MALAWI

Integrated Energy Plan

ELECTRIFICATION

IN PARTNERSHIP WITH:

Global Energy Alliance for People and Planet

20 DECEMBER 2022

Other reports in this series

Malawi – Clean Cooking Report

This report provides an overview of clean cooking opportunities to be achieved by 2030. By utilizing a dynamic data-driven methodology, the report identifies a mix of modern and cleaner cooking technologies and solutions to achieve SDG7.1 targets by 2030 including realization of Malawi's SDG7 Cleaner Cooking Compact.

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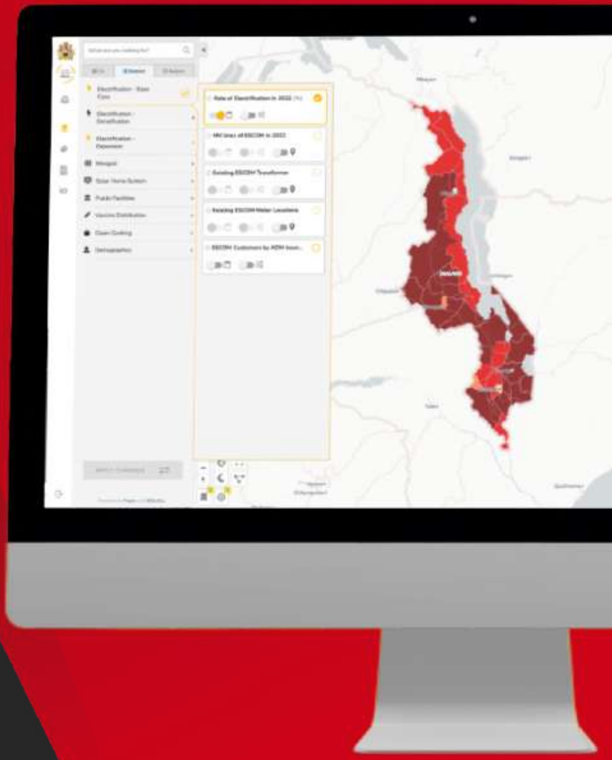

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SEFORALL SDG 7 IMPACT MALAWI

Any Questions:
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Table of Contents

Acronym List

AC	Alternating Current
DC	Direct Current
ESCOM	Electricity Supply Corporation of Malawi Limited
GIS	Geospatial Information System
IEP	Integrated Energy Plan
km	kilometer
kW / kWh	kilowatt/kilowatt-hour
LV	Low Voltage
MTF	Multi-Tier Framework
MV	Medium Voltage
NRECA	National Rural Electric Cooperative Association International
ODK	Open Data Kit
OSM	Open Street Map
SAEP	Southern Africa Electrification Program
SEforAll	Sustainable Energy for All
SHS	Solar Home System
USAID	United States Agency for International Development
USD	United States Dollars

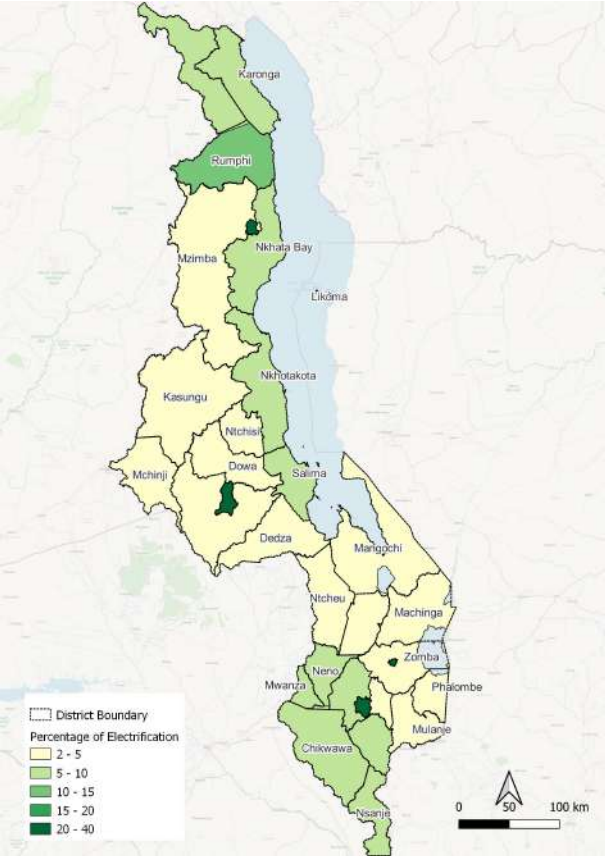
MALAWI IEP – ELECTRIFICATION

Executive Summary

Electrification challenge

- Taken together, ESCOM and off-grid providers serve approximately 750,000 households, including approximately 550,000 grid-served consumers and 200,000 off-grid consumers. In addition, 3,992 public facilities have grid service and 346 have off-grid service. Therefore, the estimated population with electricity is 3.4 million people.
- Estimated 2022 population is approximately 4,435,000 households, leaving ~3.7 million households (16.6 million people) without grid or off-grid service. Approximately 3,843 public facilities do not yet have access to electricity service.
- Significant power quality & reliability issues – insufficient power supply results in frequent outages, insufficient access to investment contributes to overloaded feeders and transformers.
- By 2030 and at the current rate of growth, there will be 5.5 million households in Malawi
- Grid and off-grid access will need to grow at an average rate of 607,567 connections per year to reach universal access by 2030, with a peak growth rate of 1.17 million connections in 2028.

