BUSINESS CASES
RENEWABLE ENERGY MINIGRIDS
ZAMBIA

Jan VAN DEN AKKER

2022

1. TABLE OF CONTENTS

LIST OF BOXES

LIST OF ACRONYMS AND ABBREVIATIONS

AfDB	African Development Bank
AFOLU	Agriculture, forestry and other land-use
AMP	Africa Minigrids Programme
ATP	Ability to pay
CAPEX	Capital expenditure
CO_2-eq	Carbon dioxide (equivalent)
CO	Country Office
CSO	Civil Society Organization
DBZ	Development Bank of Zambia
DFID	Department for International Development
DoE	Department of Energy
ERC	Evaluation Resource Center (of UNDP)
ERB	Electricity Regulation Board
ESAP	Electricity Services Access Project
ESMAP	Energy Sector Management Assistance Program
EU	European Union
EUR	Euro
GCF	Green Climate Fund
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse gas
GIS	Geographical information system
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GWh	Gigawatt-hour (billion watts)
IAREP	Increase Access to Electricity and Renewable Energy Production
IEA	International Energy Agency
IFC	International Finance Corporation
IPP	Independent power producer
IT	Information technology
Km	Kilometer
kW	Kilowatt
kWh	Kilowatt-hour
LV	Low voltage
M&E	Monitoring and evaluation
MoE	Ministry of Energy
NHCC	National Heritage Conservation Commission
MHP	Mini/micro hydropower
MoF	Ministry of Finance
MTF	Multi-Tier Framework
MTR	Mid-Term Review
MV	Medium voltage
MWh	Megawatt-hour (million watts)
NAPSA	National Pension Scheme Authority
NDC	Nationally Determined Contributions
NES	National Electrification Strategy
NREL	National Renewable Energy Labortory
O&M	Operation and maintenance
OPEX	Operational expenditure

OPPI	Office for Promoting Private Power Investment
PAYG(O)	Pay-as-you-go
PPA	Power purchase agreement
PV	Photovoltaics
RE	Renewable energy
REA	Rural Electrification Authority
REF	Rural Electrification Fund
REMP	Rural Electrification Master Plan
RGC	Rural growth centre
SME	Small and medium-size enterprise
SE4All	Sustainable Energy for All
SHS	Solar home system
SIAZ	Solar Industry Association of Zambia
SIDA`	Swedish International Development Cooperation Agency
tCO_2	Metric ton of carbon dioxide
ToC	Theory of change
ToR	Terms of Reference
UNZA	University of Zambia
USAID	United States Agency for International Development
USD	United States dollar
VAT	Value added tax
W_p	Watt-peak
WHO	World Health Organization
WTP	Willingness to pay
ZABS	Zambia Bureau of Standards
ZANACO	Zambia National Commercial Bank
ZARENA	Zambian Renewable Energy Agency
ZCF	Zambia Cooperative Federation
ZDA	Zambia Development Agency
ZEMA	Zambia Environmental Management Agency
ZESCO	Zambia Electricity Supply Corporation
ZICTA	Zambia Information and Communications Technology Authority

1. INFORMATION ON ENERGY AND ELECTRIFICATION IN ZAMBIA

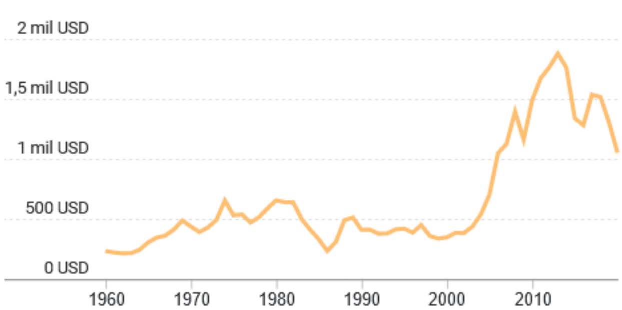
1.1 Background information on energy and electrification in Zambia

Country context

Zambia has an estimated population of approximately 19.3 million people (in 2022), the majority of whom (54.7%) live in rural areas[1]. The average household size is 5.0 people per household. Zambia has a relatively low population density when compared with other East African countries, 26 people per square kilometre. The population has been growing at a steady rate of around 3% annually and the population is expected to grow to more than 24.3 million people in 2030.

Zambia's economy is strongly dependent on its most important sector – copper mining – which alone accounts for around 70% of export revenue and contributes approximately 10% of GDP, with the bulk of the remainder coming from non-mining industries and the services sector. Zambia's GDP in 2020 was USD 18.1 billion (current USD; down from USD 26.3 billion in 2018)[2] . Zambia has experienced rapid economic growth with GDP growth increasing from 3.8% in 2000 to 10.2% in 2011 but has shown a downward trend to about 3.5-4% in 2016-2018 and reaching negative figures in 2020. These trends reflect the economy's limited diversification and vulnerability to national outside pressures, such as falling copper and rising fuel prices, as well as changes in agricultural and hydroelectricity output (affected by recurrent drought phenomena). As growth has slowed down in recent years, and public debt has risen, this has resulted in borrowings increasing to such an extent that the country has been classified to be at a high risk of debt distress [3].

Box 1 GDP per capita, Zambia (current USD)



https://datacommons.org

Population health is also vulnerable: malaria is prevalent in certain areas, and increased flooding and drought cycles (because of erratic rain) can cause health and sanitation problems, in addition to malnutrition issues from lower agricultural yields. The global coronavirus pandemic (COVID-19) has been far more than a health crisis, affecting societies and economies at their core. The policy measures to limit the spread of the disease have resulted in substantial economic impacts, with a significant contraction in the global economy in 2020. These impacts are likely to have increased the level of energy poverty in Zambia. With the international poverty line of USD 1.90 per person per day, the poverty rate is around 59%; income inequality is expressed by the Gini coefficient of 49.5% (2016)[4].

1 Source: worldometers.info, based on 18.38 million population in 2020; https://worldpopulationreview.com/countries/zambia-population

2 https://data.worldbank.org. USD 62.5 billion (in power purchase parity) in 2018 and USD 63.56 billion in 2020

3 Zambia's total public debt to foreign and local lenders was almost USD 27 billion in 2021 (of which USD 10 billion local debt), equal to about 155% of GDP. https://www.reuters.com/article/zambia-debt-idUSKBN2HA2L5. Zambia's debt woes triggered the continent's first pandemic-era sovereign default in 2020 (after having to skip interest payments that year). The Government is now is in the process of restructuring of its external debts. https://www.ft.com/content/3c56f710-601d-4a41-a374-13603bd002d4

4 https://knoema.es/atlas/Zambia/Poverty-rate-at-dollar32-a-day

Power sector

The Ministry of Energy is the overarching regulating authority responsible for the energy sector in Zambia. Zambia Electricity Supply Corporation (ZESCO) is the state-owned vertically integrated utility company, established in 1970, that operates the national grid, and is responsible for the generation of much of the electricity supply in Zambia. The country officially regulated and liberalised the power sector so that it is open for generation by IPPs. There are a few Independent Power Producers (IPPs) that feed electricity into the grid (with ZESCO as the sole off-taker). However, ZESCO is responsible for the generation of much of the electricity supplied in Zambia (owning about 83% of installed capacity)[5].

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[6] and 80% is based on large hydropower (which is increasingly vulnerable to climate change). Zambia has struggled since mid-2015 to meet increasing electricity demand, attributed to heavy reliance on hydropower with droughts during 2015 and 2016. During the power shortage in 2015-16, power was imported through the Southern African Power Pool (SAPP) and by investing in coal-fired plants[7]. Zambia has several future hydropower generation projects planned as well as several initiatives to improve transmission and distribution which will require significant investment[8]. Zambia's economic activity is concentrated in the corridor running from Lusaka to the Copperbelt and this reflects the power transmission and distribution infrastructure. Electricity consumption was 12.53 TWh in 2019 and 11.48 in 2020, with the mining sector consuming about half, almost twice that of the residential sector.

Zambia has introduced policies to incentivize a willing-buyer/willing-seller model for power purchase agreements (PPA) through Zambia's Renewable-Energy Feed-in-Tariff (REFiT) strategy, helped by programmes such as Global Energy Transfer Feed-in-Tariff (GET-FiT) programme[9] and IFC's Scaling Solar that aim to bring 200 MW of smaller-scale and 600 MW of large-scale solar PV plants, respectively. The first utility-scale projects have been constructed[10]. However, the financially distressed electricity parastatal ZESCO is currently the main off-taker of large PPAs, which is limiting large-scale development in the short term.

Prior to 2008, Zambia enjoyed the lowest electricity tariff in Southern Africa, with an average tariff of USD 0.027 per kWh (IRENA, 2013). The heavily subsidised tariffs led to challenging commercial environments for both private developers and ZESCO, resulting in very little investment in power infrastructure and new generation capacity. Also, the low tariffs have discouraged minigrid development, as the low ZESCO retail tariffs provided customers with the expectation of electricity services at a price that is often untenable on a per kWh basis with cost-reflectivity. The country has started to migrate towards cost-reflective tariffs that are in line with the objective of the Southern African Development Community (SADC). Tariffs were increased in 2017 and again in 2020 with the aim being to have more cost-reflective electricity tariffs. The average tariff in June 2020 was about USD 0.074/kWh[11].

---

5 Other power producers include Copperbelt Energy Corporation (CEC); North-Western Energy Corporation (NWEC); Lunsemfwa Hydro Power Company (LHPC); and Maamba Collieries Limited

6 An increase in the solar share from 0.04% in 2018. Source: ERB Energy Report 2020

7 The coal-fired plant, Maamba Collieries, which was commissioned in late 2016 and can generate up to 300 MW of power for ZESCO. In 2020, Zambia had a demand of about 2,310 MW for the year 2020 against an average generation of about 1,500 MW with an average daily load shedding of about 471 MW. Source: ERB (2020)

8 About USD 9 billion for generation, about USD 2.5 billion for transmission and distribution, and USD 2 billion for rural electrification. Source: Zambia Presentation at AEMP (2018)

9 In 2020, the MOE approved feasibility study rights to 39 pre-qualified developers for potential small hydropower sites

10 54.3 MW (operated by Bangweulu Power, owned by Neeon-IDCr) and 28 MW (operated by Ngonye Power, owned Enel) plants at tariffs of 6.02 US cents/KWh and 7.84 US cents/KWh and Neeon/First Solar consortium respectively. Source: MOE website; ERB Energy Sector report 2020

11 Residential tariff: < 100 kWh per month consumption: USD 0.027/kWh, between 100-300 kWh/month: USD 0.049/kWh, > 300 kWh: USD 0.111. Commercial tariff (consumption < 200 kWh/month: USD 0.061/kWh and > 200 kWh: USD 10.6/kWh. Converted from ERB Statistics 2020 data at USD 1 = ZMW 17.5 (2020). The rates provided are exclusive of 3% government excise duty and 16% VAT. In addition, fixed monthly charges need to be paid by customers

Climate

According to the latest official reporting, Zambia's GHGs emission level was 127,786 $MtCO_2$ (million metric ton CO2 equivalent) emissions from 'agriculture, forestry and land-use change (AFOLU) and, without AFOLU, 8,871 $MtCO_2$. Energy production and use was responsible for 6,444 $MtCO_2$ (and industry and waste, 2,427 $MtCO_2$). AFOLU removals were -136,267 $MtCO_2$ implying that Zambia was a net sink in 2016, i.e., had negative net emissions (of 9,508 $MtCO_2$. It is worthwhile noting that the sink reduced by 83% in comparison with the 1994 figure of -56,866 $MtCO_2$, basically due to a steady increase over time in emission from AFOLU (86,063 $MtCO_2$ in 1994), energy-related emissions (2,178 $MtCO_2$ in 1994, industry and waste, 613 $MtCO_2$), while AFOLU removals have more or less remained at the same level (-142,929 $MtCO_2$) in 1994.

Significant amounts of emissions from AFOLU sector (responsible for 93% of emissions in 2016), in particular wood removals (contributing 56% to Zambia's GHG emission, of which for commercial timber, 28%, and firewood/charcoal (28%) and from forestland conversions into cropland and settlements (25%) and biomass burning 8%. Compared to 1994, the contribution of fuelwood has been increasing relative to commercial wood removal[12]. This reflects the large role of biomass in the overall energy balance of Zambia. Of all the energy consumed in Zambia (337,356 TJ in 2019), 72% (244,830 TJ) came from biomass, mainly used for cooking by charcoal and firewood in the residential sector (206,178 TJ). The high use of fuelwood as household fuel (in particular, the relatively energy-inefficient charcoal production[13]) is considered a major driver of the country's deforestation. For the period 2000 to 2010, the deforestation rate was recorded as being 0.5%; losing approximately 250,003 ha on an annual basis. For the period 2010 to 2014, the deforestation rate increased to 0.7%; losing approximately 341,067 ha of forest per annum. It has been noted that in recent years that an increase in electricity tariffs and unreliable electricity supply (load shedding) has decreased interest in electric cooking, turning to charcoal in response.

The Zambian energy market, heavily reliant on hydropower, is vulnerable to climate shocks. In 2015 and 2016, a heavy drought forced the country to import energy from neighbouring countries under the emergency power procurement plan. Drought in 2015 has left the country facing a 985 MW power deficit at the peak of its crisis (almost half of its total generating capacity). Erratic climate conditions observed during this period caused the drop in water levels at the Kariba Lake reservoir three meters below levels recorded a year before. This means that the lake was at 12% of its full capacity compared to 50+% under normal circumstances[14]. Erratic rainfalls in 2015 and 2016 had a marked impact on the country's economy with both agricultural yields down, and the mining industry impacted by electricity shortfalls as the country is largely dependent on hydropower.

Electrification

Access to electricity has increased from 14% (1993) to 42.2% in 2019 for the overall population, of which 37.7% are connected to the main grid and 4.7% off-grid access (mostly solar lanterns, 2.5%, rechargeable batteries 1.4%, solar home and lighting 0.7%)[15]. The rural electrification rate has only recently increased from just 5% in 2015 to close to 12% in 2019 (of which 4.1% were grid-connected and 7.8% off-grid). Grid extension is the most economical option for households in large, dense settlements that are close to the existing grid. Grid rollout is driven by the public sector through the Rural Electrification Authority (REA) and the state utility ZESCO. ZESCO has a commercially-driven mandate and concentrates on the delivery of connections to economically-viable areas. ZESCO is responsible for both urban and rural areas but tends to focus on urban connections. Due to the challenges of electrifying rural areas, the Government established the Rural Electrification Authority (REA) as an autonomous agency in 2003.

---

12 Data on Zambia's GHG emissions taken from Third National Communications and First Biannual Update Report (2020)

13 Biomass-for-energy production was 321,702 TJ in 2009. Source: IEA energy balance Zambia, 2019. Charcoal is used in both urban and peri-urban areas and firewood in rural areas.

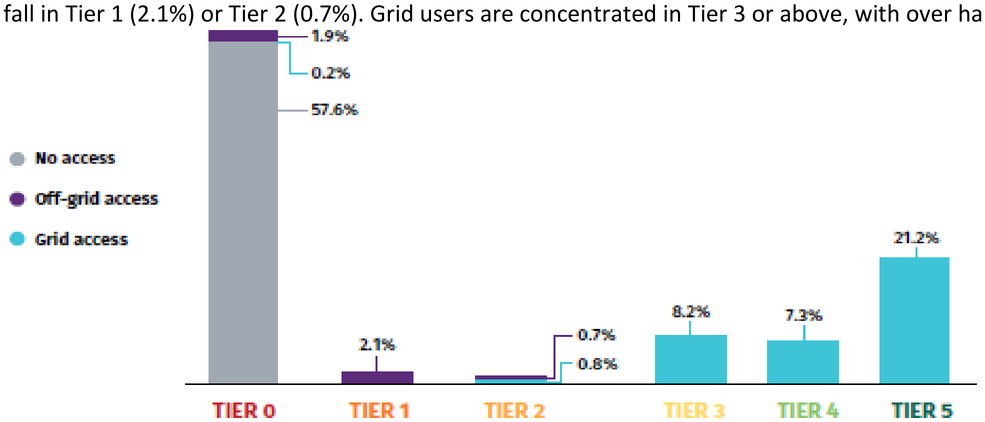
14 GCF Zambia Energy Financing Framework document; www.reuters.com/article/zambia-electricity-idUSL5N11S4D120150922

15 Zambia, Energy Access Diagnostic Report based on the Multi-Tier Framework (2019); World Bank

In recent decades, electricity access has typically relied on a model of large, centralized power generation and extending publicly-funded grid connections. In some countries, this has proved successful, in other countries the poor financial health of grid-connected power systems has held back progress. Today, innovative off-grid solutions, namely renewable energy minigrids ('minigrids') and solar home systems (often using a Pay-as-you-go, PAYG, model), offer great potential for electricity access. The particular technology choice for electricity access (grid extension, minigrids or stand-alone solar) will

Box 2 Energy access and poverty

The Multi-Tier Framework (MTF) defines access to electricity according to a spectrum that ranges from Tier 0 (no access) to Tier 5 (full access). Nationwide, 40.3% (1.4 million households) of the households are in Tier 1 or above for electricity access, and over half of those are in Tier 5 (Figure 6). Among the 59.7% of Zambian households (2.1 million households) that fall in Tier 0, the large majority has no access to any source of electricity. About 1.9% of households using off-grid solutions and 0.2% of households connected to the grid still fall in Tier 0, because their electricity supply does not satisfy Tier 1 requirements. This is due to the limited capacity or availability of off-grid solutions or to the limited availability of the grid supply. The remaining off-grid households fall in Tier 1 (2.1%) or Tier 2 (0.7%). Grid users are concentrated in Tier 3 or above, with over half of them reaching Tier 5.



ATTRIBUTES	TIER 0	TIER 1	TIER 2	TIER 3[a]	TIER 4	TIER 5
Power capacity ratings (W or daily Wh)	Less than 3 W	At least 3 W	At least 50 W	At least 200 W	At least 800 W	At least 2 kW
	Less than 12 Wh	At least 12 Wh	At least 200 Wh	At least 1 kWh	At least 3.4 kWh	At least 8.2 kWh

Source: Zambia, Energy Access Diagnostic Report, Multi-Tier Framework (World Bank-ESMAP, 2019)

be determined based on the least-cost solution for the particular site and scenario. Minigrids will have an important role to play; IEA geospatial analysis has shown that under a universal electricity access scenario by 2030, minigrids would be the cheapest technology for connecting 450 million people, two-thirds of whom live in sub-Saharan Africa[16].

This minigrid opportunity is driven by several converging trends: falling hardware costs (solar modules, batteries, energy-efficient appliances, and modular approaches), new digital technologies (including mobile money), and innovative, private-sector business models (new service offers, lowering customer acquisition costs). Just as mobile phones have eliminated the need to build costly landlines for communication, there is evidence that minigrids, with private sector involvement, could enable Africa to leapfrog traditional power systems that consist of large, polluting, and typically heavily-subsidized fossil-fueled power plants and expensive transmission lines.

