400	0.05
Clipper/shaver	15	1	15	4	0.060	0.02
Dryer	1500	0.5	750	4	3.000	0.75
Phone charger	5	2	10	8	0.080	0.01
Total					**3.91**	**0.87**

Bar and restaurant

Appliance	Power rating (W)	Number per shop	Total power (W)	Daily usage (hrs)	Daily demand (kWh)	Max power kW
Outdoor light	10	1	10	12	0.120	0.01
Indoor lights	6	2	12	6	0.072	0.01
Fan	30	1	30	8	0.240	0.03
TV - Satellite/DVD	85	1	85	3	0.255	0.09
Music system	75	1	75	6	0.450	0.08
Refrigerator	300	1	300	12	3.600	0.30
HE cooker	1000	0	0	3	-	0.00
Phone charger	5	2	10	8	0.080	0.01
Total					**4.82**	**0.52**

Small workshop

Appliance	Power rating (W)	Number per shop	Total power (W)	Daily usage (hrs)	Daily demand (kWh)	Max power kW
Outdoor light	10	1	10	12	0.120	0.01
Indoor lights	6	2	12	6	0.072	0.01
Fan	30	1	30	6	0.180	0.03
Welding	2000	1	2000	3	6.000	2.00
Drilling	200	1	200	4	0.800	0.20
Soldering	4	1	4	4	0.016	0.00
Phone charger	5	2	10	3	0.030	0.01
Total					**7.22**	**2.27**

Small mill	Power rating (W)	Number per end-user	Total power (W)	Daily usage (hrs)	Daily demand (kWh/HH)	Power demand kW
Outdoor light	10	1	10	12	0.120	0.010
Lights	4	2	8	4	0.03	0.008
Fan	75	1	75	3	0.23	0.075
Mill	2500	1	2500	4	10.00	2.500
Phone charger	5	1	5	2	0.01	0.005
Total					**10.387**	

[48] Data on household energy consumption and small PUE are based on: "Baseline information and mini-grid business models", Annex in UNDP/GEF Project Document "Zambia Mini-grids"; Call fro Proposals (2019); EU project "Support to Zambia Energy Sector: Increased Access to Electricity and Renewable Energy Production, Zambia", Annex L (Feasibility studies; UNDP *Sitolo Solar PV Mini-grid Technical Assessment Review*, (CES/CEM ; 2017); *Productive Use of Energy in African Microgrids: Technical and Business Considerations* (NREL, Energy4Impact; 2018, USAID)

concentrator, a fan, phone chargers, a fridge for 12 hours a day (i.e. switching itself on and off every four hours), and a CD4 Machine. Larger facilities (rural health clinics) may have more equipment such as an incubator (for the first treatment of premature childbirths). Apart from the vaccine refrigerators, the RHC should have a cold room for the storage of medicines and blood packages[49].

The load profile for a typical primary school includes lighting, a computer and printer, a radio, a fan, phone charging, and a small refrigerator. A secondary school is assumed to have the same appliances (but size and number differ). Furthermore, a provision has been made for computers for ICT classes (not a luxury item, but part of the official curriculum). The load profile for a place of worship includes outdoor lighting, a PA system, and a keyboard. It is assumed that church activities take place three days a week and that the choirs continue practising when the church services are over. A typical government office would have security lighting, indoor lighting, a computer and printer, a radio, a fan, and a phone charger.

Medical (health post)

Appliance	Number per clinic	Daily demand (kWh)	Max power kW
Security lights	2	0.29	0.024
Indoor lights	3	0.24	0.024
Light microscope	1	0.18	0.030
Computer	1	0.28	0.035
Printer	1	0.12	0.030
Refrigerator		-	0.000
Phone charger	2	0.08	0.020
Incubators		-	0.000
Oxygen concentrator	0.5	1.80	0.150
Cold storage room	1.0	3.60	0.300
Other (S, N, H, A)		-	0.000
Fan	2	0.10	0.010
Total		**6.69**	**0.623**
			3.000

School Primary

Appliance	Number per school	Daily demand (kWh)	Max power kW
Security lights	2	0.29	0.024
Indoor lights	4	0.22	0.032
Radio/Music/TV	1	0.14	0.035
Refrigerator	1	1.80	0.150
Fan	2	0.18	0.060
Computer	2	0.42	0.070
Printer	1	0.12	0.030
Phone charger	2	0.04	0.010
Total		**3.21**	

Water treatment	Power rating (W)	Number per end-user	Total power (W)	Daily usage (hrs)	Daily demand (kWh/HH)	Power demand kW
Pump	260	1	260	4.0	1.040	0.26
Treatment	160	1	160	4.0	0.640	0.16
Total					**1.680**	**0.420**

Worship / community hall

Appliance	Power rating (W)	Number per place	Total power (W)	Daily usage (hrs)	Daily demand (kWh)	Max power kW
Outdoor light	10	2	20	12	0.240	0.02
Indoor lights	6	0	0	6	-	0.00
Speaker/PA system	150	1	150	4	0.600	0.15
Keyboard	50	0.5	25	3	0.075	0.03
Total					**0.92**	**0.20**

Service office and powerhouse

Appliance	Power rating (W)	Number per shop	Total power (W)	Daily usage (hrs)	Daily demand (kWh)	Max power kW
Outdoor light	10	4	40	12	0.480	0.04
Indoor lights	6	4	24	7	0.168	0.02
Fan	30	2	60	4	0.240	0.06
Computer	35	1	35	6	0.210	0.04
Printer	30	1	30	3	0.090	0.03
Radio	30	1	30	6	0.180	0.03
Phone charger	5	2	10	6	0.060	0.01
Total					**1.43**	**0.23**

Given the need for clean water and the additional economic and health benefits provided by access to clean water, the co-optimization of energy and water production has been included in the Case study assessments. The many methods of treating water in rural areas include chemical treatment, reverse osmosis, and filtration. In addition to water pumping, many of these methods require electricity to power treatment equipment. The example in the Box is based on a village in Uganda using a Solar Pure Ultrafiltration UF system from Healing Waters powered by a micro-grid to produce and sell clean water at the village centre or energy kiosk[50]

[49] Data on health and schools compiled from "Baseline information and mini-grid business models", Annex in UNDP/GEF Project Document "Zambia Mini-grids"; *Health Facility Electrification Capital Landscape,* SE4All, CrossBoundar Advisory, Odyssey (2023), *Solar for Health (S4H) innovative financing feasibility study in Liberia, Malawi, Namibia, Zambia and Zimbabwe* (UNDP, 2000), *Integrated Energy Plan, Medical Cold Chain* (SE4All, 2022)

[50] *Productive Use of Energy in African Microgrids: Technical and Business Considerations* (NREL, Energy4Impact; 2018, USAID)