MALAWI ELECTRIFICATION RATE BY DISTRICT (2022)



Elasticity of Demand for off-grid electricity service

The ESCOM tariff is $0.064/kWh for residential consumers. This tariff reflects national-level economies of scale and is subsidized by the government.

For off-grid electrification, the costs of system operations are allocated to fewer users at a smaller scale, which requires a higher tariff for sustainable operation.

- Mini-grids typically have higher financing costs and shorter-term debt than public utility infrastructure, which also increases the cost of electricity service. Therefore, mini-grid tariffs are assumed to be higher, in the range of USD $0.45/kWh and the associated monthly electricity consumption is 12 kWh/month-consumer.

- Solar Home Systems (SHS) typically charge monthly fees for service rather than direct consumption-based tariffs for end users. These costs depend on the SHS size and the provider's prices, however a MTF1 Tier 1 system is commonly USD $12/month or higher, and Tier 2 systems exceed $25/month, which exceeds the WTP in all three regions. Therefore, SHS affordability will require subsidies for Low decile customers.

Region	Monthly energy expenditures (US$/month)	Anticipated ESCOM Consumption (kWh/month)	Anticipated mini-grid Consumption[1] **(kWh/month)**
Northern	$3.82	60	8.5
Central	$3.00	47	6.7
Southern	$4.23	66	9.4

Table 1. Mini-grid consumption was estimated at 12 kWh/month in all regions, however grants or subsidies may be necessary to close the affordability gap.

[1] Further inputs on the Multi-Tier Framework (MTF) is provided in the Annex.

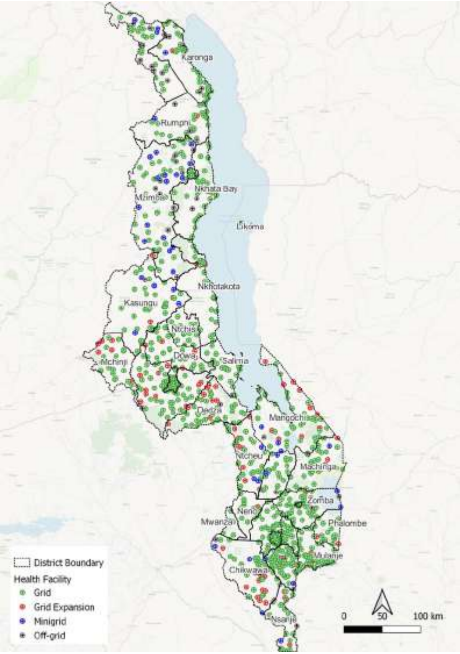
Electrification of Public Facilities

- Nationwide health facility data was provided by the ministry of health and analyzed in the medical cold chain analysis[1] to determine electrification status and approximate electrical demand.
- Health facilities were identified in the geospatial planning models and illustrated according to electrification modality in the 2030 universal electrification scenario.
- Similar analysis was conducted for electrification status of schools throughout Malawi.

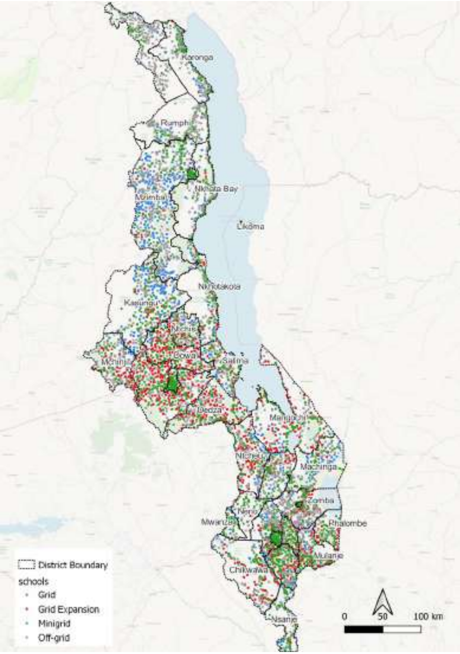
Results of public facility electrification planning are as follows:

Electrification Options	Number of Schools	Number of Health Facilities
Grid	3123	869
Grid Expansion	961	83
Mini-grid	617	53
SHS	2422	53
Total	**7123**	**1058**

HEALTH CLINIC ELECTRIFICATION RESULTS



SCHOOL ELECTRIFICATION RESULTS



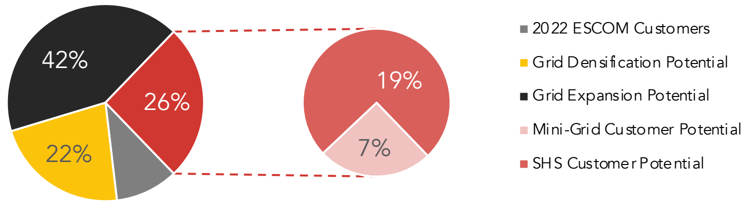
[1] The details of medical cold chain and vaccine distribution comprise another of the three components of the Malawi IEP. Further insights can be found in the IEP report on this topic.