REA is tasked with developing and implementing a plan to electrify rural areas. The 2009 Rural Electrification Master Plan (REMP) was developed by the REA in 2009 (with JICA support) to advance rural electrification. It served as an important plan

16 World Economic Forum/IEA (2018)*: 1.1 billion people still lack electricity. This could be the solution*

by focusing on rural areas with a high concentration of residential settlements and economic (so-called, Rural Growth Centres), with 1,217 RGCs identified and prioritized for electrification by the national grid. All RGCs are expected to have public institutions, markets and business enterprises. About 40% have more than 400 households.

Several shortcomings were identified in the Rural Electrification Master Plan (REMP), including the strong focus on on-grid connections (90% of all connections), despite it not being the most cost-effective solution (the plan considers 9% through solar and only 1% through minigrids) as well as the lack of a plan for non-RGC areas (60% of the rural population were therefore not considered). A new National Electrification Strategy (NES) in Zambia is currently under development, which addresses the shortcomings of the REMP, supported by geospatial modelling (see Box 4). To achieve universal electricity access in 2030, some 4.9 million new customers (meaning 17.9 million inhabitants) need to be supplied with electricity through grid densification, grid extension, minigrids (solar or hydro) and solar home systems (SHS).

According to the geospatial analysis and modelling, grid densification and extension can connect about 28% of the new customers (implying that 58% of people would be grid-connected in 2030), minigrids can serve about 27% of the new clients, while 45% would be served by stand-alone solutions. However, the national total investments required to reach universal electrification sum up to a whopping USD 2,929 Million, spread across the 2022-2030 investment periods, of which USD 2,344 million for mini-grid electrification (or USD 290 million annually).

Mini-grids

In the latest electrification modelling (see Box 4 and Box 3), the majority of the population served by grid extensions are located in the North and East of the country. Mini-grids are the least-cost technology in the North West and Western part of the country. Grid densification is centred around the major cities that are already connected. Solar home systems will be used by 32 % of the population for 0.7 % of the demand (which is low as the service level is Tier 1-2 only, see Box 2.

Mini-grids will serve 19% of the population with 35.0 % of the demand at Tier 2-to 4 service levels. In the modelling, the predominant technology for mini-grids is solar PV-battery systems due to their higher availability, with hydropower mini-grids appearing on a limited number of sites close to rivers. In principle, mini-grids[17] can be powered by several energy sources:

- Zambia has a moderate to low wind energy potential and the focus of feasibility studies and research has only recently moved to wind power. The majority of wind speeds at 100m above the ground are between 4 to 7m/s. Most of the south-western area of the country, as well as along selected areas on the escarpment in the western part of the country, has wind speeds of between 5 to 7 m/s, which may have electricity generating potential.
- The existing estimates of hydro potential in Zambia stand at about 6,000 MW. The potential for small, mini and micro-hydro[18] potential is an estimated 45-60 MW. However off-grid (mini-grid hydro) plants are hampered by the fact that the water resources (with sufficient height and water flow levels) are often located away from the demand centres in this sparsely populated country. This would necessitate the construction of transmission lines over large distances to the demand centres, rendering the mini-grid uneconomic. Approximately 60 potential small hydro sites ranging from 30 kW to 3 MW have been assessed by REA in North-western, Northern and Luapula provinces, of which 7–8 sites were considered to be potentially viable and sufficiently close to population centres[19].
- Zambia enjoys an average of 2,000 to 3,000 hours of sunshine per year. The average global horizontal irradiation (GHI) is 5.5 kWh/m2/day. Zambia, therefore, has a solar energy potential that (unlike hydro) does not differ from site to site or region to region. This makes solar an ideal power source for mini-grids and electrification by stand-alone systems, although average daily solar irradiation is not consistent throughout the year, with a noticeable decrease during the

17 For small minigrids (< 20 kW), the term microgrid is sometimes uses

18 There is no exact definition, but often : pico:<5-10 kW, micro: <100kW and mini: <1000kW, while small is < 10-30 MW

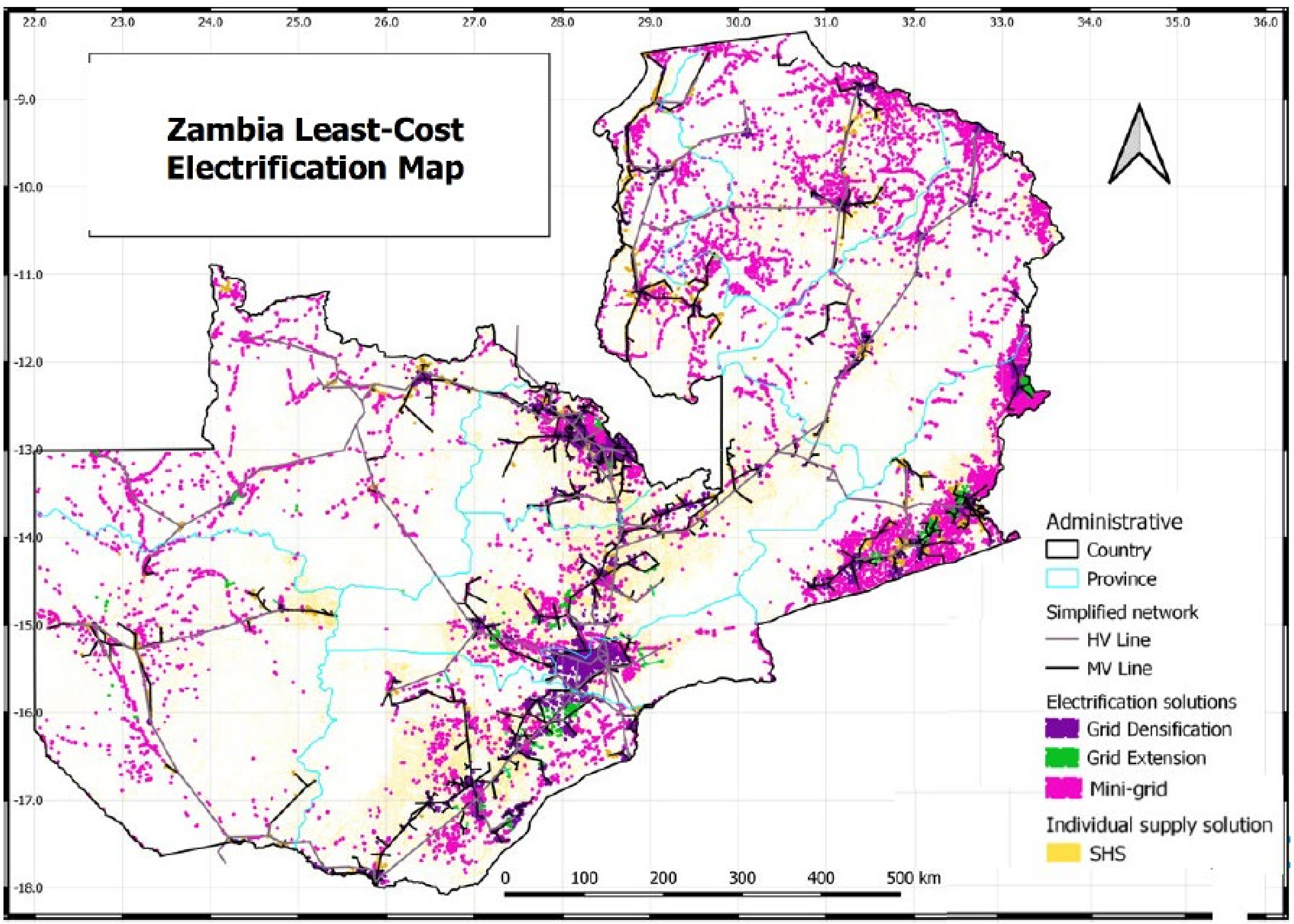
19 Assessment of Solar Energy Source Distribution and Potential in Zambia, in: Periodicals of Engineering and Natural Sciences Vol.5, No.2, June 2017, pp. 103-116 (Mwanza, et.al.). GETInvest (2019, using REA online and p.c. information)

rainy season in June and July. This seasonal variation should be taken into account when designing PV systems. The results of the WB-ESMAP-supported solar energy mapping (based on measurements at six sites spread over the country) show significant potential for solar power applications all-over the county and solar MG have recently been the focus of donor-supported programmes (such as EU's IAREP and World Bank's ESAP).

- Conversion of biomass to electrical power potential stands at 500 MW (of which 447 MW could be from agro-wastes, 46 MW from forest wastes and 4 MW from municipal waste). Analysis by SNV and Hivos in 2012 shows that sixteen of the country's 72 districts have biogas potential (livestock manure) for electricity generation[20].

In Zambia, about nine mini-grids were developed by missionaries, using hydropower. ZESCO operates eight diesel-based minigrids, and has done so for many years. ZESCO has little experience in the development and operation of renewable energy mini-grids, so far running one hydro (a 1 MW facility in Shiwang'andu, in Muchinga Province). REA developed some mini-grids, including the 640 kW Kasanjiku mini-hydro and the 60 kW solar MG in Mpanta, to which, more recently, a small number of solar MGs have been or will be added (Chunga, Lunga, etc). The first private sector MG was set up in Zengamina in Mwinilunga District, NW Prov, powered by a 705 kW mini-hydro. The number of private sector solar MGs being planned or under development has been growing rapidly (see Box 5).

Box 3 Electrification solutions map



Source: *Least-Cost Geospatial Electrification Plan for Grid and Off-Grid Rollout in Zambia*, World Bank by Engie-Impact (2022**)**

[20] Mwanza et.al (2017); GETInvest (2019); *Mini-Grid Market Opportunity Assessment: Zambia* (AfDB-SE4All, 2018)

Box 4 Electrification and geospatial modelling

The United States Agency for International Development's (USAID) Southern Africa Energy Program (SAEP) has developed a geospatial model that determines the least-cost electrification solution for each household in Zambia. Another least-cost geospatial modelling exercise was carried out as input for the new National Electrification Strategy (NEP), supported by World Bank's ESAP (project (see Box 33 for the electrification map). The WB-ESAP analysis is based on the assumption there will be 25.3 million people in Zambia in 2030, estimating that USD 2.93 billion would be needed spread over 2022-2030 to reach universal electricity access through grid densification and extension, minigrids and stand-alone PV options

The models map the country's population centres; current grid lines and substations; and localities most suitable for solar, hydro and other renewable power generation, taking into account availability of resources, suitability of technologies in view of the level of rural energy demand in villages and rural income levels, expected cost development of technologies and possible productive uses. The end results are maps showing Zambia's lowest-cost electrification options (grid extension, mini-grids or solar home systems) for each currently unelectrified household across the country, of which the most recent map (WB ESAP's) is shown in Box 33**.** The modelling shows that minigrids (supplying energy at Tier 2-4 level, see Box 31) and off-grid solutions (supplying 1-2 Tier level) can play a significant role in electrification alongside grid connections (with Tier 4-5 level) for a substantial portion of the (rural) population for Zambia to achieve universal access by 2030.

However, the models have widely different outcomes regarding the role of each of the non-grid solutions with the USAID model having the largest role for stand-alone solutions, while the recent WB-Engie geospatial sees a lead role for minigrids. The differences are due to different cost assumptions of minigrid and stand-alone PV technologies and the role of productive uses. Agricultural activity, like irrigation and maize milling, can operate during household demand off-peak times, thereby potentially reducing household connection costs without increasing the capital outlay of the mini-grid that much. The USAID modelling estimates the role in 2030 of minigrids as varying between 1% and 10% of new connections, depending on assumptions on cost and role of productive uses. Even in the most MG-favourable USAID scenario, the minigrid share in 2030 is about 8% of all connections as compared to the 19% estimates in the ESAP-Engie modelling.

Another least-cost geospatial modelling exercise was carried out as input for the new National Electrification Strategy (NEP), supported by World Bank's ESAP project (see Box 33 for the electrification map). The analysis is based on the assumption there will be 25.3 million people in Zambia in 2030, estimating that USD 2.93 billion would be needed spread over 2022-2030 to reach universal electricity access through:

	WB-ESAP / Engie model							USAID model	
	Population in 2030 (million)	**Population (2030) %**	**Demand supplied** (GWh/yr)**	**Category demand**	**Number of localities**	**Cost (million USD)**	**Cost per customer (USD)**	**Connection Share (%)**	**Cost (million USD)**
Already electrified*	7,497	30	2,109	Tier 4-5				34***	
Grid densification	4,699	19	1,157	Tier 4-5	596	329	357	13	500
Grid extension	232	1	123	Tier 4-5	39	52	854		
Minigrid	4,829	19	1,851	Tier 2-4	2,390	2344	2,422	8****	200
SHS	7,999	32	35	Tier 1	1,696	205	121***	48	3,300
TOTAL	25,256	100	5,275		4,721	2,930		100	4,000

* Already electrified in 2019 at access rate of 42% (population, 17.86 million)

** The demand is less than potential demand (7,256 GWh/yr) by households (6,592 GWh/yr) and agricultural PUE (933 GWh/yr) due to supply limitations in distributed supply options, such as SHS.

*** Average cost of a solar home system. For a cost explanation of the minigrid, see references below

**** 18% on top of the 16% electrification in 2017

***** Incorporating such productive use in the least-cost mix and assuming favourable minigrid cost development brings the mini-grid share connections to about 8%,

Source:

- *Geospatial model for Zambia* (April 2018, PowerAfrica/USAID). See also: USAID (2018), *Zambia's Power Sector Assessment*; *Solar Home System Expansion Program: Session 1*, Presentation and discussion document (Feb 2018);
- *Preparation of a Least-Cost Geospatial Electrification Plan for Grid and Off-Grid Rollout in Zambia,* World Bank by Engie-Impact (2022)

Box 5 Experiences with minigrid development in Zambia

<table>
<tr><td colspan="3">Public sector owned and operated</td></tr>
<tr><td>ZESCO operates two diesel-powered and one hydropower minigrid. ZESCO is responsible for the construction and operation of the grid.</td><td>• ZESCO operates two diesel-powered minigrids
• Shinwang'andu mini-hydro power (1 MW) at, Chinsali District in Muchinga Prov</td><td>Financed by ZESCO (86%) and GEF (14%). The facility was producing 710 MWh in 2014 with 300 kWh storage capacity. Users pay a flat tariff per month (plus connection fee of K 150)
Note: Until recently ZESCO operated seven isolated diesel-based mini-grids but only two remained operational at the end of 2017. The two mini-grids are run from 06:00 – 24:00. Older diesel stations have been de-commissioned as the national grid is extended</td></tr>
<tr><td colspan="3">REA developed and community operated</td></tr>
<tr><td>Identified and developed by REA, these sites are then transferred to and operated by a community cooperative. The mini-grids are run on non-profit principles and charge minimal fees but may potentially have viability issues</td><td>• Mpanta Solar (60 kW), Samfya District, Luapula Prov,[Kafita cooperative]. Operational since 2013</td><td>USD 1.3 million; co-financing by UNEP/UNIDO/GEF. Energy for 480 households (HH, some 2300 people), school, RHC. Users pay a flat tariff per month of USD 4-10 (plus connection fee of K 150), resulting in a tariff of USD 0.033/kWh (hardly enough to cover O&M cost)
Note: Missions have installed a number of community-based mini-hydro mini-grids (e.g. Nyangombe, 73 kW; Mangingo, 17 kW, Lwawu, 50 kW) that typically power residence, hammer mill and mission buildings</td></tr>
<tr><td colspan="3">Public-private partnership</td></tr>
<tr><td rowspan="2">REA has identified the sites that were part of IAREP Call for Proposals in 2019. In the PPP model, responsibility is broken down and allocated along the lines of development, financing, construction, operations and ownership. REA has about 200 sites earmarked for solar MG development</td><td>• Kasanjikyu mini-hydro (640 kW) in Mwinilunga District, NW Prov</td><td>USD 10 million investment, targeting 2250 connections Incl 11 schools, hospital, constructed in 2019. Ability to pay (ATP) estimated at USD 15 (residential) and USD 20 /month. Cost-reflective taruff USD 0.57/kWh (with 100% CAPEX subsidy, USD 0.08/kWh)</td></tr>
<tr><td>• Lunga 300 kW (Lunga District, Luapula Prov
• Chunga 90 kW (at Kafue Nat Park)
• Chishi (Bangweulu Lake, Luapula Prov)</td><td>The sites were offered for development in 23019 IAREP Call for Proposals (Lot 1) in two contracts (with EUR 0.5-2 million support).
Chunga: 100 clients (4 km distribution. Available energy 118 MWh/yr), Invest: USD 0.45 million. LCOE: USD 1.16/kWh. Tariff with 80% subsidy: USD 0.54/kWh (eq. monthly payment: USD 0.39-3.05; WTP: USD 10). With 100%: USD 0.38/KWh
Lunga: about 1500 clients (17 km distribution; available enrrgy: 770 Mwh/yr). CAPEX: USD 3.2 million, ATP: USD 15.2/month. LCOE: USD 1.1/kWh. Tariff with 80% subsidy: USD 0.36/kWh (eq. monthly payment: USD 0.29-1.80; WTP: USD 1.33-3.30). With 100%: USD 0.20/KWh.</td></tr>
<tr><td colspan="3">Private sector (with grant support)</td></tr>
<tr><td rowspan="5">Private developers will usually seek a combination of viability gap financing (grants provided by e.g. IAREP, BFGA, others), equity. Typically, solar MG are smaller than PPP or utility-managed MGs. Some developers plan the mini-grid around one or more anchor productive uses (e.g. Solera). Other prioritise low-demand customers (e.g. SMG). Private developers often provide a 'standard' technology which helps to reduce cost and mobile payment options.