Universal Access by 2030

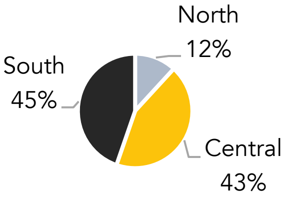
Region	2022 ESCOM Customers	Grid Densification Potential	Grid Expansion Potential	Mini-Grid Customer Potential	SHS Customer Potential	Total
North	79,939	117,799	33,910	100,727	309,010	641,385
Central	217,771	485,346	1,284,440	113,057	255,685	2,356,299
South	262,510	600,028	951,554	135,339	473,640	2,423,070
Total	**560,220**	**1,203,172**	**2,269,903**	**349,123**	**1,038,336**	**5,420,754**

- To increase access from 12.5% of today's population (4.5 million households) to universal access by 2030 (with a total population of 5.5 million households), 42% of new consumers will be connected via grid expansion and 22% will be connected via densification of customer connections within ESCOM's existing network.
- Off-grid electrification will account for 26% of the electrification plan of which 7% represent mini-grid expansion and 19% via standalone solar solutions.
- The regional division of electrification expansion (including grid and off-grid) shows the majority of connections in south and central regions (45% and 43%, respectively) with 12% in the north.

2030 UNIVERSAL ELECTRIFICATION PLANNING RESULTS



TOTAL CUSTOMERS BY REGION



Note that all customer data in the report is presented in terms of the number of households, and not the total population.

Electrification Financing Requirements

Electrification Modality	Public Sector, Government, and Development Partner Financing			Private Sector and End-User Co-Financing	
	Base Case: BAU[1.] GoM Financing Requirements (USD)	Sensitivity 1: ICB[2.] GoM Financing Requirements (USD)	Sensitivity 2: Low-Cost[3.] GoM Financing Requirements (USD)	Off-Grid Funding by Private Sector Developers (USD)	Connection Fees Paid by End-Use Consumer Grid & (USD)
Densification	$464,562,316	$464,562,316	$464,562,316	-	$109,868,712
Grid expansion	$2,938,414,330	$1,950,687,253	$1,824,560,052	-	$166,911,090
Mini-grids	$196,548,240	$196,548,240	$196,548,240	$287,769,674	$7,052,686
Standalone solar (Tier 2)	$90,854,403	$90,854,403	$90,854,403	$250,758,152	$20,766,721
Total	**$3,629,729,750**	**$2,642,002,673**	**$2,515,875,471**	**$387,613,528**	**$304,808,087**

1. Business as Usual (BAU), a scenario assuming current costs of components
2. International Competitive bidding (ICB), a scenario assuming cost reductions due to the introduction of international competitive bidding.
3. Low-cost electrification standards, assuming the Malawian grid codes are updated to use low-cost design measures in rural electrification, along with ICB procurement strategies as in Sensitivity 1.

MALAWI IEP – ELECTRIFICATION

Malawi IEP Electrification Overview

IEP Objectives and Tasks

The principal objective of the electrification component of the IEP project is to prepare a framework to support increased access to electricity service by 2030

- Expanding grid service via densification and grid expansion
- Expanding off-grid service by exploring mini-grid and standalone solar expansion
- Optimizing investment by (i) lowering costs and (ii) increasing the impact of infrastructure and connections.

The IEP focused on the following activities:

- Update the first-order geospatial analysis of 2018 with the latest available data (i.e., ability to pay, housing structures, and ESCOM grid data) with more sophisticated modelling
- Overlay clean cooking (MECS) into the model
- Develop a [geospatial] model to assist the government in evaluating the trade-offs of different approaches for rolling out a national COVID-19 vaccine, considering the constraints and opportunities around cold chain storage and transportation and their associated costs

Project context and objectives: Electrification Plan

IEP OBJECTIVE:

- To develop an updated and enhanced Integrated Energy Plan (IEP) for Malawi, by
  - Updating the existing geospatial analysis, incorporating more recent data-sets
  - Overlaying a clean-cooking layer into the model
  - Overlaying the energy requirement for productive uses
  - Ensuring the new IEP, including and their underlying tools and data are well understood
  - Ensuring that the model output is accessible and usable by external stakeholders (Malawi IEP Tool)

ELECTRIFICATION ANALYSIS:

- Develop a geospatial model
- Update/import data from ESCOM, mini-grid locations, cost data
- Evaluate grid densification & expansion opportunities
- Evaluate mini-grid opportunities
- Refine grid/off-grid via comparative cost analysis

OUTPUTS:

- Detailed report and interactive model illustrating methodology, results of energy expenditure surveys, & results for electrification expansion modeling by technology and region/district of Malawi. Evaluate financing needs and implementation plan

Status in Mid-2022

ESCOM Coverage

- 550,000 customers[1] equivalent to 12.5% of 2022 population
- Extensive network coverage but largely concentrated in urban areas
- ESCOM and MAREP collaborate to expand rural areas
- Rural electrification funding has been limited in recent years
- Five-year World Bank program to support access expansion will connect ~120,000 new consumers by 2027

Off-grid Electrification

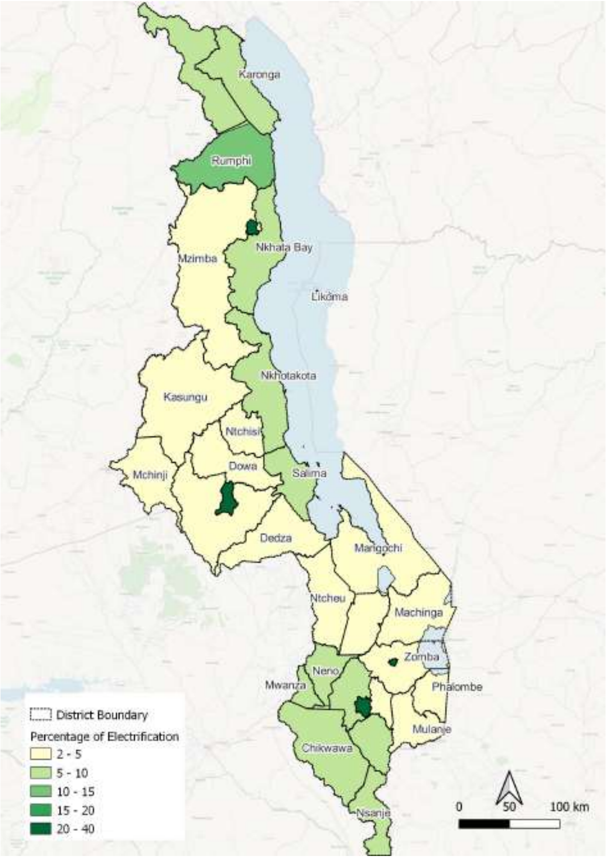
- Multiple solar companies are engaged in providing Tier 1 and Tier 2 solar service and have achieved a pace of ~50,000 new sales per quarter
- Ten mini-grids are under development, seven of which range in size from 15 to 80 kW while the other three are 160, 300 and 1,000 kW respectively.
- Off-grid solar is beginning to grow at a rapid pace while mini-grids are at early stages of development and service

1. ESCOM commercial data.

Electrification challenge

- Taken together, ESCOM and off-grid providers serve approximately 750,000 households, with ESCOM serving 550,000 households and an additional 200,000 solar home systems in use.
- Estimated 2022 population is approximately 4,435,000 households, leaving ~3.7 million households without grid or off-grid service. In addition to the households, there are 7,123 schools (44% presently grid-connected) and 1,058 health facilities (82% presently grid-connected) to be electrified.
- Significant power quality & reliability issues – insufficient power supply results in frequent outages, and insufficient access to investment contributes to overloaded feeders and transformers.
- By 2030 and at the current rate of growth, there will be 5.5 million households in Malawi
- Grid and off-grid access will need to grow at an average rate of 607,567 connections per year to reach universal access by 2030, with a peak growth rate of 1.17 million connections in 2028.

MALAWI ELECTRIFICATION RATE BY DISTRICT (2022)



MALAWI IEP – ELECTRIFICATION

Data Collection and Validation

Data Requests

ESCOM data request:

- Geographic data of the ESCOM network
- Construction cost data for MV, LV, services and meters
- Low cost for rural grid expansion
- Commercial data to evaluate electricity consumption for new consumers
- Tariffs, current and future

Off-grid data request:

- Mini-grids in operation and those under development
- Solar standalone service providers, rate of expansion, cost of service

Other

- Population data from National Statistics Office
- Housing structures from Open Buildings – Google database
- Roads from Open Street Map (OSM)

Data Request Status

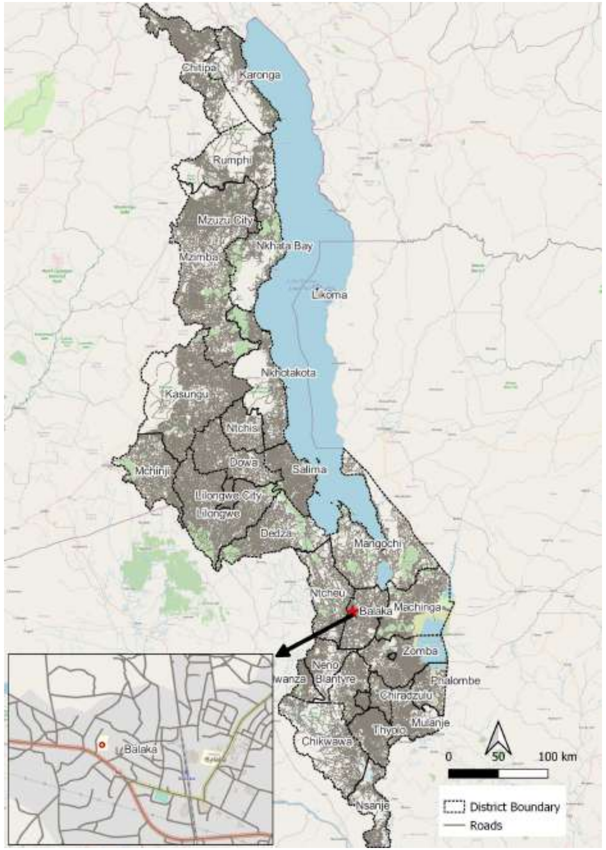
Data requested	Status
ESCOM commercial data: specifically, average monthly consumption for residential and small commercial consumers; total consumers by category	Received
ESCOM construction cost for MV, LV, transformers, & services	Received
Does ESCOM use low-cost design/construction standards such as bi-phase or single phase for rural areas? If so, please share construction standards and cost	ESCOM has not yet developed low-cost standards
ESCOM load projection & generation expansion plan to meet load	IRP received
Mini-grids in service as well as those that are in development pipeline	Received from MAREP, UNDP
Solar standalone service companies in Malawi, areas of influence, systems in service	Discussions facilitated by GEA
Survey enumerators recruited through National Statistics Office	Completed