Private MG developers operating in Zambia are Engie, Smart Minigrid (SMG), Solera.</td><td>• Sinda, solar 30 kW, Eastern Prov</td><td>Investment cost (USD 270,000, with USADF grant of USD 100,00). Owned and operated by Muhanya Solar. Operations started in 2017, serving 60-20 households in 2.5 km distribution. Muhanya with the NGO Musika experiments with PAYG (with MTN and Airtel). Approx. energy yield: 52 MWh (year 1). OPEX: approx. USD 12500/yr. LCOE: about USD 1.7/kWh. With 70% grant drops to USD 0.23/kWh. In 2017 customers paid USD 13-40 per month, translating into average tariff of USD 0.23 per kWh</td></tr>
<tr><td>• Standard Microgrid (Kafue, other sites)</td><td>Standard MG has 15 kW units (that can provide power to 150 HH). Local entrepreneurs operate as agents, re-selling prepaid credit to community members. Cloud based grid software enables the remote technical support team to monitor the performance of many grids from one location. Focus is general on low-consuming customers hence the smaller MG size.</td></tr>
<tr><td>• Chatandika, 28.3 kW solar MG</td><td>Engie's SolarPower Cornmer provides energy to 127 homes (designed for demand of 22.5 kW, 238 HH, and clinic, 2 kW; 96 kWh storage; 9 km distribution. Total cost: EUR 250,000 (70% equity, 30% grant) Smart metering and the cloud-based payment platform (with pay-as-you-). Witb EU-IAREP support, Engie plans to set up 60 MGs (50 kW at 28 sites and 100 kW at 32 sites) and with BGFA, 100 kW at 11 sites, a combined 10 MW in total</td></tr>
<tr><td>• Solera (Luangwa bridge, other sites)</td><td>Solera has the 25 kW SunSquare. It supports Mobile Money Payments to pay for Services, through integration with multiple Telecom Operators. Focus on developing productive uses (currently some 50 SMEs)</td></tr>
<tr><td>• Zengamina mini-hydro 750 kW in Mwinilunga District, NW Prov
(plans to add a new MHP (Zengamina II, 1.5 MW (at Chiyesu) and possibly connect to the main grid at Mwinilungu)</td><td>Zambia's first private MG. Cost: about USD 3 million with funding from NWPT and UK-based charities. Zengamina Power Co) was constructed between 2004-2008 and in operation since 2008. Power is supplied to about 700 customers (incl. plus Kalene Hill Mission and hospital, school, and some PUE (pineapple canning, rock crushing). A 33 kV line was built to supply a nearby commercial farm. Initially, average tariffs were about USD 0.08-0.11/kWh (different tariffs for HH, businesses and social services, later changed to USD 0.06-.13/KWh plus stepped tariff USD 7-9/month). Tariff system designed in public consultation. However, revenues are not enough to have financial viability, only achieving breakeven on OPEX (not CAPEX) after 7 years. Generation was about 2.2 GWh in 2019</td></tr>
</table>

Sources: GetInvest.eu (2019); Ruralec (Engie Case study), REA Presentations (P. Kabango; P. Mubanga), ENEA (2016), Muhanya solar (p.c.), Zengamina Power Co (p.c.), www.muhanyasolar.com, www.usadf.gov/off-grid; AfDB/Se4All (2018); GetInevst case study Sinda; ERB 2019

1.2 Barriers to renewable energy minigrid development

A) Policy-regulatory environment for minigrids

Baseline situation

The recent surge in mini-grid (MG) development has been helped by advances in MG-specific regulatory framework, focusing on licensing, economic and technical requirements. The 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. After the road-testing of the mini-grid regulations in 2019, the ERB finalized and approved the mini-grid regulatory framework in February 2020, which covers the four areas of legal, tariffs, grid encroachment and technical (see Box 35).

Box 6 Licensing process for minigrids

Business registration	Companies in Zambia are required to be registered with the Patents and Companies Registration Agency. There are no local ownership requirements f
Securing land	Securing land is an important step of the project development process. There are two categories of land in Zambia: a) Customary land, comprising about 94% of land in Zambia, is held under customary tenure and falls under the jurisdiction of Zambia's traditional authorities, the Chiefs; and b) Statutory (or state) land, comprising around 6% of land, is governed and administered by a number of statutory
Clearance from The Department of National Parks & Wildlife	If a proposed development site is located within a Game Management Area (GMA) or a National Park, the developer must submit an application to the Director of DNPW requesting clearance.
Concession from National Heritage Conservation Commission	If the project site is within a protected cultural heritage area, the developer must apply for a concession from the NHCC. All waterfalls in Zambia are designated as heritage areas.
Environmental permitting	A developer (i.e., the entity that is proposing and will be developing the project) cannot implement a project until the Zambia Environmental Management Agency (ZEMA) has granted a no objection letter with conditions for the project.
Water use permit	For hydropower projects, including mini-hydro projects, the developer must acquire a water use permit issued by the Water Resources Management Authority (WARMA).
Investment endorsement	While obtaining an investment endorsement is optional, its procurement is likely to guarantee a developer the appropriate licence to commence project operations and secure a tariff, as advised by the ERB. Public-private partnerships also need approval from MoE's Office of
Issuing of the Licence by ERB	Before commencing operations of a mini-grid, the developer must apply for a Combined Licence for Generation, Transmission, Distribution and Supply of Electricity from ERB. The developer can only request the licence after completing the off-grid construction

The new framework 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. Mini-grids of all sizes and technologies require a license to be approved by the ERB[21]. All mini-grid licenses are issued as combined generation, distribution and sales licenses, with the option to also only apply for a separate license. MGs that were already existing before ERB's MG regulations were introduced can continue without change in their licensing conditions or approved tariff system. Together with ZABS (Zambia Bureau of Standards), work has been carried out on technical standards for mini-grids.

Environmental impact studies are mandatory most of the time but can be simplified for small-scale projects with, for example, an Environmental Project Brief

[21] The ERB licensing fees are based on a percentage of the total investment cost (0.1%) and is payable as a one-off application fee as well as a monthly license fee (0.7% of monthly turnover. Applicants for solar energy projects are exempted from the monthly license fees

(EPB) which essentially is a simplified EIA. Both EIAs and EPBs require the approval of the Zambia Environmental Management Agency (ZEMA). For solar PV plants, storage batteries are regarded as hazardous wastes so solar power producers using battery storage are required to apply for a Hazardous Waste Licence in line with S.19(1) of the Regulations. This is a post-operational license that needs to be applied for after the plant becomes operational. The license is valid for three years. Application for renewal of a licence is to be made six months before expiry. Water use authorisations for hydropower plants are managed by Zambia's Water Resources Management Authority (WARMA). Fees and charges for hydropower projects are based on the amount of electricity generated and/or amount of water used. Hydropower projects under 500 kW exporting are exempt from the water permit requirement and all the prescribed fees.

Land use authorisations for MGs can be obtained through receiving a long-term lease from the Lands Commission. If the land in issue is under customary tenure, the Chief in the area would have to be approached for a right of use by the MG developer. Agreements with the local communities (local Chief) in accordance may be required to install the distribution network. The developer will be required to enter into an agreement (memorandum of understanding) with the community prior to submitting a full application with respect to agreed tariffs/end-user price between the developer and the community. This Village Level Agreement will form the basis for a tariff application with ERB as ERB allows for a different tariff regime for mini-grids based on cost recovery and backed by ability and acceptance of the community to pay.

Some tax, import duty and other non-fiscal incentives have been created to attract investments in renewable energy technologies. For example, a tax waiver was introduced for all imported goods for the purpose of supply, installation and maintenance of solar systems, regardless of investment size.

However, the discussion has been ongoing about what parts of renewable energy should be exempt and what not. Investors that invest more than USD 500,000 in a priority sector (which includes the energy sector) can also receive tax and import duty incentives. There are a number of incentives which are available for smaller projects[22].

Remaining barriers

- *The existence of clear strategies and budgeted policies on the role of minigrids vis-à-vis grid extension and stand-alone options for rural electrification in Zambia is limited*

As previously mentioned, the REMP requires revision. World Bank-supported geospatial modelling provides an indication where off-grid solutions (through mini-grid and stand-alone solar PV systems) will be the least-cost option for most rural areas, given the low population density and high grid extension cost. While geospatial planning forms a basis, at this point, the National Electrification Strategy is still a work in progress. Zambia does not have an approved electrification plan budget allocation between ZESCO and REA and how to involve the private sector in the huge amounts of investments needed for electrification (see Box 32). This means that it is necessary to conduct field research on the ground and consult closely with MoE, ZESCO, REA and ERB to identify and collate site-specific opportunities.

While ERB licensing for MGs has been streamlined, permits also depend on regulatory approval from other agencies (that may not have special procedures for small generating projects. An agency such as ERB or MoE's Promoting Private Power Investment (OPPPI) may be assigned as 'one-stop-shop' entity to coordinate better the various procedures and avoid lengthy licensing processes.

The approval of the mini-grid regulatory framework coincided with the adoption by the Government of the Electricity Act and Energy Regulation Act (drafted in 2019) in 2020. The new legislation impacts the mini-grid licensing processes, and introduces other changes, especially concerning feasibility studies, tariffs, construction, monitoring and enforcement. Thus, the MG framework will need to be aligned with the new laws, for example, regarding net-metering. Unfortunately, aspects of the new 'light-handed' regulations for minigrids seem to contradict stipulations in the updated Acts on equal treatment of licence applicants, whether large or small in size.

[22] Where the project investment is between USD 250,000 and USD 500,000, incentives may include investment guarantees

Box 7 Overview of mini-grid regulatory framework, Zambia

Topic	≤ 100 kW Very light handed	100-1000 kW Light handed regulated	≥ 1000 kW Fully regulated
Legal-licensing	• Fixed term, predetermined geographical area • Developer chooses tariff/usage charge design, ERB may intervene if tariffs too high	• Fixed term, predetermined geographical area • Pre-approved tariffs –developer provide 5-year tariff levels and escalation rates • ERB uses an in-house modelling tool to check the alignment of the tariff request	• Fixed term, predetermined geographical area • Normal tariff approval and review process -tariffs regulated in 5-year regulatory periods; tariffs adjusted every year
Tariff	• Mini-Grid free to apply tariffs after submission of data and data is deemed by ERB to be compliant with the requirements under the tariff rules. • ERB may intervene if tariffs are excessive. • Developer must show to ERB tariffs adjusted to reflect subsidy • Developer chooses tariff/usage charge design	• Up-front tariff approval • Developers are asked to provide 5-year tariff levels and escalation rates • ERB uses an in-house modelling tool to check the reasonableness of tariff request • Tariffs stay fixed in real terms for 5 years, subject to a change which breached “materiality threshold” • ERB may trigger a detailed tariff review for unreasonable Category II Mini-Grids tariffs. Developer chooses tariff/usage charge design	• Tariffs regulated in 5-year regulatory periods during Periodic Reviews. • Tariffs adjusted every year for cost true-up and indexation • Allowed costs calculated according to the building-block approach • Interim ERB approves “regulatory parameters” at beginning of each period • Review can be triggered depending on a “materiality threshold” • Developer chooses tariff/usage charge design

Technical requirements depend on installed generation capacity

Technical Requirements	≤2kW AC/DC	≤10kW AC/DC	>10kW AC	≥100kW AC	≥1,000kW AC
1. Project Planning	+	+	+	+	+
2. Environmental Assessment Study					
PV	-	-	-	-	+
Wind	-	-	-	(+)	+
Hydro	-	-	+	+	+
Bio	-	-	+	+	+
3. Construction	+	+	+	+	+
4. Generation and Storage	+	+	+	+	+
5. Distribution of energy	(+)	(+)	(+)	(+)	(+)
6. Consumer connection and Wiring	+	+	+	+	+
7. Metering	(+)	(+)	(+)	+	+
8.					
Health	+	+	+	+	+
Safety - Physical Security	+	+	+	+	+
Cyber Security	-	-	-	+	+
Environment	-	-	-	+	+
9. Assets Protection	+	+	+	+	+
10. Performance Reporting to ERB	(+)	(+)	(+)	+	+
11. Grid Connection	-	-	(+)	+	+

In case of future **main grid encroachment**, the MG Regulations allow following:

a. Main Grid (ZESCO, other) acquires only the client base and builds a complete new Distribution Network. Minigrid operator (MGO) abandons all assets of the Mini-grid and removes from the area.

b. Main Grid acquires the client base and the distribution network of the mini-grid. MGO disconnects and abandons all generation and storage assets of the mini-grid and removes from the area.

c. Main Grid acquires the client base and the complete distribution network, generation and storage assets of the mini-grid.

d. MGO becomes a Small Power Distributor for the Main Grid. MGO discontinues operation of his generation and storage assets and resells only energy from the Main Grid as a retailer. The customer base remains with the MGO.

e. MGO becomes a small power producer or integrated/embedded power producer. MGO sells all is generated energy to the Main Grid. Main Grid acquires the client base and the distribution network of the Mini-grid from MGO.

f. MGO and Main grid conclude contract for Net-metering. In case of excess energy from the Mini-grid, MGO has the right to sell the excess energy to the Main Grid. In case of energy deficit, the Main Grid delivers the requested energy to MG

Source: Electricity Regulation Board; GETInvest (2019)

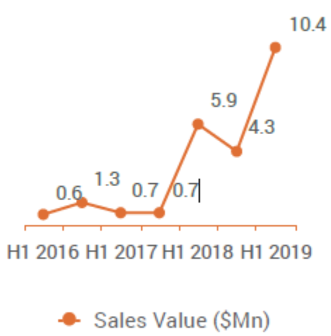
B) Business models and private sector involvement

Baseline situation

The mini-grid landscape in Zambia is nascent but rapidly evolving. Several delivery models for minigrid electricity have been deployed thus far in Zambia, including utility, private sector, community, and hybrid (public-private) models, which are summarised in Box 5. Until recently mini-grids were implemented by public sector agencies.

ZESCO operated seven isolated diesel-based mini-grids (of which only two remain in operation) and one MG based on mini-hydropower. REA put the first solar MG in operation in Mpanta in 2013 near Bangweulu Lake (with UNIDO/GEF funding). Recently, a minigrid using hydropower was commissioned by REA in Kasanjiku in North-Western Province. As REA can formally not own generation installation, the assets have been transferred to a community-based cooperative. In addition, some missions have operated mini-hydro facilities to power their buildings and surrounding community. The team behind the Zengamina project, Zambia's first private minigrid, has set up Hydro Electric Power (HEP) Limited to develop the independent hydro-powered minigrid business and is virtually the only private hydropower mini-grid developer up to date.

Box 8 Stand-alone solar market



Sales growth of stand-alone solar products

The share of households (HHs) using solar home system are (SHS) or solar lighting system (SLS) is fairly small, about 1% of rural households. The use of solar solutions is a relatively recent phenomenon in Zambia. About 91% of the households in the country obtained their first solar device just within the past five years, according to the recent WB Multi-Tier energy access study. The cost of purchase of a low capacity off-grid solution is lower than the grid connection fee. Thus, providing off-grid access through solar devices of at least 3 watts (or 12 watt-hours) can move Tier 0 households to higher tiers (most likely Tier 1 or 2) for access to electricity. Recent years have seen a proliferation of solar portable lighting products that give energy access to 4.3% of rural households. Although strictly speaking, the solar lanterns (<3 W with a single lantern, costing about USD 9-40) do not meet the Tier 1 criterion (see Box 31.) it is an important means for Tier 0 households (no access) to get some lighting services.

Alongside, a pico-SHS sector (< 10-30 W with LED light, radio, phone charging, costing about USD 70-200) is emerging as alternative between solar lanterns and more expensive larger solar home system (30-200 W or larger, costing about USD 300-500). Most common distribution models involve distribution through conventional dealer networks (distributor, retailer). The dealership model is often used for extending end-user financing (by providing credit to dealers and/or franchises to allow them to sell to clients on an instalment basis). This model is applied by companies (such as Azuri, Vitalite, Fenix/Engie). Another model is 'one-stop-shop' in which companies provide products move through a proprietary distribution channel, in which finance can be offered by the company manufacturer (e.g. Greenlight, SunTech, in Zambia). Other models include institutional partnership (in which a company teams up with a NGO or rural bank to market its products to its customer base/members)

Systems are usually bought by cash (82% in 2018) but PAYGO schemes are on the increase, in particular for larger systems, such as SHS. 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. According to the WB multi-tier energy access survey, only about 9% of respondents were willing to pay upfront for SHS. However, willingness to pay (WTP) could be boosted through PAYGO models with installment periods of 6 to 12 months to 15-21% level. The WB ESAP project is USD 2 million credit line loan facility for off-grid solutions aiming at companies importing/ selling solar equipment and developers of minigrids, and also, to set up PAYGO or similar financial mechanisms to boost affordability among end-users of solar equipment.

These companies could affordable and flexible products in the Tier 2 to 3 range and become competitors with minigrid developers in in the market MGs are aiming at. However, solar companies and MG developers may want to team up. In some cases (e.g., Engie, PowerGen, Azuri, GreenLIght) they can provide both services. One model is that the minigrid administration office also serves as 'solar kiosk' that sell or rent out solar products or charging services or 'business hub' offering support (technical, marketing, finance) on productive use to small businesses. In this way, the facility can reach out to households to offer lower Tier energy services according to their ability/willingness to pay or to serve remote households in the service area that are too far to be physically connected to the MG's distribution network

Source: *Mapping the Solar Market, Zambia* (Intellicap, Signify Foundation; 2019); GETInvest (2019)

Over the past years, several solar mini-grids are in operation, in construction or planned, either developed by the private sector or in some form of public-private partnership, supported by the European Union, Beyond the Grid for Africa, or others. Several private players have entered the MG market.

Muhanya Solar has implemented one 30 kW solar MG in Sinda (Eastern Prov.). Supported by the Beyond the Grid Fund for Zambia, EU's IAREP programme and other sources of funding, Standard Microgrid is planning to install up to 150 microgrids and has set up a 28 kW solar MG in Chitandika. Eastern Prov), while Engie PowerCorner is planning to set up 60 minigrids with Eu-IAREP support. Other entrants in the market include Entiba Energy (planning two 50 kW minigrids in Chitungulu with 250 kWh battery storage, Eastern Prov., providing power to some 150 new users), the Egyptian-based Solera, and ID Solar Solutions.

The first MG, installed by public entities or missions, did not have a commercial focus. However, with the participation of private companies, recent developments have seen service levels on a commercial basis. While some developers focus on low-demand customers (such as Standard MG), others have developed business models that focus on productive uses and small enterprises (such as Solera) or try to build a microgrid starting from anchor loads, such as schools and clinics[23] or a productive use (e.g., Engie PowerCorner). The private developers often use standardised equipment (e.g., Standard MG, 15 kW units; Solera's 25 kW SunSquare) that is pre-assembled and fits in a container for easy transport and can thus be deployed quickly. Most of them also include smart metering and cloud-based supply, as well as demand-side management and a payment platform, which helps them to reduce their operational cost.

Barriers to more commercial MG development

- *Most rural areas in Zambia have low population densities with low energy demand and servicing these customers may not be financially viable*

Most rural areas in Zambia have low population densities and servicing these customers may not be financially viable. Building up a customer base to increase the load factor and revenue stream is challenging in areas of low population density where economies of scale are lacking. Areas with low population densities also have high distribution costs, which further increases the costs to develop off-grid systems. At the usual 'social' tariff levels applied in Zambian MGs, both publicly and privately owned mini-grid operators (see the examples of Zengamina and Mpanta, mentioned in Box 5) report problems with payments by their customers and fee collection, combined with the lower-than-expected connection rate in the first years of operation. This puts severe limits on the revenue stream, leading to cash-flow problems and endangering their financial viability. The demand for energy services is related to the level of income and its influence on financial sustainability is often underestimated. Most of the mini-grid schemes have low load factors (20% to 50%), even after several years of operation, and only a percentage of the total households in the distribution area are connected. To achieve a sufficient load factor and to increase revenue streams, anchor loads such as telecom towers, agro-processing or other types of productive uses need to be included in the customer base.