Data Request Status

Data requested	Status
MV & LV characteristics – conductor size, ruling span, average cost per km (US$/km)	Received
MV characteristics for phase-to-phase or single-phase construction & cost (US$/km)	N/A – ESCOM does not use single-phase MV construction
Transformer cost for 315, 200, 100, 75, 50 & 25 kVA cost per unit (US$)	Received
Service drop cost for single and three phase services (US$)	Received
Mini-grid characteristics for existing mini-grids (size and distribution characteristics)	Received – discussions with private mini-grid developers
Solar home system characteristics for existing service providers	Received – discussions with private SHS providers

Malawi Road Network

- Road network consists of primary, secondary and tertiary roads
- Required for electrification, clean cooking and vaccine distribution analysis
- In electrification analysis, roadways are used to define MV and LV line alignments. The road network is used by the routing algorithm to project grid expansion
- Used in clean cooking analysis to evaluate access to markets for fuel and stove products
- Used in vaccine distribution to evaluate cold chain requirements and distribution pathways
- OSM data was found to provide high-resolution sub-meter road network data including primary, secondary and tertiary roads



Updating the ESCOM Geographic Database

ESCOM provided a comprehensive database to Columbia University Millennium Promise (2018) that included all existing MV infrastructure. ESCOM provided an updated database to NRECA/SEforAll for this study.

While this was extensive and of high quality, there were anomalies in the database that required cleaning:

- Identify anomalies
- Connect gaps in MV feeders and taps
- Add connectors to transformers and/or add missing transformers

Figure 1: MV lines without transformers

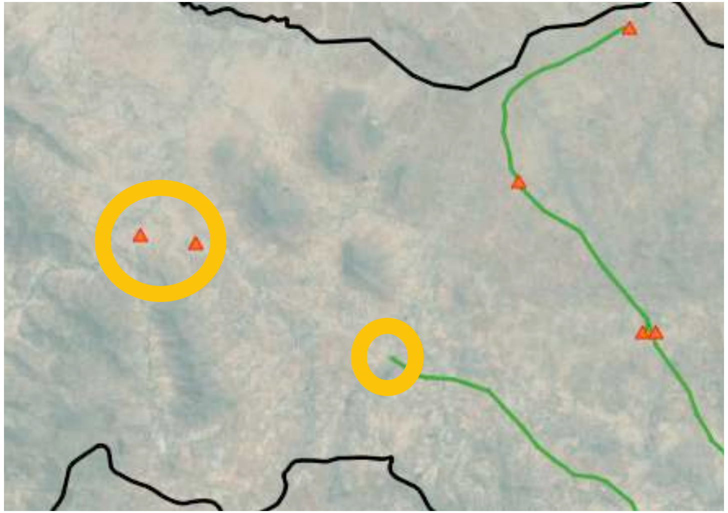


Figure 2: Transformers not connected to MV

A workshop was provided for MoE and ESCOM on the procedures to clean the database.

Cleaning Database Inconsistencies

Database inconsistencies result in difficulties in load flow modeling, while inconsistent material properties create difficulties with data queries. Cleaning these anomalies is not difficult but necessary to complete the electrification analysis

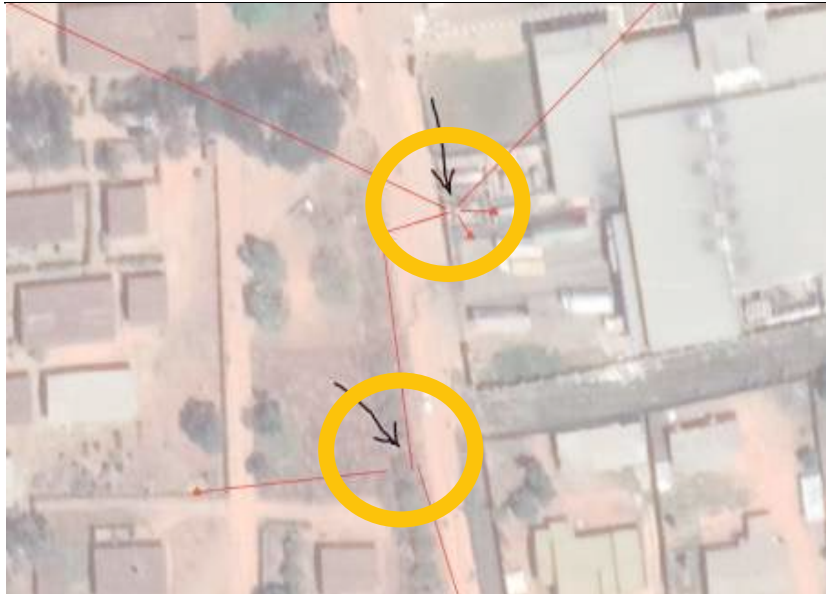


Figure 3: Gaps in MV lines

conducto1
185mm2 3 core 11kV cable XLPE
185mm² 3 core 11KV cable XLPE
185mm² 3 CORE 11KV CABLE XLPE
25mm? (ALMOND)
25mm? ALMOND
25mm2 (ALMOND)
25mm² (ALMOND)
25mm² (almond)
25mm² ALMOND
25mm²(ALMOND)
35mm² (ALMOND)
70mm? 3 CABLE 11KV CABLE XLPE
70mm? 3 CORE 11KV CABLE XLPE
70mm? 3core 11KV CABLE XLPE
70mm? 3core 11kV cable XLPE
70mm? 3CORE 11KV CABLE XLPE

Figure 4: Inconsistent material descriptions

ESCOM Database Integrated into Geospatial Database

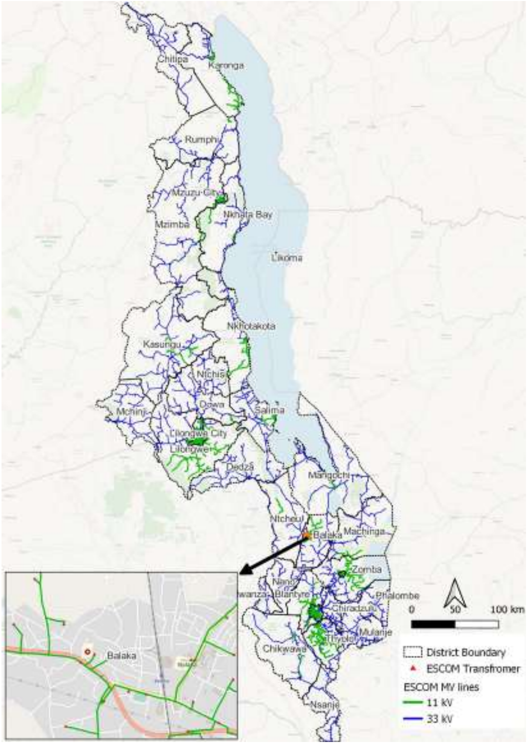
As noted, the ESCOM database was updated from the version provided in 2018 for the first order geospatial analysis performed by Millennium Promise and funded by the World Bank:

Original MV data (2018):

- 9,521 km MV line
- 5,733 MV/LV transformers

Updated ESCOM data (2022):

- 12,888 km MV line – 35% increase
- 7,118 MV/LV transformers – 24% increase



Data Collection: Mini-Grid Developers

There has been initial success in development of mini-grids in Malawi, primarily for health facilities and partnerships with non-profit organizations and research organizations. Private sector mini-grid developers have yet to establish a significant portfolio in Malawi and financing remains scarce for private sector mini-grid development.

- The Mulanje Electricity Generation Agency (MEGA) is a wholly-owned subsidiary of the Mulanje Mountain Conservation Trust (MMCT) that has installed one small hydro mini-grid in southeastern Malawi. The total installed capacity is 268 kW serving 1618 customers, 11 maize mills, 12 schools, 1 health clinic, 8 churches, and many businesses in the region.
- The Energy Access through Social Enterprise and Decentralization (EASE) project is a partnership between the University of Strathclyde, United Purpose, Community Energy Malawi, and Washted that has developed and installed a containerized 12 kW solar mini-grid serving 60 customers in the village of Mthembanji, Dedza District, shown on page 24.
- Churches Action in Relief and Development (CARD) have installed 4 mini-grids totaling 75 kW.
- EGENCO has installed solar mini-grids on Likoma Island (1,000 kW) and Chizumulu Island (300 kW).
- There are 8 mini-grids developed to serve health centers and dispensaries in 2018.
- Columbia[1] University performed a geospatial analysis that identified 74 mini-grid candidate sites, none of which are constructed to date.

1. Millennium Promise, First Order Geospatial Least Cost Electrification Plan.

Power station at MEGA Bondo hydro plant

LEARN MORE

Power house in EASE mini-grid

LEARN MORE

Data Collection: SHS Distributors

The total installation capability of solar home system (SHS) distributors was approximately 50,000 units per quarter in 2021. Seven SHS distributors have received support from USAID's Southern African Energy Program (SAEP). These companies are the following:

- Yellow Solar (multi-national)
- Zuwa Energy (national)
- VITALITE (multi-national)
- Solar Works (national)
- SolarAid/SunnyMoney (multi-national)
- Greenlight Planet (multi-national)
- Green Impact Technologies (national)

These companies have varying installed volume of SHS and different areas of focus within Malawi. Some providers are focused exclusively in rural areas, whereas others rely on distribution channels which are less targeted.