- *Off-grid tariffs in Zambia are subjected to much social pressure, and willingness and ability to pay (WTP/ATP) are far lower than cost-reflective rates*

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. 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.

According to the 2015 Living Conditions Monitoring Survey, the average monthly income for households is about USD 75 in rural areas and USD 290 in urban. The average expenditure in rural areas was USD 70 a month (of which USD 40 on food

[23] E.g., Standard MG partnered with the NGO Empowered by Light providing lighting for schools).

items). Using a benchmark of 10% of income for estimated ability to pay (ATP) for electricity, rural households might be expected to afford USD 8-10/month.

Another way of determining ATP is to look at what non-electrified households spend on energy. The IAREP feasibility study mentions figures of USD 4-7 per month, while another report mentions USD 8.5 per month[24]. It should be noted that rural incomes can be highly seasonal; some agricultural households may face a lean period at the end of the "warm and wet" season (Nov-Apr), with tightened cash flows, which could affect the ability to pay (ATP) for electricity bills or upfront connection fees.

A World Bank study found a willingness to pay (WTP) by households of USD 4.6 a month for solar home systems and USD 8.4 for mini-grid service, while commercial users are willing to pay USD 30 a month[25]. Surveys undertaken as part of the before-mentioned IAREP feasibility study give WTP levels in the order of USD 1.3-3.3 up to USD 10 per month. It should be noted that WTP statements by respondents in such surveys may be influenced by their knowledge of actual monthly expenditures in neighbouring electrified areas and reflect the subsidized ZESCO tariffs, about USD 4.8 a month (residential) and USD 18.6 (businesses)[26] rather than their ability to pay (ATP).

The real cost of operation of minigrids is much higher. For example, the cost-reflective tariffs (based on levelized cost of energy, LCOE) for the Sinda, Lunga, Chunga and Chishi solar MGs is in the range of USD 0.98-1.65 per kWh). Such tariffs would imply monthly expenditures of USD 13-19 for low-income households, USD 40-46 for medium-income and USD 80-150 for higher-income households, clearly above ATP/WTP levels. In the case of Sinda solar MG, the tariff settled on a monthly fee of about USD 18.6-22 per month, translating into about (based on average consumption data) USD 0.23/kWh. The IAREP feasibility studies show that (with 75% capital subsidy and 15% return on investment), tariffs would be about USD 0.33-0.50 per kWh, which works out in monthly expenditures of USD 4.4-6.6 for low-income households, USD 13.7-15.8 for middle-income and USD 27.2-USD 51.4 for higher-income households[27]. These findings are in line with World Bank estimates that a CAPEX subsidy of 75% on a typical mini-grid would allow for affordable tariffs while delivering a 15% return on investment[28]. Revenues from electricity sales, even if increased by PUE, will in many cases hardly be enough for private minigrid companies to survive.

C) Financing and financing modalities

Baseline situation

Funding for the REF has been poor. Since the establishment of REA, inadequate financing of the REF has limited the growth of REA's operational capabilities, which in turn hampers rural access efforts. In general, the 3% levy for rural electrification collected on all retail electricity bills is not remitted in full to the REF. Even, if the electricity levy collections would be fully remitted, the amount would still fall short of the annual requirements of grid extension and densification in line with the universal energy access 2030 target. Due to the magnitude of resources required, all sources of funding should therefore be mobilized and aligned along the GRZ priorities, including from the private sector.

---

24 IAREP *Off-Grid Solar Market Trends report (2016),* Bloomberg; Lighting Global

25 As part of the preparations for the proposed Credit for an Energy Service Access Project, the World Bank (WB) used a study on willingness to pay (WTP) for rural electricity services in Southern Province in Zambia. See: ESB International (Electricity Supply Board), Feasibility Study for the Project "Sustainable Electricity Supply Southern Division", commissioned by the Government of Germany Division". ESB carried out a socioeconomic survey to randomly selected 233 households and 38 small businesses, 2015.

26 GETInvest (2018)

27 Typically, higher-income households include mainly people with some form of formal employment, rural health workers', schoolteachers' and government department/institutional staff houses. Source: IAREP, Call for Proposals, *Annex L, Additional documentation made available to the prospective applicants for Lot 1: Mini-grid and solar home system options in Lunga, Chunga and Chishi Island Demonstration Projects* (2019)

28 2017 Project Appraisal Document for an Electricity Service Access Project for Zambia

Box 9 REF budget inflows

(in USD)	REF – total inflow	Government	Donors, partners
2017	11,440,990	11,440,990	-
2018	13,416,793	9,963,448	3,453,345
2019	8,509,043	7,307,232	1,201,810

Converted from ZMW to USD using the exchange rates of 10.01 (2017), 11.94 (2018) and 14.09 (2019). Data compiled from REA Annual Reports (2017, 2018, 2019).

The financial sector in Zambia continues to experience high-interest rates and a severe shortage of liquidity. According to the World Economic Forum's Global Competitiveness Report 2015–2016, companies in Zambia consider access to financing the main constraint to growth. Loans to small and medium and off-grid energy companies are constrained by an insistence of the commercial banks on physical collateral (sometimes representing over 100% of the value of the loan), high interest rates (usually over 30% or higher), underdeveloped procedures related to credit risk quantification and asset-liability management, nascent credit information systems, and the dominance of short-term capital. In addition to commercial financing, privately developed mini-grids require public co-funding to cover the viability gap (the difference between the cost of providing a connection and what consumers are willing/able to pay for it). Crowding in both the domestic and international private sectors to expand access will require the GRZ to improve the enabling environment, including increasing access to commercial and concessional finance, developing financial mechanisms to provide public co-funding, resolving various regulatory hurdles, and building up the existing capacity of sector institutions

Barriers

- *Mini-grid initiatives are financed on a project-by-project basis, rather than as part of a long-term vision part of an off-grid electrification plan and without public or private funds to match*
- *Commercial financing for MGs 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*

The current tariffs applied in MGs are based on the willingness or ability to pay (WTP/ATP) but prevent reaching financial self-sustainability. Thus, to avoid that mini-grid electricity tariffs would have to be at rates that are intrinsically much higher than WTP/ATP-based tariffs, grant funding (from the government, cooperation partners or charities) remains to be a key enabler to finance the first mini-grids (as long as developers are bound by socially acceptable tariffs). *The downside of this is that minigrids tend to be financed on a project-by-project basis, rather than as part of a long-term vision part of an off-grid electrification plan and with funds to match.* Once the grants and other financial support ends of the multilateral or bilateral funding agency ends, the programme stops and new MG projects cease to be developed as these are not viable without some grant contribution.

Solar companies and mini-grid developers have expressed a strong need for debt financing in both U.S. dollar and Zambian kwacha, including working capital lines and long-term finance for mini-grids. The opportunity for domestic financing of private mini-grids is limited. The market, technology, and business models of minigrid companies are rather unknown to local commercial banks. This contributes to perceptions of high risk and banks prefer more conventional investment opportunities that have a higher return and lower risk profiles than MG. In addition, interest rates for loans in local currency are high, averaging 25.4% over the period 2006-2021[29], and significant collateral may be required. Bank loans also typically have short tenures but financing for mini-grid projects might require a 10-year credit line. Furthermore, if a mini-grid is to be built on land ruled by customary land (often the case in rural villages), a local bank cannot consider land as collateral in the financial eligibility assessment.

The Development Bank of Zambia (DBZ) offers slightly better options. DBZ has a private-sector project finance facility that allows for loans up to 10 years in ZMW or foreign currency. A two-year grace period may be available. The minimum loan

[29] Source: https://www.ceicdata.com/en/indicator/zambia/bank-lending-rate. Bank lending rate reached an all-time high of 33% p.a. in Jan 2006 and a record low of 16% p.a. in May 2013 and in March 2021 stood at 25.7%

size is USD 200,000 or its equivalent in ZMW. As part of the World Bank ESAP, a USD 2.5 million fund for the off-grid sector developers and companies will be made available via DBZ to commercial banks as part of the ESAP project.

- *Public support 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*

The Government of the Republic of Zambia (GRZ) established the Rural Electrification Fund (REF) in 1994 when it committed a 3% excise levy on electricity bills to the fund through an administrative arrangement. One goal in the Rural Electrification Act No. 20 of 2003, was for the new REA to oversee and manage the Fund. In practice, Other REF resources are appropriations by the Parliament and donors' contributions. In practice, the estimated USD 50 million per year funding requirement calculated by REA has not been achieved to date, and the levy from ZESCO is not (always) remitted, limiting REA's operations. The REF is one of three sources of funds for REA to implement the rural electrification programme in Zambia, the others being budget allocations from the Ministry of Finance, and loans and donations. To date, most of the funding has been for medium voltage transmission expansion and distribution systems connected to the ZESCO. Capital funding by REA for off-grid projects has been limited to about USD 3 million annually[30], based on data provided in its annual reports. This is only a fraction of what would be needed annually during 2022-2030 for mini-grid investments [31] and for electrification investments in general (USD 325 million annually; see Box 4).

The REF is in theory also able to support private sector rural electrification projects including mini-grids through 'smart capital subsidies'. REA can provide up to 100% grant financing for renewable energy projects. However, in the case of private sector participation, the private sector needs to contribute a minimum level of equal to 20% of the project costs and then, theoretically, REA can contribute to the project's funding (with remaining funds to be secured by the developer, at a minimum internal rate of return of 10% before subsidies) up to a maximum of 50%. *However, REF has been barely functional in practice for off-grid development. Information on how to access the Fund is not easily available and little is known by developers in Zambia*. So far, only one private mini-grid project, the Zengamina 750 kW hydro mini-grid, has successfully obtained support from REF.

D) Digitalisation and knowledge management

Baseline – mobile network

Zambia has mobile network coverage across populated areas and all service providers run mobile payment services. There are four mobile service providers: Airtel, MTN, Vodafone (data only) and Zamtel[32]. Coverage and access to mobile services are present in all 10 provinces including most of the districts. National geographical network coverage is 78% of the country and network coverage by population is 86% (ZICTA, 2021). All service providers are currently running mobile payment services on all their networks. Coverage aligns to densely populated areas such as urban areas, main road networks and selected rural areas. About 57% of adults own a mobile (21% in rural areas, while 65% have access to mobile services (48% in rural areas. The number of mobile internet users in the country is estimated at 10.4 million in 2021, representing approximately 56% of the population[33]. Most people who are digital literate are urban dwellers aged 40 and below, who have regular access to the internet. This means that people in rural settings or who do not have internet access most likely have inadequate digital literacy skills. About 70% of adults (9.5 million in 2020) have access to formal financial services, which is higher in urban areas (84%), where 53% of adults live, than in rural areas (56%), not surprisingly highest among

30 In 2017: USD 3.0 million, 2018: USD 3.6 million, 2019: USD 2.6 million, of which large part USD 3 million annually for the Kasanjiku mini-hydro

31 If the 3% levy on electricity sales would be transferred fully, this would boost REF. For example, taking ZESCO's sales revenues in 2017 of about USD 820 million would give USD 25 million. It is worth noting that the number of grid connections (densification and extension) in the 2022 geospatial model (see Box 32) has been made in line with ZESCO's financial ability to scale up which is the modelling has been estimated at some 100,000 annually (implicating an average USD 357 million annually over 2022-2031)

32 In 2021, Zamtel had the largest area coverage with 52%, followed by MTN Zambia (36%) and Airtel Zambia (43%). Source: ZICTA

33 http://onlinesystems.zicta.zm:8585/statsfinal/index.html

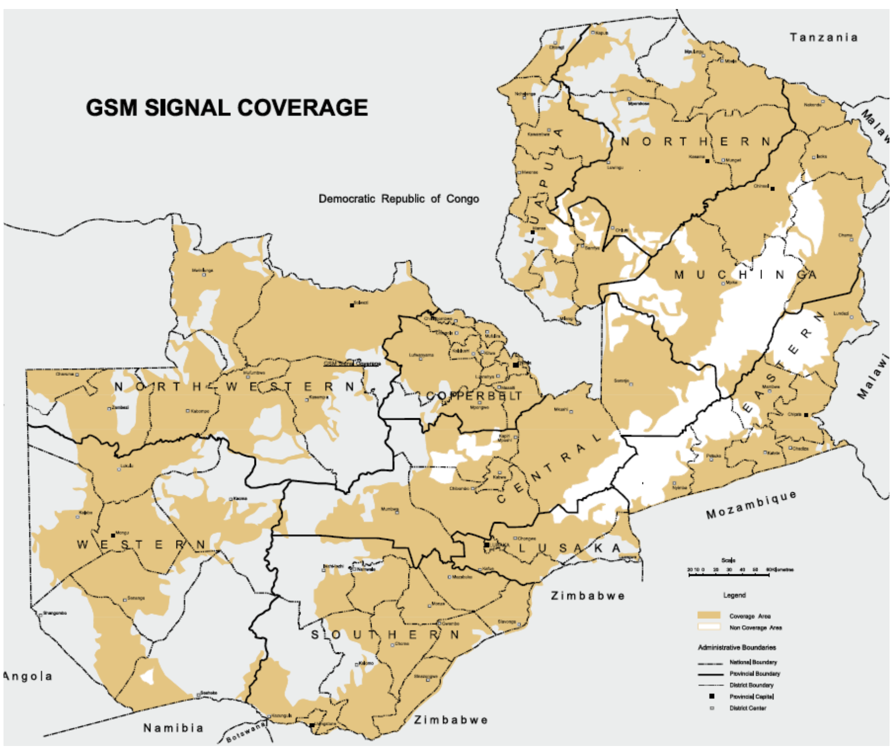
middle- and higher income groups (80-84%)[34]. In 2020, the existing base of users of digital finance services was approximately 16.6 million registered accounts, of which 6.5 million were considered active. This means a substantial increase in comparison with 2016 (7 million registered accounts of which 1.3 million are active). The number of active agents increased from 12,400 in 2016 to 90,166 in 2019, indicating rapid growth in the agent distribution work.

Mobile money usage in Zambia remains limited. There are several money transfer services and mobile money providers, including Airtel, MTN, Zoona, Kazang, Shoprite and Zanaco. According to the Helix Institute of Digital Finance, Zambia could become a mobile money market, whereby agents support customers to make transactions due to an apparent consumer preference for working with agents[35]

Baseline – Minigrids and digital services

Most private developers apply digital technology in their minigrids. Engie PowerCorner applies smart metering and the cloud-based payment platform greatly limits operation and management costs, such as logistics and fault resolution. All customers have access to electricity by topping up their pay-as-you-go (PAYGO) meter. Solera supports mobile money payments to pay for Services, through integration with telecom operators. 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. Similarly, Standard MG's cloud-based grid management software enables the technical support team to monitor the performance of many grids from one location and remotely troubleshoot issues that exceed the capacity of local management.

Box 10 Mobile geographical coverage



Source: Zambia Information and Communications Technology Authority (2015)

Remaining barriers

- 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, monitor quality of service) to broadly improve sector oversight and planning. Different MG developers use different software and data reporting protocols making standardization difficult. 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.

[34] Including commercial banks and other formal services (pensions, insurance, microfinance, mobile money) but not including informal services (local energy savings groups, or informal moneylenders/*kaloba*). Source: FinScope Zambia 2020 Survey Report

[35] GETInvest, 2019

Box 11 Mini-grid stakeholders, Zambia, and their role in project outputs

Stakeholder	Mandate and/or business
Ministry of Energy (MoE)	(MoE) is responsible for the development and management of energy resources in a sustainable energy policy, strategies, plans and programmes and the coordination of stakeholders in the sector. - Department of Energy (DoE) focuses on programs and projects relating to renewable energy, energy efficiency, electricity and power development. - Department of Planning and Information (DPI) policies and legislation and monitors and evaluates the Ministry's programs and projects. - The Office for Promoting Private Power Investment (OPPPI) is mandated to promote private investment in the electricity sector
Rural Electrification Authority (REA)	Under MoE, REA carries out public activities in connection with rural electrification, including management of the Rural Electrification Fund and the development and implementation of rural on-grid and off-grid electrification planning
Energy Regulation Board (ERB) and other agencies	ERB is responsible for, among others: electricity licensing (among others) of Independent Power Producers (IPPs), determination of electricity tariffs, development of standards (in collaboration with the Zambian Bureau of Standards), investigation of customer complaints and arbitration of conflicts among sector stakeholders. Several other agencies are involved in licensing and permits of minigrid operations (Box 6, including ZEMA Zambia Environmental Management Agency), NHCC (National Heritage Conservation Commission), WARMA (Water Resources Management Authority),
ZESCO Limited	ZESCO is fully owned by the Industrial Development Corporation, a state-owned investment holding company. ZESCO operates the electricity grid (transmission and distribution), is responsible for much of the country's power generation
Off-Grid Task Force	The Off-Grid Taskforce is a government-led platform which brings together representatives of various Government ministries, statutory bodies, the private sector and development partners to coordinate initiatives and activities in the off-grid electrification space.
Development Bank of Zambia, Pension Fund and commercial banks	DBZ has a private-sector project finance facility that allows for loans up to 10 years in ZMW or foreign currency. A two-year grace period may be available. The minimum loan size is USD 200,000 or its equivalent in ZMW. As part of the World Bank ESAP, a USD 2.5 million fund for the off-grid sector developers and companies will be made available via DBZ to commercial banks as part of the ESAP project. The idea is to entice selected commercial banks to enter in the off-grid market Some banks have expressed interest (e.g., Stanbic and Zanaco) provided there is minimum portfolio size, Another stakeholder is the Zambian National Pension Scheme Authority
ZARENA (Zambia Renewable Energy Association)	ZARENA is to promote and advocate for the increased use of renewable Energy by developing an effective network of members and stakeholders, emphasising the need for quality and best practices throughout the sector.
SIAZ (Solar Industry Association of Zambia (SIAZ)	SIAZ is a platform for the private sector within the rapidly growing off-grid solar industry (solar home systems and mini/micro grids). Active mini-grid developers, include Standard MG, Zengamira, Engie, Solera, Muhanya. Solar companies, include: Videre, Sunny Money, SunTech, ID Solutions, Muhanya, Sunray, Davis & Shirtliff, Fenix Int'l/Engie, Azuri
AMDA (Africa Mini-Grid Developers Associations	The regional industry association representing private utilities developing small, renewable, localized power grids. AMDA currently has 41 members across 17 African countries and has chapters in Zambia, Nigeria, Kenya and Tanzania
NGOs, universities	The Centre for Energy, Environment and Engineering Zambia (CEEEZ) is a non-governmental research organization whose activities involve analysis, policy recommendations, and the provision of training in energy and the environment. The Impact Assessment Association of Zambia (IAAZ) is an association formed in Zambia to provide a forum for advancing innovation and communication of best practices in environmental impact assessments At the University of Zambia (UNZA), the Department of Physics of the School of Natural Sciences is involved in energy and environment as related to consultancy, capacity-building and research in energy and the environment

Box 12 Policy and plans related to off-grid electrification

Policy / planning document	Relevance
Vision 2030 and National Development Plans	The National Long-term Vision 2030 (Vision 2030) expresses Zambia's aspirations for the year 2030. The vision will be operationalised through the five-year development plans, starting with the 5th National Development Plan, and annual budget. The 7th National Development Plan 2017 to 2021 (NDP) sets out the strategy to improve energy production and distribution for sustainable development by enhancing the generation, transmission and distribution of electricity, promoting renewable and alternative energy, and improving electricity access to rural and peri-urban areas
National Energy Policy (1994, revised 2008, 2019)	The NEP2008 set the scene for the liberalisation of the electricity sector and specifies measures to improve electricity access through a) enacting legislation for the public and private sector, b) investment and participation, and c) applying viability gap funding mechanisms, d) enabling isolated grid systems with cost-reflective tariffs. The 2019 update further mentions that The Government will also establish the Energy Fund. This Fund will facilitate the development of the entire energy sector.
Electricity Act and Energy Regulation Act (1995, amended 2003, and again in 2019/20)	The Acts provide the overarching legal framework for the generation, transmission, distribution and supply of electricity in Zambia, including the Electricity (Licensing) Regulations and the Electricity (Supply) Regulations. The Energy Regulation Act formally established the Energy Regulation Board (ERB) and defined its functions and powers.
Rural Electrification Act (2003)	The Act established the Rural Electrification Authority (REA), specified its functions and equipped it with a Rural Electrification Fund (REF)
Zambia Distribution Grid Code (2016)	The Code provides the basic rules, procedures, requirements and standards for the operation, maintenance, and development of electricity distribution systems in Zambia.
Renewable Energy Feed-in Tariff Strategy23 (2017)	REFit, established by the Ministry of Energy aims to increase national generation output through private sector investment in small and medium-size renewable energy plants of up to 20 MW. The scheme allocated 200MW of electricity capacity supply from renewable sources (of small to medium scale) to be connected with the grid.
The Power System Development Master Plan	Comprehensive sector planning document for the period up to 2030, developed in 2010
Rural Electrification Master Plan (REMP)	In 2008 REA developed REMP for the term 2009-2030. The plan identifies 1,217 un-electrified Rural Growth Centres (RGCs) to be electrified through grid extension, standalone solar systems and mini-grids by 2030 to achieve 51% rural electricity access. Largely outdated, the Plan is being updated with World Bank support (ESAP project) into a National Electrification Strategy (NES)
Minigrid Regulations	First developed in 2018 and approved by ERB in 2020, introduces very light-handed' regulations (regarding licensing, tariffs, technical; requirements, grid encroachment, power distribution) for minigrids below 100kW and 'light-handed' regulations for mini-grids between 100kW-1MW;
Environmental Management Act (2011)	This Act makes provision for integrated environmental management, the protection and conservation of the environment, and the sustainable management and use of natural resources and related matters. Part I sets out the principles governing environmental management.
Nationally Determined Contributions (NDC)	This document outlines Zambia's Intended Nationally Determined Contributions (INDCs), which aim for a reduction of between 20,000 $GgCO_{2e}$ and 38,000 $GgCO_{2e}$ or 25% and 47% against 2010 baseline conditions.

Box 13 Recent donor-supported rural energy programmes

- *Increased Access to Electricity and Renewable Energy Production (IAEREP)*

IAREP is a EUR 40 million EU-funded programme set to run up to 2022 to help improve the enabling environment for and encourage private sector participation in delivering energy access and clean energy services in Zambia. One component has focussed on "Enhancement of the Policy, Legal, Regulatory Environment, and Capacity Building for Renewable Energy and Energy Efficiency" and has supported the development of a MG-specific framework. The second Component has focussed on "Feasibility Studies and Demonstration Projects". A Call for Proposals was launched in 2019 in three Lots. Lot 1 covered mini-grid projects using solar photovoltaic technology for isolated communities in REA-selected sites (Lunga and Chunga, Chishi) for which feasibility studies were developed with IAREP support and to be implemented in PPP modality with REA. Lot 2 included proposals for off-grid renewable energy projects implemented by the private sector and Lot 3 energy efficiency proposals. The Call resulted in six grants awarded from a total of above EUR 23 million. One project was rewarded under Lot 1 (Lunga) and four (out of 10 presented) under Lot 2. Initiation of the projects has met quite some delays and issues have not been fully settled.

- *Electricity service access project*

The SIDA-funded Beyond the Grid for Africa (BGFA; managed by REEEP on behalf of the Swedish Embassy) operated between 2016-2020 with a budget of about EUR 20 million. A Call for Proposals was launched in 2018 and awarded four companies with co-financed grants in the area of solar PV products (Vitalite, and Engie/Fenix), improved cooking solutions (Clean Cooking Solutions), and microgrids (Standard MG). A second round was organised in 2020 for stand-alone products and minigrids (e.g., benefitting Zengamina, Vitalite, RDG Collective, and others). More information can be found at: https://beyondthegrid.africa/news/beyond-the-grid-fund-for-africa-signs-its-first-projects-with-off-grid-energy-service-companies-in-zambia/

- *World Bank Electricity Service Access Project*

This USD 36.8 million programme is being implemented by REA (during 2017-2023) to support on-grid electrification (component 1), including 'last mile' connections, and off-grid access expansion (component 2). Regarding off-grid, ESAP supports a) upstream activities to enable the private sector participation in rural off-grid electrification, including identifying and scoping off-grid sites and building the needed capacity at key institutions, and b) designing financial mechanisms. The new National Electrification Strategy (NES) and Geospatial Master Plan (see Box 4) are under development. World Bank made available two pilot financing facilities for private sector investment in energy access that have been operationalized from 2022: (1) An Off-Grid Smart Subsidy Program (OGESSP) of about USD 3.0 million for partial subsidies for private sector mini- grids[1], selected under the yet-to-be-developed National Electrification Strategy; (2) An Off-Grid Loan Facility of about USD 2.0 million, providing working capital, loans or trade finance available via the Development Bank of Zambia, and will offer loans to certain types of solar equipment suppliers (in USD or ZMW), mini-grid developers and end-users of solar equipment (e.g., productive uses) and to support PAYG (pay-as-you-go) schemes with developers and solar companies (in ZMW). *ZCF solar mills programme*

ZCF (Zambia Cooperatives Federation) has been implementing solar-powered hammer mills at a cost of about USD 200 million. The programme has aimed to install 2000 mills, mainly funded through a loan from the Development Bank of China. The ZCF would support the mini-milling plants by buying 2 million tonnes of maize per year to place on the market and contribute to the reduction of maize meal prices. Many have failed to sell maize bran in the quantities needed to raise the K 1700 per month repayment (to ZCF over a 15-year period), pay their staff and cover other costs, being limited by lack of battery storage so they cannot work outside sunny hours. It is not known how many solar mills are working at this moment. The PV system consists of 60 panels with a total 15 kW capacity, but in practice may be only 2 to 7 kW is used for milling. It has been suggested to increase viability by using the idle capacity to serve used as rural enterprise hubs for small economic activities, e.g., telecom, financial services (mobile payment, micro-finance), micro-businesses (repair shops) and to provide power to nearby houses.

- *AfDB-GCF Zambia Renewable Energy Financing Framework*

The USD 154 million programme (of which USD 52.5 million is provided by the Green Climate Fund) builds on the KfW-supported GETFiT (Global Energy Transfer Feed-in-Tariff) Zambia programme that aims to assist the Government in the implementation of its Renewable Energy Feed-in-Tariff (REFiT) Strategy (described in Annex G.2) for grid-connected independent power producers (PPs). The Programme does not provide direct financing to off-grid or mini-grid projects under development.

In addition, the programme has a technical assistance package (USD 4 million grants, of which USD 2.5 million provided by GCF and USD 1.5 million by AfDB) with two components. The first component aims at enhancing local financial institutions' RE and project financing capabilities. Its activities will support selected local financial institutions (FIs) (commercial banks and institutional investors, such as the Zambian National Pension Fund, NAPSA) in Zambia to build the expertise and processes that are needed to originate, appraise, finance and supervise renewable energy projects; and building the overall capacity of the Zambian financial industry for its enhanced understanding on renewable energy and infrastructure financing.

2. MINIGRID MODEL BUSINESS CASES

The Model Business Cases Annex analyses[36] 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), social services (school, clinic, community centre, worship), 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 grid, and for the commercial operation of the system. The latter includes maintenance of the PV generator and the distribution grid and connections and the sale of electricity to customers.

Box 14 Key data of recently proposed solar PV minigrids

IAREP tender	Lunga	Chishi	Mpanta	Average	Developer-identified (09 proposals)
Households	1,428	841	373	881	
Shops	25	16	12	18	
Barber shops	13	8	4	8	
Bar/restaurants	15	8	4	9	
Health clinic / post	1	1	1	1	
Primary school	1	3	1	2	
Secondary school	1	1	1	1	
Worship	9	5	6	7	
Offices	5	2	3	3	
Clients	1,498	885	405	929	419 (126-1390)
Demand (kWh/client/yr)	444	309	392	416	
Size (kW/client)	0.36	0.25	0.16	0.31	0.26 (0.08-0.61)
Size (kW)	537	224	66	276	86 (33-237)
Network (km)	17	18	8	16	
Investment/kW	5,321	7,700		6,042	6922 (3612-7614)
Investment/client	1,892	1,950		1,930	1560 (126-2553)
Investment ('000 USD)	2,858	1,740			590 (223-2614)

The model has been prepared considering experiences with pre-feasibility demand and minigrid supply analysis for the IAREP-supported Call for Proposals for REA-identified sites (for Lunga, Chishi and Mpanta) and a summary of nine developer-identified sites. A summary of characteristics is given in Box 39.

Assumptions

A model is prepared based on energy demand and load assumptions gathered from IAREP surveys (mid 2018) and other sources of information. The *Appendix to* this Annex provides more details.

A) Greenfield project: small minigrid (< 100 kW)

Case 1 Solar PV minigrid

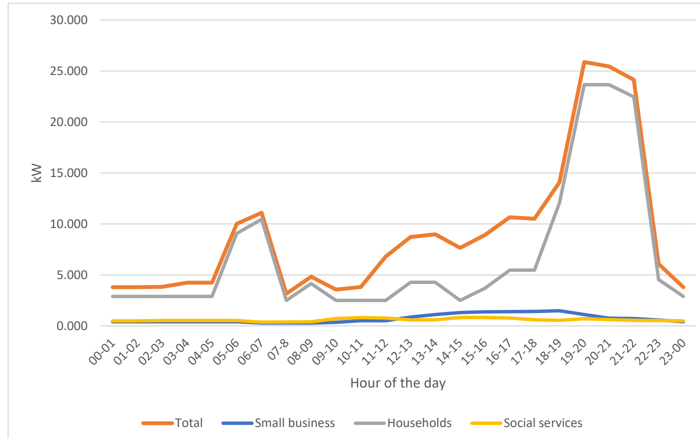
In this case, we assume a demand of 200 households (by year 7 of the MG implementation) plus some small businesses and social services (school, health) but no larger productive uses of energy (PUE). Not all villagers will connect in the first year. Demand will start at 50% of the demand in year 5 of 243 kWh per day and then increase. Between year 5 and year 10 demand is assumed to grow at 2% annually to 269 kWh/day with a daily peak load of 36 kW and thereafter demand remains flat. A minigrid based on solar PV-battery generation option will deliver electricity from 100% renewable energy[37]. 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 8.6 km, a distance which represents the relatively low population density in man.

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

37 The mini-grid does not have a diesel generator. The systems are assumed to be designed as such because the logistics of regularly procuring, transporting and storing diesel fuel and operating and maintaining a diesel generator can be challenging in remote areas

Box 15 Energy demand and load curve, minigrid (without large PUE)

Consumer group		Number	Total daily demand (kWh) (Year 10)	Peak power demand (kW)
Households	Subtotal	200	163.13	23.66
	35%	70	18.24	
	55%	110	87.01	
	10%	20	57.88	
Salon/barber		3	2.20	
Shops		4	8.98	1.07
Community/worship		1	0.92	
Office/powerhouse		1	1.43	0.36
Clinic	Small	1	8.75	0.45
School	Small	1	3.21	0.27
Bar/restaurant		2	6.03	0.44
Utilities		1	21.20	3.00
Total		*14*	*52.72*	
		214	**215.85**	
PUE		0	0.00	0.00
Total		**214**	**215.85**	**26.00**



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 214 clients by Year 5, after which demand will slowly increase to the maximum design value of 215.85 kWh per day. Relative low demand in the first year is a common problem and taken into account in the cost-benefit analysis table presented in Box 18

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 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 is assumed across all customer types. In reality, the tariff would likely be differentiated per end-user category. Zambia does not have an adapted tariff system for small minigrids and private mini-grids may charge different tariffs subject to regulatory approval.

Box 16 Minigrid solar PV capacity and battery configuration, Case 1 (village, no large PUE)

Base data, PV system					
PV system	69	kW	Unit cost	0.40	per Wp
Peak sun hours	4.78	per day	Solar panels	27,600	USD
System efficiency and degrad	0.92		Unit cost battery	100	USD/kWh
Sesasonal correction	1.22		Battery	43,200	USD
Degradation (oversizing factor)	1.15			432	kWh
Demand	78,784	kWh/yr	PV structures	8,280	
Daily energy demand	215846	Wh/day	Unit cost inverters	360	USD/kVA
Max power demand	26000	VA	Inverter	31,200	USD
System requirements	4996	Ah/day	Cabling, protection, etc	5,000	USD
Battery needs (900 Ah@6V) - storage 1 day DOD=.6	9160	Ah/day	Civil works, site	35,000	USD
Number of batteries	80		Protection, grounding, ect.	5,000	USD
Network LV	8.56	km	Spare parts	3,450	
Network MV in locality	0	km	*Total hardware cost*	*158,730*	*USD*
LV/MV substation (USD 6000 each)	0		Installation (at 7%)	11111	**USD**
Inverter	87	kVA	**Total coost**	**169,841**	USD
Voltage level	48	VDC			
Night time fraction	69%		**Cost per kW**	**2,461**	**USD/kW**
Usable energy	0.60		Cost per customer	742	USD/kW
Battery sizing factor	0.73		Capacity per client	322	kW/client

Month	Solar kWh/kW$_p$	Energy (kWh/month) Demand	Supply
Jan	3.91	6,691	6,694
Feb	4.11	6,044	6,350
Mar	4.49	6,691	7,683
Apr	5.03	6,475	8,332
May	5.20	6,691	8,890
Jun	5.15	6,475	8,523
Jul	5.21	6,691	8,907
Aug	5.40	6,691	9,240
Sep	5.42	6,475	8,978
Oct	5.05	6,691	8,644
Nov	4.36	6,475	7,220
Dec	3.99	6,691	6,825
Average	**4.78**		**96,287**

$$\textbf{Solar PV Capacity for a Solar PV Battery system (kW)} = \text{Daily electricity consumption in (kWh)} \times \textit{Seasonal Multiplier}\ (1.22) \div (1 - \textit{Losses Factor}\ (8\%)) \div \textit{Daily peak sun hours}\ (\textit{hours}) \times (1 + \textit{Solar PV Oversizing Factor}$$

$$\textbf{Battery Capacity for a Solar PV} - \textbf{Battery system(kWh)} = \text{Average daily electricity consumption in Year 3 (kWh)} \times \textit{Night time fraction}\ (\%)$$

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. Financing costs are not included as it is not known to what extent developers need to or are able to access debt financing.

Box 17 Ability and willingness to pay

According to the 2015 Living Conditions Monitoring Survey, the average monthly income for households is about USD 75 in rural areas and USD 290 in urban. Average expenditure in rural areas was USD 70 a month (of which USD 40 on food items). Using a benchmark of 10% of income for estimated ability to pay (ATP) for electricity, rural households might be expected to afford USD 8-10/month. Another way of determining ATP is to look at what non-electrified households spend on on-heating energy. The IAREP feasibility study mentions figures of USD 4-7 per month, while another report mentions USD 8.5 per month. It should be noted that rural incomes can be highly seasonal; some agricultural households may face a lean period at the end of the "warm and wet" season (Nov-Apr), with tightened cash flows, which could affect ability to pay for electricity bills or upfront connection fees. A World Bank study found a willingness to pay (WTP) by households of USD 4.6 a month for solar home systems and USD 8.4 for mini-grid service, while commercial users are willing to pay USD 30 a month. Surveys undertaken as part of the before-mentioned IAREP feasibility study gives WTP data in the order of USD 1.3-3.3 up to USD 10 per month. It should be noted that WTP statements by respondents in such surveys may be influenced by their knowledge of actual monthly expenditures in neighbouring electrified areas and reflect the subsidized ZESCO tariffs, about USD 4.8 a month (residential) and USD 18.6 (businesses) rather than their ability to pay (ATP).

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. Another consideration is REA's internal set of rules which stipulates that support for private electrification initiatives cannot exceed 50% of the initial investment. The table on the left in Box 18 presents four cases:

(a/b) No grant is available

The LCOE is USD 0.811/kWh. If no investment subsidy is provided, even lower-income households would have to pay about USD 7.19-9.80 a month (tariff at USD 0.91-1.24/kWh, giving a project IRR of 12-18%). The social discount rate is assumed to be 12%. This is above the ATP/WTP range (discussed in Box 19). 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 in general), especially in the initial years, has been one issue in minigrids in Zambia in the past.

(c/d 50% grant funding.

The LCOE is USD 0.494 per kWh. If a 50% investment grant is provided, their monthly payment drops to USD 4.38-5.69 per month (tariff at USD 0.55-0.72/kWh, giving a project IRR of 12-18%). This is more within the range of ATP/WTP.

A likely business case is that of a 50% investment subsidy, which would allow a small profit margin for the developer, at end-user tariffs that would be in the range of ATP/WTP of lower-income households.

Another issue is financing. In case there is no grant financing, the developer needs to provide 100% or get debt financing. Box 44 presents the scenario in which the developer provides 15% equity (with 85% debt financing). This is debt is not readily available to finance minigrid investments in Zambia, while few developers will be able to provide 100% equity. Grant support will also from this viewpoint help get the financing mix (grant with equity and/or debt). Box 19 presents the case of 50% grant, 15% equity and 35% debt financing, assuming the end-user is charged USD 0.718 USD/kWh.