MALAWI IEP – ELECTRIFICATION

Energy Expenditure Survey

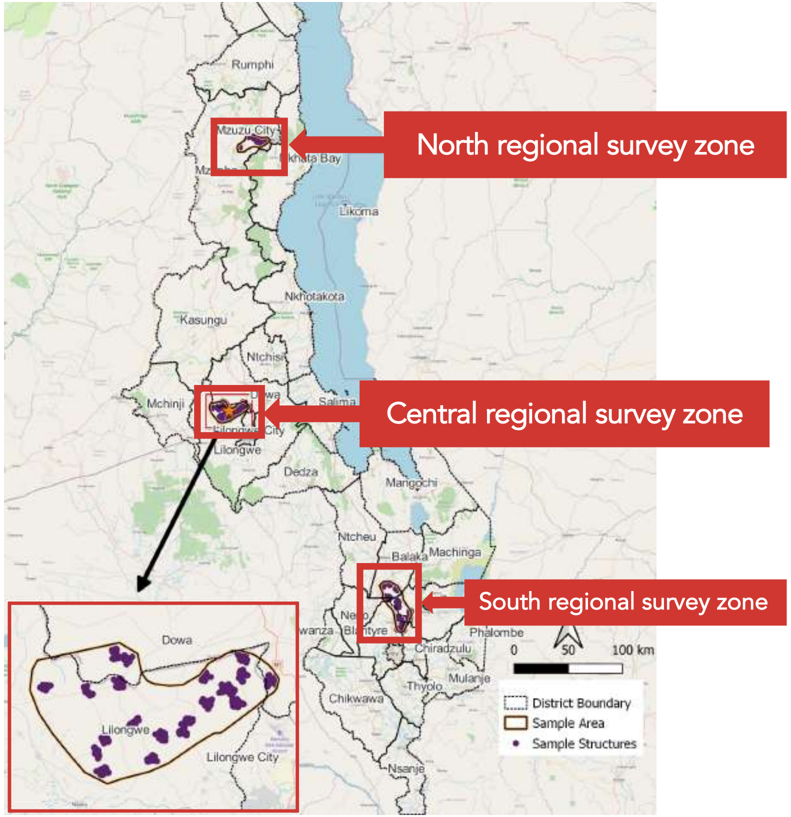
Energy Expenditure Survey

The primary purpose of the energy expenditure surveys was to evaluate electricity consumption/demand for newly connected consumers.

With a sample size exceeding 1,500, energy expenditure surveys were undertaken from April-June 2022 in off-grid zones. Identified in the northern, central and southern regions in order to assemble a representative sample of Malawi's off-grid population throughout the country.

Each survey sample included residential, commercial and public facility consumers (health centers and schools) in order to determine the relative prevalence and willingness to pay (WTP) for these customer segments. Energy expenditures were evaluated for residential and SME populations; all public facilities in the survey area were also evaluated

Survey participants were selected from randomized housing structures to achieve a survey sample with a 95% confidence interval and 5% error rate



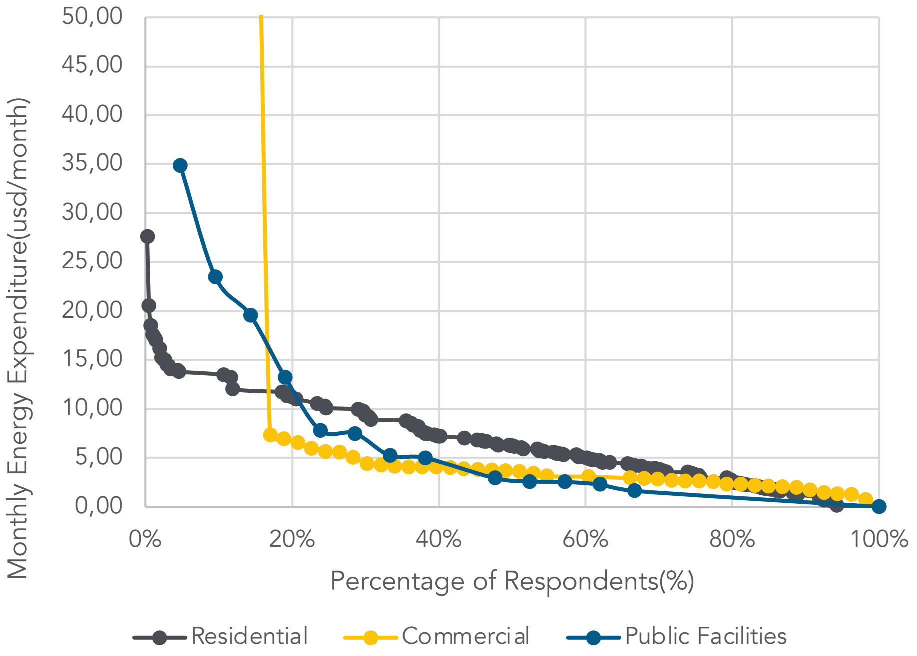
Detail: Central survey zone population centers for enumeration.

Energy Expenditure Results: Northern Region

Energy expenditures by decile:

Decile	Percentage of Residential Customers[1]	Energy expenditures (USD/Month)	Projected Consumption (kWh/Month)[2]
High	0-20%	$15.16	236.80
Mid	20-50%	$7.91	123.57
Low	50-100%	$3.18	49.67

MONTHLY ENERGY EXPENDITURE CHART FOR NORTHERN MALAWI



1. Electrification projects are most often designed with a 70% penetration rate target. Therefore, approximately half of the customers in the "Low" decile are unlikely to connect to ESCOM or mini-grid service.