Box 18 Solar PV minigrid CAPEX, OPEX and LCOE with tariff and subsidy optimization

Solar PV generation			
Size		**69**	kW
Economic lifetime		20	yr
Demand		78,784	kWh/yr
Max production		1	kWh/yr
Total cost, solar PV		169,841	USD
O&M, insurance		3.5%	
Replacement batteries (after 10 yrs)		43,200	USD
Distribution and wiring system			
Unit cost		11,000	USD
Length LV distribution system		8.6	km
Unit cost		16,000	USD
Length MV lines		0.0	km
Subtotal cost (LV, MV, station)		94,160	USD
HH metering & wiring USD/client	180	38520	USD
Total cost		132,680	USD
O&M, insurance		3.5%	
Transport, customs and logistics	15%	45,378	USD

Lifecycle cost per unit of kWh		
Discount rate	12%	
Investment cost per kW	5042	USD/kW
Investment, solar mini-grid	**347,899**	**USD**
Annualised cost of investment	52,360	USD/yr
Operation and maintenance (O&M)	10,588	USD/yr
Total annual cost	**62,948**	
LCOE, hydropower mini-grid	*0.811*	*USD/kWh*
Capital subsidy	50%	
Grant support	**173,950**	USD
Discount rate	12%	
Investment, solar mini-grid	173,950	USD
Annualised cost of investment	29,072	USD/yr
Operation and maintenance (O&M)	10,588	USD/yr
Total annual cost	**39,660**	**USD/yr**
LCOE, solar PV	*0.494*	*USD/kWh*

Investment cost (USD/client)	**1626**
Breakdown investment cost (USD/kW)	**5042**
- Site, civil works	557
- Generation	665
- Storage	1078
- Distribution	1923
- Other	819

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	ZMW
Tariff (USD/kWh)	0.9078	LL HH	7.19	108
Benefits (Revenues - costs)		MM HH	21.84	328
		HI HH	79.91	1199
NO GRANT + margin		**Monthly payment**		
TARIFF LEVEL FOR IRR=18%			USD	ZMW
Tariff (USD/kWh)	1.2368	LL HH	9.80	147
Benefits (Revenues - costs)		MM HH	29.76	446
		HI HH	108.87	1633
GRANT REA/GEF	50%	**Monthly payment**		
TARIFF LEVEL FOR NPV=0			USD	ZMW
Tariff (USD/kWh)	0.5533	LL HH	4.38	66
Benefits (Revenues - costs)		MM HH	13.31	200
		HI HH	48.70	731
GRANT REA/GEF + margin	50%	**Monthly payment**		
TARIFF LEVEL FOR IRR=18%			USD	ZMW
Tariff (USD/kWh)	0.7180	LL HH	5.69	85
Benefits (Revenues - costs)		MM HH	17.27	259
		HI HH	63.20	948

					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		**347,899**	0	0	0	0	0	0	0	0	0	43,200
O&M Cost			USD			10,588	10,588	10,588	10,588	10,588	10,588	10,588	10,588	10,588	10,588
Consumption MG (kWh/yr)						35,607	49,850	56,971	64,093	71,214	72,668	74,151	75,664	77,208	78,784
Consumption non-PUE						35,607	49,850	56,971	64,093	71,214	72,668	74,151	75,664	77,208	78,784
Consumption PUE(kWh/yr)						0	0	0	0	0	0	0	0	0	0
NO GRANT															
TARIFF LEVEL FOR NPV=0	Tariff	0.9078	USD/kWh			0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91
	Revenues MG		USD million			32,325	45,254	51,719	58,184	64,649	65,969	67,315	68,689	70,090	71,521
Benefits (Revenues - costs)	Disc rate	12%	NPV	0	-347,899	21,736	34,666	41,131	47,596	54,061	55,380	56,727	58,100	59,502	17,733
			IRR	12%											
NO GRANT + margin															
TARIFF LEVEL FOR IRR=18%	Tariff	1.2368	USD/kWh			1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24
	Revenues MG		USD million			44,038	61,654	70,461	79,269	88,077	89,874	91,708	93,580	95,490	97,439
Benefits (Revenues - costs)	Disc rate	12%	NPV	144,123	-347,899	33,450	51,065	59,873	68,681	77,488	79,286	81,120	82,992	84,902	43,650
			IRR	18%											
GRANT REA/GEF	50%														
TARIFF LEVEL FOR NPV=0	Tariff	0.5533	EUR/kWh			0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	Revenues MG		USD million			19,701	27,582	31,522	35,463	39,403	40,207	41,028	41,865	42,719	43,591
Benefits (Revenues - costs)	Disc rate	12%	NPV	0	-173,950	9,113	16,994	20,934	24,874	28,815	29,619	30,439	31,277	32,131	-10,197
			IRR	12%											
GRANT REA/GEF + margin	50%														
TARIFF LEVEL FOR IRR=18%	Tariff	0.7180	USD/kWh			0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
	Revenues		USD million			25,566	35,792	40,905	46,019	51,132	52,175	53,240	54,327	55,435	56,567
Benefits (Revenues - costs)	Disc rate	12%	NPV	72,154	-173,950	14,978	25,204	30,317	35,430	40,543	41,587	42,652	43,738	44,847	2,778
			IRR	18%											

	Year 11	**Year 12**	**Year 13**	**Year 14**	**Year 15**	**Year 16**	**Year 17**	**Year 18**	**Year 19**	**Year 20**
Capital Cost	0	0	0	0	0	31,200	0	0	0	0
O&M Cost	10,588	10,588	10,588	10,588	10,588	10,588	10,588	10,588	10,588	10,588
Consumption MG (kWh/yr)	78,784	78,784	78,784	78,784	78,784	78,784	78,784	78,784	78,784	78,784
Consumption non-PUE	78,784	78,784	78,784	78,784	78,784	78,784	78,784	78,784	78,784	78,784
Consumption PUE(kWh/yr)	0	0	0	0	0	0	0	0	0	0
NO GRANT – Tariff	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91
NO GRANT – Revenues MG	71,521	71,521	71,521	71,521	71,521	71,521	71,521	71,521	71,521	71,521
NO GRANT – Benefits (Revenues - costs)	60,933	60,933	60,933	60,933	60,933	60,933	29,733	60,933	60,933	60,933
NO GRANT + margin – Tariff	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24
NO GRANT + margin – Revenues MG	97,439	97,439	97,439	97,439	97,439	97,439	97,439	97,439	97,439	97,439
NO GRANT + margin – Benefits (Revenues - costs)	86,850	86,850	86,850	86,850	86,850	86,850	55,650	86,850	86,850	86,850
GRANT REA/GEF – Tariff	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
GRANT REA/GEF – Revenues MG	43,591	43,591	43,591	43,591	43,591	43,591	43,591	43,591	43,591	43,591
GRANT REA/GEF – Benefits (Revenues - costs)	33,003	33,003	33,003	33,003	33,003	33,003	1,803	33,003	33,003	33,003
GRANT REA/GEF + margin – Tariff	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
GRANT REA/GEF + margin – Revenues	56,567	56,567	56,567	56,567	56,567	56,567	56,567	56,567	56,567	56,567
GRANT REA/GEF + margin – Benefits (Revenues - costs)	45,978	45,978	45,978	45,978	45,978	45,978	14,778	45,978	45,978	45,978

Box 19 Solar PV minigrid financial indicators (with 50% grant, 35% debt financing and 15% equity)

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	-174																				
Earnings EBITDA	-174	15	25	30	35	41	42	43	44	45	3	46	46	46	46	46	46	15	46	46	46
pre-tax NPV 72																					
IRR 18.0%																					
payback (yrs) 5.0																					
Depreciation		-12	-12	-12	-12	-12	-12	-12	-12	-12	-12	-12	-12	-12	-12	-12	-12	-12	-12	-12	-12
Earnings EBIT (before interest and tax)		3	14	19	24	29	30	31	32	33	-9	34	34	34	34	34	34	3	34	34	34
Cost of finance				-22	-20	-19	-17	-14	-12	-8	-5	0	0	0	0	0	0	0	0	0	0
Earnings before taxes		3	14	-3	3	10	13	17	20	25	-13	34	34	34	34	34	34	3	34	34	34
Tax		0	0	0	0	0	-2	-2	-3	-3	0	-4	-4	-4	-4	-9	-9	-1	-9	-9	-9
Net income		3	14	-3	3	10	12	15	18	22	-13	30	30	30	30	26	26	2	26	26	26
Plus:																					
Depreciation and interest		12	12	34	32	30	28	26	23	20	16	12	12	12	12	12	12	12	12	12	12
Cash flow (after tax)	-174	15	25	30	35	41	40	41	41	42	3	42	42	42	42	37	37	14	37	37	37
IRR 16.1%																					

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	226																				
Soft loan	0						0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bank loan	122			-30	-30	-30	-30	-30	-30	-30	-30										
Change in cash	174	15	25	0	6	11	10	11	11	12	-27	42	42	42	42	37	37	14	37	37	37
Cumulative cash balance	174	189	214	215	220	231	241	252	263	275	248	289	331	373	414	452	489	503	541	578	615

Financing requirement

	Amount (USD 000)	Annual repayment	Share	Interest	Grace period	Repay period
Grant	174		50.0%			
Equity	52		15.0%			
Soft loan	0	0.00	0.0%	8.0%	5	10
Local loan	122	-29.86	35.0%	18.0%	2	8

Corporate tax rate	
yr1-4	0.0%
yr5-13	12.5%
yr14-	25.0%

End-user tariff 0.718 USD/kWh

For this modelled case (with 50% grant and 35% loan), an end-user tariff of USD 0.72/kWh, with a 50% grant, can provide a 16% required return on investment in some scenarios. Box 20 provides the financial aspects of the case with no grant, 85% debt financing, showing it will also give an IRR of 16%, provided the end-user is charged the full tariff of USD 1.24 per kWh. However, such a tariff may approach the limitations of the lower-income households' ability to pay, while lower tariffs will not allow the developer to have a margin or even restrict the lender's ability to repay the loan.

In the no-grant case, the average tariff is USD 1.237/kWh, implying monthly expenditure of the lower-income households of USD 9.80 per month with middle-income households spending USD 30 a month. A 50% grant would enable reducing the end-user tariff to USD 0.718/kWh, implying monthly expenditures of lower-income households of USD 5.70 and USD 17 a month, respectively.

A developer of the hypothetical mini-grid site may need to find ways to address the gap between revenue needed for viability and customer affordability, such as:

- Reducing investment and operational costs. Another way to reduce cost is to develop a portfolio of sites in the same area by achieving some economies of scale.
- Having tariffs that vary per customer group. If, for example, the tariff for business users is higher, these can cross-subsidize the lower-income group.
- It is attractive to increase the productive or commercial uses of energy. In particular, if these are already operational from year 1, these can help to boost revenues in the first years when the demand has not yet reached its full level (see the comment on low demand in the first years of operation in Box 15).

A solar PV 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, the initial and anticipated future load, the number of larger consumers and, customer ability to pay and expectations for the level.

Box 20 Solar PV minigrid financial indicators (with no grant, 85% debt financing and 15% equity)

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	-348																				
Earnings EBITDA	-348	33	51	60	69	77	79	81	83	85	44	87	87	87	87	87	87	56	87	87	87
pre-tax NPV 144																					
IRR 18%																					
payback (yrs) 5.0																					
Depreciation		-23	-23	-23	-23	-23	-23	-23	-23	-23	-23	-23	-23	-23	-23	-23	-23	-23	-23	-23	-23
Earnings EBIT (before interest and tax)		10	28	37	45	54	56	58	60	62	20	64	64	64	64	64	64	32	64	64	64
Cost of finance				-53	-50	-46	-41	-35	-28	-20	-11	0	0	0	0	0	0	0	0	0	0
Earnings before taxes		10	28	-17	-4	9	15	23	31	41	9	64	64	64	64	64	64	32	64	64	64
Tax		0	0	0	0	0	-2	-3	-4	-5	-1	-8	-8	-8	-8	-16	-16	-8	-16	-16	-16
Net income		10	28	-17	-4	9	13	20	27	36	8	56	56	56	56	48	48	24	48	48	48
Plus:																					
Depreciation and interest		23	23	76	73	69	64	58	52	44	34	23	23	23	23	23	23	23	23	23	23
Cash flow (after tax)	-348	33	51	60	69	77	77	78	79	80	42	79	79	79	79	71	71	48	71	71	71
IRR 16.2%																					

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	52																				
Soft loan	0						0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bank loan	296			-73	-73	-73	-73	-73	-73	-73	-73										
Change in cash	0	33	51	-13	-4	5	5	6	7	7	-30	79	79	79	79	71	71	48	71	71	71
Cumulative cash balance	0	33	85	72	68	73	78	84	90	97	67	146	225	304	383	454	525	572	643	714	785

Financing requirement

	Amount (USD 000)	Annual repayment	Share	Interest	Grace period	Repay period
Grant	0		0.0%			
Equity	52		15.0%			
Soft loan	0	0.00	0.0%	8.0%	5	10
Local loan	296	-72.52	85.0%	18.0%	2	8

Corporate tax rate	
yr1-4	0.0%
yr5-13	12.5%
yr14-	25.0%

End-user tariff 1.237 USD/kWh

Case 2 – Minigrid with micro-hydropower

This Model Business Case analyses the financial feasibility of an off-grid micro-hydropower plant supplying the same hypothetical community in rural Zambia, discussed in Case 1. By a generic example, 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 is able to 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.

As in case 1, the hypothetical village is assumed to have 250 households by year 5 of the MG implementation (with 90% of energy demand and 100% reached by year 10) plus some small businesses and social services (school, health) but no larger productive uses of energy (PUE). Not all villagers will connect in the first year. Demand will start at 35% of the maximum design demand of 216 kWh per day and then increase. Between year 5 and year 10 demand is assumed to grow at 2% annually to the full 216 kWh/day with a maximum daily peak load of 26 kW and thereafter demand remains flat (see also Box 15 for the demand load profile). Given the anticipated load profile, the hydropower plant is estimated to have a power capacity of 26 kW.

Investment and operating costs for the hydropower plant and for the distribution network are provided in Box 21. These are based on data published by IRENA and GET.Invest and other sources. 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,

Box 21 CAPEX and OPEX, 32 kW micro hydropower facility

Hydropower (unit cost figures)	USD	USD/kW
Site preparation and infrastruct (road)	3,400	136
Civil works (inlet, forebay, penstocks, support)	64,600	1,900
Powerhouse	6,800	200
Electromechanical equipment	57,800	1,700
Installation and supervison	34,000	1,000
TOTAL	**166,600**	**4,900**

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 16). The main mini-grid system parameters, CAPEX, OPEX, LCOE and are summarised in **Box 21.**

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. The table on the left in Box 22 presents four cases:

(a/b) No grant is available
The LCOE is USD 0.64/kWh. If no investment subsidy is provided, even lower-income households would have to pay about USD 7-10 a month (tariff at USD 0.61-0.84/kWh, giving a project IRR of 12-18%). The social discount rate is assumed to be 12%. This is above the ATP/WTP range (given in Box 19). 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, has been one issue in minigrids in Zambia in the past.

(c/d 50% grant funding.
The LCOE is USD 0.45 per kWh. If a 50% investment grant is provided, their monthly payment drops to USD 4.2-7.3 per month (tariff at USD 0.37-0.48/kWh, giving a project IRR of 12-18%). This is more within the range of ATP/WTP.

A likely business case is that of a 50% investment subsidy, which would allow a small profit margin for the developer, at end-user tariffs that would be in the range of ATP/WTP of lower-income households.

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.

B) Greenfield project: case of small minigrid (< 100 kW) with demand stimulation

Case 1 Adding productive use of energy (PUE)

From the perspective of the minigrid operator, productive users of power are the most valuable. Their usage tends to be significant and predictable, thus forming a reliable source of revenue. Indirectly, 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 larger 'productive uses' in the Zambian rural context are maize milling, irrigation (of cash crops), cold storage (e.g., for artisanal fishing communities) and local workshops. The business case studied examines the inclusion of a maize mill (sized 5 kW) and one or two repair- or workshops with a 1.5 kW power demand.

Box gives a summary with the following assumptions:

- Annual added demand is 14,782 kWh/year (after year 1 and staying constant thereafter) bringing total energy demand (after year 10) to 309,314 kWh/yr. The PUE is only operated during the day. Thus, the system peak load remains the same, 26 kW. In the case of hydropower, the system kW size remains the same.

Box 22 Hydropower minigrid CAPEX, OPEX and LCOE with tariff and subsidy optimisation

Hydropower generation			
Size		**26.00**	kW
Economic lifetime		20	yrs
Max production		204,984	
Load utilization		38%	
Demand		78,784	kWh/yr
Total cost, hydropower generation		156,680	USD
O&M, insurance		5.5%	
Distribution and wiring system			
Unit cost		11,000	USD
Length LV distribution system		8.6	km
Unit cost		16,000	USD/km
Length MV lines		0	km
Subtotal cost		94,160	USD
HH metering & wiring USD/client	180	38520	
Total cost		132,680	
O&M cost		3.5%	
Transport, customs and logistics	15%	43,404	USD
Overhaul (year 16)	50%	78340	
Lifecycle cost per unit of kWh			
Discount rate		12%	
Investment cost per kW		12799	
Investment, hydropower minigrid		**332,764**	USD
Annualised cost of investment		44,550	USD/yr
Operation and maintenance (O&M)		13,261	USD/yr
Total annual cost		**57,811**	
LCOE, hydropower mini-grid		*0.861*	*USD/kWh*
Capital subsidy		50%	
Grant support		**166,382**	
Discount rate		12%	
Investment, hydropower minigrid		166,382	USD
Annualised cost of investment		22,275	USD/yr
Operation and maintenance (O&M)		13,261	USD/yr
Total annual cost		**35,536**	**USD**
LCOE, hydropower plant		*0.522*	*USD/kWh*

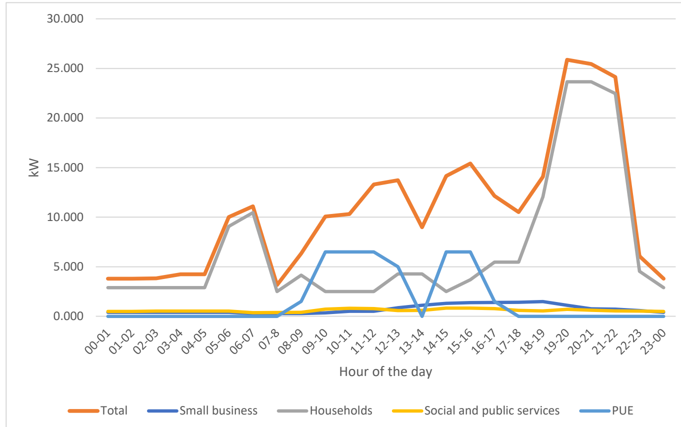
The table below gives the implications of different tariffs for the monthly payments of different household groups.

NO GRANT		**Monthly payment**		
TARIFF LEVEL FOR NPV=0			USD	ZMW
Tariff (USD/kWh)	0.9033	LL HH	7.16	107
Benefits (Revenues - costs)		MM HH	21.84	328
		HI HH	79.51	1193
GRANT REA/GEF 50%		**Monthly payment**		
TARIFF LEVEL FOR IRR=18%			USD	ZMW
Tariff (USD/kWh)	1.2181	LL HH	9.65	145
Benefits (Revenues - costs)		MM HH	29.76	446
		HI HH	107.23	1608
GRANT REA/GEF	50%	**Monthly payment**		
TARIFF LEVEL FOR NPV=0			USD	ZMW
Tariff (USD/kWh)	0.5642	LL HH	4.47	67
Benefits (Revenues - costs)		MM HH	13.31	200
		HI HH	49.67	745
GRANT REA + profit margin	50%	**Monthly payment**		
TARIFF LEVEL FOR IRR=18%			USD	ZMW
Tariff (USD/kWh)	0.7219	LL HH	5.69	85
Benefits (Revenues - costs)		MM HH	17.27	259
		HI HH	63.20	948

						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		**332,764**	0	0	0	0	0	0	0	0	0	0	0		0	0	0	78,340	0	0	0	0
O&M Cost				USD			13,261	13,261	13,261	13,261	13,261	13,261	13,261	13,261	13,261	13,261	13,261	13,261	13,261	13,261	13,261	13,261	13,261	13,261	13,261	13,261
Consumption MG (kWh/yr)							35,607	49,850	56,971	64,093	71,214	72,668	74,151	75,664	77,208	78,784	78,784	78,784	78,784	78,784	78,784	78,784	78,784	78,784	78,784	78,784
Consumption non-PUE							35,607	49,850	56,971	64,093	71,214	72,668	74,151	75,664	77,208	78,784	78,784	78,784	78,784	78,784	78,784	78,784	78,784	78,784	78,784	78,784
Consumption 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		0.9033	USD/kWh			0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
	Revenues MG			USD million			32,164	45,030	51,462	57,895	64,328	65,641	66,980	68,347	69,742	71,166	71,166	71,166	71,166	71,166	71,166	71,166	71,166	71,166	71,166	71,166
Benefits (Revenues - costs)	Disc rate	12%		NPV	0	-332,764	18,903	31,768	38,201	44,634	51,067	52,380	53,719	55,086	56,481	57,904	57,904	57,904	57,904	57,904	57,904	57,904	-20,436	57,904	57,904	57,904
				IRR	12%																					
NO GRANT + margin		0%																								
TARIFF LEVEL FOR IRR=18%	Tariff		1.2181	USD/kWh			1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22
	Revenues MG			USD million			43,374	60,724	69,399	78,074	86,749	88,519	90,325	92,169	94,050	95,969	95,969	95,969	95,969	95,969	95,969	95,969	95,969	95,969	95,969	95,969
Benefits (Revenues - costs)	Disc rate	12%		NPV	137,928	-332,764	30,113	47,463	56,138	64,812	73,487	75,258	77,064	78,908	80,789	82,708	82,708	82,708	82,708	82,708	82,708	82,708	4,368	82,708	82,708	82,708
				IRR	18%																					
GRANT REA/GEF		50%																								
TARIFF LEVEL FOR NPV=0	Tariff		0.5642	EUR/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 MG			USD million			20,090	28,126	32,144	36,162	40,180	41,000	41,837	42,691	43,562	44,451	44,451	44,451	44,451	44,451	44,451	44,451	44,451	44,451	44,451	44,451
Benefits (Revenues - costs)	Disc rate	12%		NPV	0	-166,382	6,829	14,865	18,883	22,901	26,919	27,739	28,576	29,429	30,301	31,190	31,190	31,190	31,190	31,190	31,190	31,190	-47,150	31,190	31,190	31,190
				IRR	12%																					
GRANT REA + margin		50%																								
TARIFF LEVEL FOR IRR=18%	Tariff		0.7219	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			USD million			25,705	35,987	41,128	46,269	51,410	52,460	53,530	54,623	55,737	56,875	56,875	56,875	56,875	56,875	56,875	56,875	56,875	56,875	56,875	56,875
Benefits (Revenues - costs)	Disc rate	12%		NPV	69,088	-166,382	12,444	22,726	27,867	33,008	38,149	39,198	40,269	41,361	42,476	43,614	43,614	43,614	43,614	43,614	43,614	43,614	-34,726	43,614	43,614	43,614
				IRR	18%																					

Box 23 Impact of large PUE on energy demand, load curve and LCOE of a small-sized minigrid

Consumer group		Number	Total daily demand (kWh) (Year 10)	Peak power demand (kW)
Households	Subtotal	200	163.13	23.66
	35%	70	18.24	
	55%	110	87.01	
	10%	20	57.88	
Salon/barber		3	2.20	
Shops		4	8.98	1.07
Community/worship		1	0.92	
Office/powerhouse		1	1.43	0.36
Clinic	Small	1	8.75	0.45
School	Small	1	3.21	0.27
Bar/restaurant		2	6.03	0.44
Utilities		1	21.20	3.00
Total		*14*	*52.72*	
		214	215.85	
PUE		2	40.50	0.00
Total (rounded)		**216**	**256.35**	**26.00**



Appliance	Power rating (W)	Number per village	Total power (W)	Daily usage (hrs)	Daily demand (kWh)	Max power kW
Water pumping	2500	0	0	4	-	0.00
Hammer mill	5000	1	5000	6	30.00	5.00
Workshop	1500	1	1500	7	10.50	1.50

- In case of solar PV, the battery capacity is slightly expanded to allow for one day of storage. To accommodate the increased energy demand, the panel must increase from 69 to 82 kW.

The hydropower system does not need to be resized to accommodate the new demand and load (as long the system cam meet the peak demand, which is in the evening). The PV system needs to be expanded but at a lower total cost per kW (as the battery storage is not expanded due to the daytime of the PUE). In both cases, adding a PUE outside peak hours has a positive impact on the LCOE (see the comparison between cases in the summary Box 27)

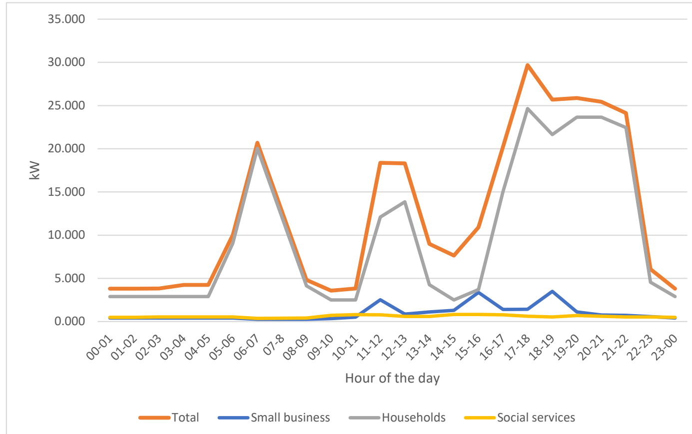
Case 2 Demand stimulation with electric cooking

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 microgrid electricity, thereby boosting the sales of power. The grids can hereby offer lower power tariffs, hereby partly offsetting the increase in the monthly power bill.

The Business case discussed here assumes a 850 W HE cooker is used by 1/4 of the middle-income households and a 1 kW HE cooker by half of the high-income households (for 2 hours a day). The figures are average, so can also be interpreted as meaning that half of the middle-income 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 demand will increase (in comparison with the case without PUE and without HE cooking, see Section A.2), thus larger solar PV or hydropower capacity is needed under the assumption that the peak demand increase remains relatively small (due to demand-side management measures). Indicators of the case are presented in Box 24.

Box 24 Impact of electric cooking on energy demand and load curve of a small-sized minigrid

Consumer group	Number		Total daily demand (kWh) (Year 10)	Peak power demand (kW)
Households	Subtotal	200	239.88	24.66
	35%	70	18.24	
	55%	110	133.76	
	10%	20	87.88	
Salon/barber		3	2.20	
Shops		4	8.98	1.07
Community/worship		1	0.92	
Office/powerhouse		1	1.43	0.36
Clinic	Small	1	8.75	0.45
School	Small	1	3.21	0.27
Bar/restaurant		2	12.03	2.42
Utilities		1	21.20	3.00
Total		*14*	*58.72*	
		214	**298.60**	
PUE		0	0.00	0.00
Total		**214**	**298.60**	**30.00**



Hydropower generation		**Solar PV generation**	
Size	**30.00** kW	Size	**96** kW
Economic lifetime	15 yrs	Economic lifetime	15 yr
Max production	236,520	Demand	108,988 kWh/yr
Load utilization	46%	Max production	1 kWh/yr
Demand	108,988 kWh/yr	Total cost, solar PV	205,312 USD
Total cost, hydropower generation	175,400 USD	O&M, insurance	3.5%
O&M, insurance	5.5%	Replacement batteries (after 10 yrs)	56,160 USD
Distribution and wiring system		**Distribution and wiring system**	
Unit cost	11,000 USD	Unit cost	11,000 USD
Length distribution system	8.6 km	Length LV distribution system	8.6 km
Unit cost	16,000 USD	Unit cost	16,000 USD
Length MV lines	0 km	Length MV lines	0 km
Subtotal cost	94,160 USD	Subtotal cost	94,160 USD
HH metering & wiring USD/client 180	38520	HH metering & wiring USD/client 180	38520 USD
Total cost	132,680	Total cost	132,680 USD
O&M cost	3.5%	O&M, insurance	3.5%
Transport, customs and logistics 15%	46,212 USD	**Transport, customs and logistics** 15%	50,699 USD
Overhaul (year 16) 50%	87700		
Lifecycle cost per unit of kWh		**Lifecycle cost per unit of kWh**	
Discount rate	12%	Discount rate	12%
Investment cost per kW	11810	Investment cost per kW	4049 USD/kW
Investment, hydropower minigrid	**354,292** USD	**Investment, solar mini-grid**	**388,690 USD**
Annualised cost of investment	52,019 USD/yr	Annualised cost of investment	65,315 USD/yr
Operation and maintenance (O&M)	14,291 USD/yr	Operation and maintenance (O&M)	11,830 USD/yr
Total annual cost	**66,309**	**Total annual cost**	**77,145**
LCOE, hydropower mini-grid	*0.664 USD/kWh*	*LCOE, hydropower mini-grid*	*0.658 USD/kWh*
Capital subsidy	50%	Capital subsidy	50%
Grant support	**177,146**	**Grant support**	**194,345** USD
Discount rate	12%	Discount rate	12%
Investment, hydropower minigrid	177,146 USD	**Investment, solar mini-grid**	194,345 USD
Annualised cost of investment	26,009 USD/yr	Annualised cost of investment	36,780 USD/yr
Operation and maintenance (O&M)	14,291 USD/yr	Operation and maintenance (O&M)	11,830 USD/yr
Total annual cost	**40,300 USD**	**Total annual cost**	**48,610 USD/yr**
LCOE, hydropower plant	*0.404 USD/kWh*	*LCOE, solar PV*	*0.403 USD/kWh*

Base data, PV system			
PV system	96 kW	Unit cost	0.40 per Wp
Peak sun hours	4.78 per day	Solar panels	38,400 USD
System efficiency and degrad	0.92	Unit cost battery	100 USD/kWh
Sesasonal correction	1.22	Battery	56,160 USD
Degradation (oversizing factor)	1.15		561.6 kWh
Demand	108,988 kWh/yr	PV structures	11,520
Daily energy demand	298596 Wh/day	Unit cost inverters	360 USD/kVA
Max power demand	30000 VA	Inverter	36,000 USD
System requirements	6912 Ah/day	Cabling, protection, etc	5,000 USD
Battery needs (900 Ah@6V)		Civil works, site	35,000 USD
- at 1.05 days storage DOD=.6	11750 Ah/day		
Number of batteries	104	Protection, grounding, ect.	5,000 USD
Network LV	8.6 km	Spare parts	4,800
Inverter	100 kVA	*Total cost*	*191,880 USD*
Voltage level	48 VDC	Installation (at 7%)	13,432 USD
Night time fraction	64%	**Total cost**	**205,312 USD**

Box 25 Impact of demand stimulation through HE cooking on tariffs and household demand (solar minigrid)

Case 1, no investment grant | **Case 2, with 50% investment grant**

Without HE cooking (see Section 2)

NO GRANT + margin		**Monthly payment, grant = 50%**		0%	GRANT REA/GEF + margin	50%	**Monthly payment, business case**		
TARIFF LEVEL FOR IRR=18%			USD	ZMW	TARIFF LEVEL FOR IRR=18%			USD	ZMW
Tariff (USD/kWh)	1.2368	LL HH	9.80	147	Tariff (USD/kWh)	0.7180	LL HH	5.69	85
Benefits (Revenues - costs)		MM HH	29.76	446	**Benefits (Revenues - costs)**		MM HH	17.27	259
		HI HH	108.87	1633			HI HH	63.20	948

With HE cooking, expenditures at previous tariff

NO GRANT + margin		**Monthly payment, grant = 50%**		0%	GRANT REA/GEF + margin	50%	**Monthly payment, business case**		
TARIFF LEVEL FOR IRR=18%			USD	ZMW	TARIFF LEVEL FOR IRR=18%			USD	ZMW
Tariff (USD/kWh)	1.2368	LL HH	9.80	147	Tariff (USD/kWh)	0.7180	LL HH	7.34	110
Benefits (Revenues - costs)		MM HH	45.74	686	**Benefits (Revenues - costs)**		MM HH	26.56	233
		HI HH	165.30	2479			HI HH	95.96	854

With HE cooking, with lower tariffs due to the demand stimualtion

NO GRANT + margin		**Monthly payment, grant = 50%**		0%	GRANT REA/GEF + margin	50%	**Monthly payment, business case**		
TARIFF LEVEL FOR IRR=18%			USD	ZMW	TARIFF LEVEL FOR IRR=18%			USD	ZMW
Tariff (USD/kWh)	1.0023	LL HH	7.94	119	Tariff (USD/kWh)	0.5833	LL HH	4.62	69
Benefits (Revenues - costs)		MM HH	37.07	556	**Benefits (Revenues - costs)**		MM HH	21.57	324
		HI HH	133.96	2009			HI HH	77.96	1169

It is interesting to analyse the impact of the penetration of HE cooking (based on the before-mentioned assumptions). The average energy demand in middle-income and high-income will increase from 0.791 kWh and 2.894 kWh/day to 1.216 kWh and 4.394 per day. However, as tariffs can be lowered (assuming the same project IRR goal) the actual expenditures will be relatively less. For example, a middle-income household that (assuming there is no grant financing) spends USD 29.76 a month (in the case of no HE cooking scenario, paying a tariff of USD 1.24/kWh) would see its expenditure increase 1.5-fold to almost USD 46 a month. However, the demand stimulation has a positive effect on the system tariff (now at USD 1.00 per kW) so that the actual average payments are less (USD 37 a month). In other words, more households cooking (as long as it's not overloading the system) means higher revenues.

While electricity expenditures increase, electric cooking has benefits in terms of time savings and avoided fuel costs. Cooking some foods (such as beans) can take considerable time and consume quite a lot of wood (or charcoal). The cooker may be an extensive item, about USD 90, hence, it was assumed that low-income households cannot or do not want to acquire the cooker[38].

Comparison of cases of the village with 200 households with and without demand stimulation

	Microhydro, 200 H			**Solar PV, 200 HH**		
LCOE (USD/kWh)	**w/ e-cooking**	**w/ PUE**	**no demand stimulation**	**w/ e-cooking**	**w/ PUE**	**no demand stimulation**
No grant	0.664	0.721	0.861	0.658	0.708	0.811
Grant 50%	0.404	0.437	0.522	0.403	0.432	0.494

The general conclusion is that, if demand-side measures are taken to avoid increasing peak load, demand stimulation can have a positive impact on the system's levelized cost of energy (LCOE).

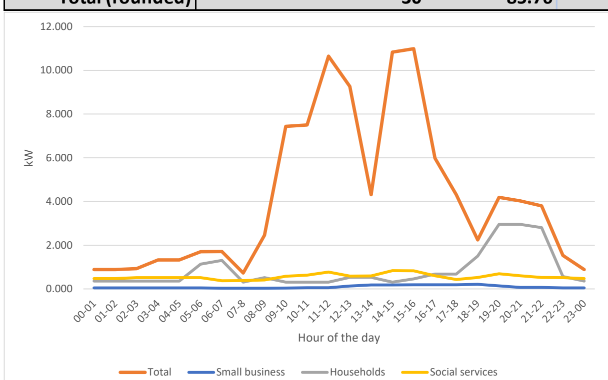
38 Based on Electric Pressure Cooking: Accelerating Microgrid e-Cooking through Business & Delivery Mode Innovations (PowerGen, CLASP; 2020)

C) Brownfield project: minigrid overlay on existing PUE

The Zambia Cooperative Federation ZCF (Zambia Cooperatives Federation) has been implementing a programme solar-powered hammer mills at a cost of about USD 200 million. The programme has aimed to install 2000 mills in various parts of Zambia. Most of the machines are used for milling maize, a staple food in Zambia, and each is powered by 60 solar panels with a capacity of 15 kilowatts.

Box 26 Business case of rehabilitation and expansion of ZCF-supported solar mill

Consumer group		Number	Total daily demand (kWh) (Year 10)	Peak power demand (kW)
Households	Subtotal	25	20.39	2.96
	35%	9	2.28	
	55%	14	10.88	
	10%	3	7.24	
Salon/barber		0	0.00	
Shops		1	2.25	0.21
Community/worship		0	0.00	
Office/powerhouse		1	1.43	0.19
Clinic	Small	0	0.00	0.45
School	Small	0	0.00	0.27
Bar/restaurant		0	0.00	0.00
Utilities		1	21.20	3.00
Total		*3*	*24.87*	
		28	**45.26**	
PUE		2	40.50	0.00
Total (rounded)		**30**	**85.76**	**11.00**



Solar PV generation			
Size		**28**	kW
Economic lifetime		20	yr
Demand		31,304	kWh/yr
Max production		1	kWh/yr
Total cost, solar PV		81,791	USD
O&M, insurance		4.0%	
Replacement batteries (after 10 yrs)		17,280	USD
Distribution and wiring system			
Unit cost		11,000	USD
Length distribution system		1.2	km
Subtotal cost		13,200	USD
HH metering & wiring	USD/client 180	5400	USD
Total cost		18,600	USD
O&M, insurance		4.0%	
Transport, customs and logistics	15%	15,059	USD

Lifecycle cost per unit of kWh		
Discount rate	12%	
Investment cost per kW	4123	USD/kW
Investment, solar mini-grid	**115,449**	**USD**
Annualised cost of investment	17,770	USD/yr
Operation and maintenance (O&M)	4,016	USD/yr
Total annual cost	**21,785**	
LCOE, solar mini-grid	*0.682*	*USD/kWh*
Capital subsidy	50%	
Grant support	**57,725**	USD
Discount rate	12%	
Investment, solar mini-grid	57,725	USD
Annualised cost of investment	10,042	USD/yr
Operation and maintenance (O&M)	4,016	USD/yr
Total annual cost	**14,057**	**USD/yr**
LCOE, solar PV	*0.425*	*USD/kWh*

The original investment of about USD 27,000 is an estimated of the value of the 15 kW solar PV and auxiliary equipment installed and does not include the value of the productive use (the mill) itself. It is assumed that the cooperative will own the productive use in agreement as off-taker with the energy developer.

Budget (USD)	115,449
Original investment (ZCF)	26,880
Gap	88,569
Grant	30,845
Developer	57,725

The plants were designed not only to power the mills but also for other services in the vicinity, such as powering up to 25 houses or small commercial uses. However, this has not happened in practice, as this would require battery storage and other adaptations in the power generation system not taken into account in the original design. Second, the lack of battery storage and inability to work properly on cloudy days was cited by about 60% of respondents in a recent survey as reasons of the low performance of the mills. This has had a vicious effect of farmers not supplying maize if they are not sure if it can be milled[39].

[39] *Economic Assessment of Solar Milling Plants*, by. H. Hunyenyembe in Texila International Journal of Management (2015)

The ZCF has approached REA with the idea to pilot a number of solar mills to act as an energy service hub for small economic activities and supply electricity to nearby dwellings. The business case presented here assumes the realization of the original idea of installing sufficient power capacity to provide the milling service, while also providing power to 25 houses, a small shop and a small workshop. It is assumed that the whole investment cost of the solar generation is about USD 115,500, including a capacity of 28 kW solar, battery storage and a small power distribution network, of which cost the amount of USD 57,725 (50%) is invested by the developer with the other half including the USD 26,900 estimated as the value of the originally installed 15 kW solar panels) and the remaining investment gap covered by a grant (e.g. GEF).

D) Larger minigrid (> 100 kW) with PUE

The last business case presented here is a community with 1500 households with various small commercial activities, productive uses (maize mill, workshops) and several social-public services (secondary school, health centre and offices). While in a larger minigrid certain economics of scale are achieved, the cost of distribution is relatively higher as, due to distances covered, a MV line with MV/LV substations needs to be added, unlike the cases discussed in sections G.1 to G. There is demand stimulation in the form of larger PUE (maize milling, technical workshop, water pumping). Overall, the resulting LCOE is therefore similar to the previous cases. This business case corresponds to the larger PPP solar PV minigrids that have been proposed or supported by REA (such as Lunga or Chishi, see Box 14**)** or the proposed 200 kW hydropower minigrid at Chipota Falls.

E) Summary of business cases

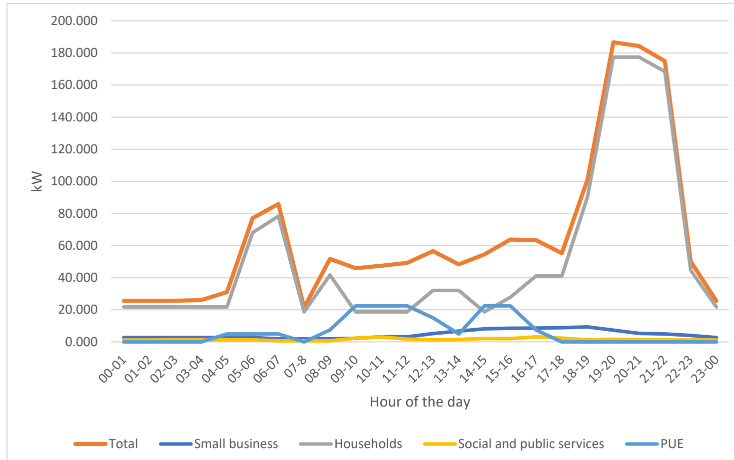
Box 27 Summary table, business cases

		Cases included as example in Output 2.1 pilots				Alternatives			
	All pilots	***1. Greenf*** **HE cooking PV**	***2. Greenfield PV***	***3. Greenfield (hydro)***	**4. ZCF** ***Inverse overlay***	***5. Greenfield PV (PPP)***	***6. Greenfield*** **PV+PUE**	**7. Greenfield** ***Large hydro (PPP)***	**8 Greenfield** ***Large PV (PPP)***
Average daily consumption (kWh/yr/client)									
- residential		438	298	298	298	298	298	303	303
- social and public		2,592	2592	2592	4,130	2,592	2,592	1,200	1,200
- small commercial		941	698	698	820	698	698	773	773
- large PUE					7,391		7,391	6,590	6,590
Number of clients	672	214	214	214	30	214	216	1,579	1,579
- residential	625	200	200	200	25	200	200	1500	1500
- social and public	17	5	5	5	2	5	5	18	18
- small commercial	28	9	9	9	1	9	9	52	52
- large PUE	1				1		2	9	9
Investment cost	1,300,252	388,690	347,899	332,764	230,899	347,899	363,759	2,577,982	2,659,207
- GEF INV grant	650,126	194,345	173,950	166,382	115,449	50,588	181,880	616,074	656,687
- REA/DoE confirmed cofin (grant)/ZCF	26,880	0	0	0	26,880	182,392		1,345,833	1,345,833
- Other (developer); 50%	592,402	194,345	173,950	166,382	57,725	114,920	181,880	616,074	656,687
Levelised cost (LCOE; USD/kWh) w/ grant		0.403	0.494	0.522	0.425	n/a	0.432	n/a	
Levelised cost (LCOE, w/o grant), USD/kWh		0.658	0.811	0.861	0.682	0.811	0.708	0.866	0.821
Number of pilots	5	1	1	1	2	1	1	1	1
Annual energy consumption (kWh/yr)	297,859	108,988	78,784	78,784	31,304	78,784	93,566	574,949	574,949
Installed capacity (kW)	247	96	69	26	56	69	82	187	503
- cost per kW RE capacity	5264	4049	5042	12799	4,123	5,042	4,436	13,786	5287
Installed battery capacity (kWh)	1339	562	432	-	346	432	475	-	3197
GHG (avoided diesel generator) tCO2/yr	282.0	93.4	67.5	67.5	53.6	67.5	80.2	492.6	492.65
Lifetime emissions (20 yrs; tCO2)	5,641	1,868	1,350	1,350	1,073	1,350	1,603	9,853	9,853
Emissions (using AMG methodology)	527	185	155	155	33	155	169	1,143	1,143
Lifetime emissions (20 yrs; tCO2)	10,542	3,694	3,090	3,090	668	3,090	3,386	22,865	22,865
Energy bill, households, with 50% grant									
Tariff at project IRR=18% (USD/kWh)		0.583	0.718	0.722	0.672	0.718	0.627	0.710	0.721
- Lower-income HH (USD/month) - no cooking		3.57	5.69	5.69	5.32	5.69	4.97	6.49	6.59
- Middle-income HH (USD/month)		21.57	17.27	17.27	16.17	17.27	15.09	17.35	17.35
- Higher-income HH (USD/moth)		77.96	63.20	63.20	59.15	63.20	55.21	62.49	63.47
Description in Annex		G.2 Case 2	G.1 Case1	G.1 Case 2	G.3		G.2 Case 1	G.4	G.4

Monthly expenditures, HH w/ and w/o e-cooking (USD/month)		
MI HH with e-cooking	26.06	32.07
MI HH with no e- cook	14.03	17.27
HI HH with e-cooking	84.61	104.15
HI HH with no e-cooking	71.30	87.77
LI HH with e-cooking	12.16	14.97

Box 28 Business case of larger minigrid (hydropower or solar PV)

Consumer group	Number		Total daily demand (kWh) (Year 10)	Peak power demand (kW)
Households	Subtotal	1500	1244.44	177.41
	35%	525	157.76	
	55%	825	652.58	
	10%	150	434.10	
Salon/barber		12	8.78	
Shops		25	56.15	6.21
Community/worship		9	8.24	
Office/powerhouse		5	7.14	2.52
Clinic	Large	1	16.52	0.80
School	Large	1	4.98	0.55
Bar/restaurant		15	45.26	3.33
Utilities		2	21.20	3.00
Total		*70*	*168.26*	
		1570	**1412.70**	
PUE		9	162.50	0.00
Total		**1579**	**1575.20**	**187.00**



Hydropower generation					**Solar PV generation**				
Size			**187.00**	kW	Size			**503**	kW
Economic lifetime			20	yrs	Economic lifetime			20	yr
Max production			1,474,308		Demand			574,949	kWh/yr
Load utilization			39%		Max production			1	kWh/yr
Demand			574,949	kWh/yr	Total cost, solar PV			966,520	USD
Total cost, hydropower generation			895,890	USD	O&M, insurance			3.0%	
O&M, insurance			4.5%		Replacement batteries (after 10 yrs)			319,680	USD
Distribution and wiring system					**Distribution and wiring system**				
Unit cost			11,000	USD	Unit cost			11,000	USD
Length LV distribution system			63.2		Length LV distribution system			63.2	km
Unit cost			16,000		Unit cost			16,000	USD
Length MV lines			21	km	Length MV lines			21	km
Subtotal cost			1,061,613	USD	Subtotal cost			1,061,613	USD
HH metering & wiring	USD/client	180	284220		HH metering & wiring	USD/client	180	284220	USD
Total cost			1,345,833		Total cost			1,345,833	USD
O&M cost			3.0%		O&M, insurance			3.0%	
Transport, customs and logistics		15%	336,259	USD	**Transport, customs and logistics**		15%	346,853	USD
Overhaul (year 16)		50%	447945						
Lifecycle cost per unit of kWh					**Lifecycle cost per unit of kWh**				
Discount rate			12%		Discount rate			12%	
Investment cost per kW			13786		Investment cost per kW			5287	USD/kW
Investment, hydropower minigrid			**2,577,982**	USD	**Investment, solar mini-grid**			**2,659,207**	**USD**
Annualised cost of investment			345,137	USD/yr	Annualised cost of investment			398,810	USD/yr
Operation and maintenance (O&M)			80,690	USD/yr	Operation and maintenance (O&M)			69,371	USD/yr
Total annual cost			**425,827**		**Total annual cost**			**468,180**	
LCOE, hydropower mini-grid			*0.866*	*USD/kWh*	*LCOE, hydropower mini-grid*			*0.821*	*USD/kWh*
Capital subsidy			50%		Capital subsidy			50%	
Grant support			**1,232,149**		**Grant support**			**1,329,603**	USD
Discount rate			12%		Discount rate			12%	
Investment, hydropower minigrid			1,345,833	USD	**Investment, solar mini-grid**			1,329,603	USD
Annualised cost of investment			180,179	USD/yr	Annualised cost of investment			220,804	USD/yr
Operation and maintenance (O&M)			80,690	USD/yr	Operation and maintenance (O&M)			69,371	USD/yr
Total annual cost			**260,869**	**USD**	**Total annual cost**			**290,175**	**USD/yr**
LCOE, hydropower plant			*0.509*	*USD/kWh*	*LCOE, solar PV*			*0.492*	*USD/kWh*

Base data, PV system					
PV system	503	kW	Unit cost	0.40	per Wp
Peak sun hours	4.78	per day	Solar panels	201,200	USD
System efficiency and degrad	0.92		Unit cost battery	100	USD/kWh
Sesasonal correction	1.22		Battery	319,680	USD
Degradation (oversizing factor)	1.15			3196.8	kWh
Demand	574,949	kWh/yr	PV structures	60,360	
Daily energy demand	1575202	Wh/day	Unit cost inverters	360	USD/kVA
Max power demand	187000	VA	Inverter	224,400	USD
System requirements	36463	Ah/day	Cabling, protection, etc	7,500	USD
Battery needs (900 Ah@6V)			Civil works, site	60,000	USD
- at 1 days storage DOD=.6	66849	Ah/day			
Number of batteries	592		Protection, grounding, ect.	5,000	USD
Network LV	63.2	km	Spare parts	25,150	
Network MV in locality	21	km	***Subtotal cost***	***903,290***	***USD***
LV/MV substation (USD 6000 each)	5		Installation (at 7%)	63,230	
Inverter	623	kVA	**Total cost**	**966,520**	

ANNEX Energy demand base data

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 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.

Without 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
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
Cooker	850	0	0	2	-	0.000
Small refrigerator	50	0.5	25	12	0.300	0.025
Total					**0.791**	

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	0	0	2	-	0.000
Refrigerator	150	0.75	112.5	12	1.350	0.113
Phone charging	5	2	10	2	0.020	0.010
Total					**2.894**	

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
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	0.25	212.5	2	0.425	0.213
Small refrigerator	50	0.5	25	12	0.300	0.025
Total					**1.216**	

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	0.75	750	2	1.500	0.750
Refrigerator	150	0.75	112.5	12	1.350	0.113
Phone charging	5	2	10	2	0.020	0.010
Total					**4.394**	

- Lower- income households living in one or two-roomed mainly grass-thatched houses use lighting, phone chargers and radio/TV with daily consumption of 373 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 living in mainly grass-thatched or sometimes 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 791 Wh.
- High-income rural end-users living mainly in iron sheet roofed houses would 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 2,894 Wh. It should be noted that the

Shops/small commercial

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 system/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
Phone charger	5	2	10	8	0.080	0.01
Total					**2.25**	**0.25**

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	15	1	15	8	0.120	0.02
Clipper/shaver	40	1	40	4	0.160	0.04
Phone charger	5	2	10	8	0.080	0.01
Total					**0.73**	**0.11**

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	150	1	150	12	1.800	0.15
HE cooker	1000	0	0	3	-	0.00
Phone charger	5	2	10	8	0.080	0.01
Total					**3.02**	**0.37**

Clinic	**Large (health centre)**						**Small (clinic)**		
Appliance	Power rating (W)	Number per clinic	Total power (W)	Daily usage (hrs)	Daily demand (kWh)	Max power kW	Number per clinic	Daily demand (kWh)	Max power kW
Security lights	12	6	72	12	0.86	0.07	3	0.43	0.036
Indoor lights	8	10	80	10	0.80	0.08	5	0.40	0.040
Light microscope	30	1	30	6	0.18	0.03	1	0.18	0.030
Computer	35	1	35	8	0.28	0.04	1	0.28	0.035
Printer	30	1	30	4	0.12	0.03	1	0.12	0.030
Refrigerator	150	1	150	12	1.80	0.15	1	1.80	0.150
Phone charger	5	4	20	4	0.08	0.02	2	0.04	0.010
Incubators	200	1.0	200	24	4.80	0.20		-	0.000
Oxygen concentrator	300	1.0	300	12	3.60	0.30	1.0	3.60	0.300
Cold storage room	300	1.0	300	12	3.60	0.30	0.5	1.80	0.150
CD4 Machine	50	1.0	50	6	0.30	0.05		-	0.000
Fan	5	2	10	10	0.10	0.01	2	0.10	0.010
Total					**16.52**	**1.28**		**8.75**	**0.791**

School	**Secondary**						**Primary**		
Appliance	Power rating (W)	Number per end-user	Total power (W)	Daily usage (hrs)	Daily demand (kWh)	Max power kW	Number per school	Daily demand (kWh)	Max power kW
Security lights	12	4	48	12	0.58	0.05	2	0.29	0.024
Indoor lights	8	10	80	7	0.56	0.08	4	0.22	0.032
Radio/Music system	35	1	35	4	0.14	0.04	1	0.14	0.035
Refrigerator	150	1	150	12	1.80	0.15	1	1.80	0.150
Fan	30	4	120	3	0.36	0.12	2	0.18	0.060
Computer	35	6	210	6	1.26	0.21	2	0.42	0.070
Printer	30	2	60	4	0.24	0.06	1	0.12	0.030
Phone charger	5	2	10	4	0.04	0.01	2	0.04	0.010
Total					**4.98**	**0.71**		**3.21**	

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**

Government 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**

definition of low, middle and high income is not according to Zambian statistical income standards 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 centres and posts (here referred to as 'clinic') in the villages 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, oxygen concentrator, and incubator (for first treatment of premature childbirths). A basic load profile for a rural facility includes security lighting, indoor lighting, a microscope, a computer and a printer, an oxygen 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 may have more equipment such as an incubator. Apart from the vaccine refrigerators, the RHC should have a cold room for the storage of medicines and blood packages.

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.

G) Energy supply base date

Month	Solar kWh/kW_p
Jan	3.91
Feb	4.11
Mar	4.49
Apr	5.03
May	5.20
Jun	5.15
Jul	5.21
Aug	5.40
Sep	5.42
Oct	5.05
Nov	4.36
Dec	3.99
Average	**4.78**

The Energy Sector Management Programme (ESMAP) of the WB, has carried out modelling of the solar resources in Zambia at five sites.[40] ESMAP provides photovoltaic power production data for Zambia using numerical models developed by GeoModel Solar, taking into account meteorological parameters, such as air temperature, wind, and humidity. Since the minigrid site can be anywhere in Zambia, the model presented uses average data. The minigrid system must be capable to produce enough energy to cover the energy demand at any time of year, considering the available solar radiation and the predicted energy demand for each month.

Specialised software can be used to determine energy demand data, daily load profile and irradiation data. The model presented is based on a simple spreadsheet model with the following design considerations:

- System autonomy: 1 day of storage

40 Chilanga, Choma, Kaoma, Kasama, Lusaka, and Mutanda

- The system must be able to generate enough energy to meet the energy demand at any time of the year.

Box 29 Cost comparison between various studies

	Africa MG	NES geospatial	ZMG project (< 100 kW)	ZMG project (> 100 kW)
kW peak demand per site	-	135	26-30	187
kW solar	-	189	62-96	500
Cost in USD per kW				
Solar PV	2,865	-	2667-3119	2661
- Site/civil works	140		415-557	169
- Generation	640		624-665	545
- Storage	1,285		960-1078	1082
- Other	800		670-820	815
+ O&M/insurance	4%	2%	3.5%	3.5%
Mini hydro	-	-	7385-7695	6589
+ O&M/insurance	4%	4%	5.5%	5.5%
Distribution (LV a/o MV)	665		1382-1923	2611
Average LV length per HH (m)	-	45	40	40
Cost in USD per client				
Solar PV (excl. distr)		1455-1525	1006-1194	857
Hydropower (excl. distr)		2294	935-1035	780
Distribution		965 LV+MV	620 LV	860 LV+MV

The table above gives an comparison between various cost assumptions or indicators given in:

- UNDP/GEF Africa Minigrid programme (project documentation)
- EngiePower/World Bank study for Preparation of a Least-Cost Geospatial Electrification Plan for Grid and Off-Grid Rollout in Zambia (2022)
- Analysis on solar and hydropower minigrids presented in this Annex (PPG phase analysis for project document formulation