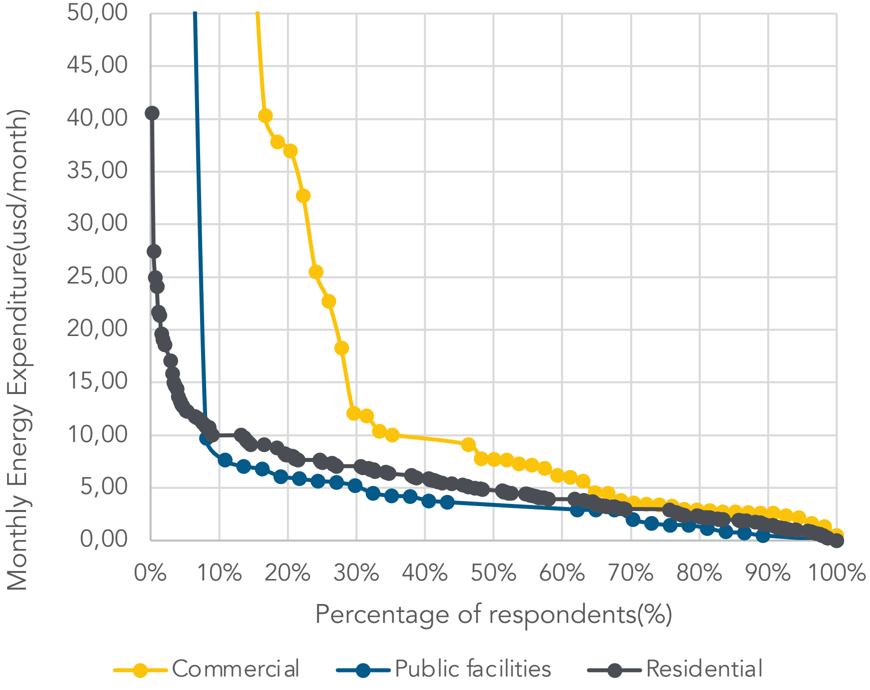
2. Assumes all future grid expansion customers are assessed the present-day ESCOM tariff at US$0.064/kWh.

Energy Expenditure Results: Central Region

Energy expenditures by decile:

Decile	Percentage of Residential Customers[1]	Energy expenditures (USD/Month)	Projected Consumption (kWh/Month)[2]
High	0-20%	$11.61	181.45
Mid	20-50%	$6.21	97.04
Low	50-100%	$2.65	41.42

MONTHLY ENERGY EXPENDITURE CHART FOR CENTRAL MALAWI



1. Electrification projects are most often designed with a 70% penetration rate target. Therefore, approximately half of the customers in the "Low" decile are unlikely to connect to ESCOM or mini-grid service.

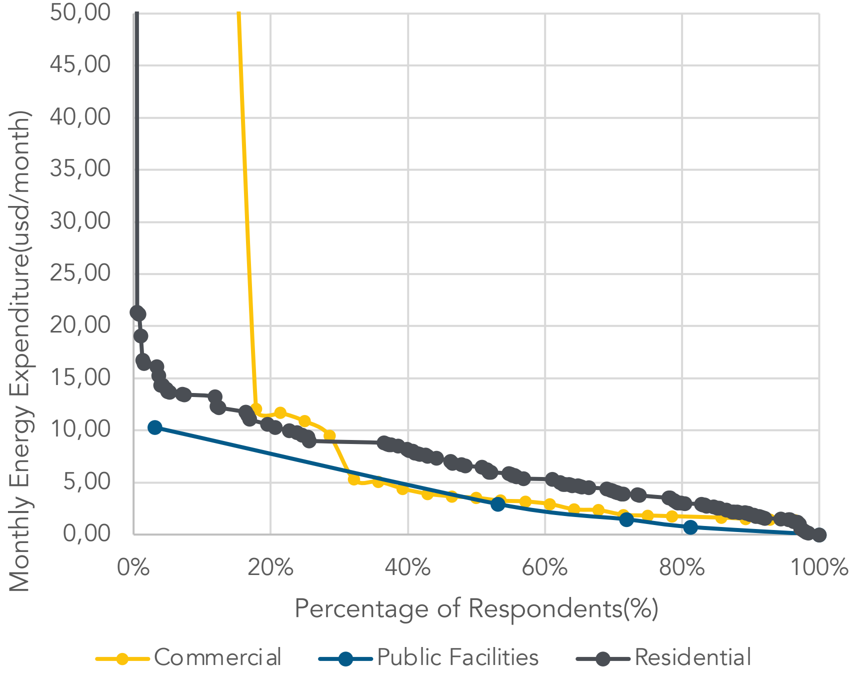
2. Assumes all future grid expansion customers are assessed the present-day ESCOM tariff.

Energy Expenditure Results: Southern Region

Energy expenditures by decile:

Decile	Percentage of Residential Customers[1]	Energy expenditures (USD/Month)	Projected Consumption (kWh/Month)[2]
High	0-20%	$25.35	396.12
Mid	20-50%	$8.00	125.06
Low	50-100%	$2.88	44.98

MONTHLY ENERGY EXPENDITURE CHART FOR SOUTHERN MALAWI



1. Electrification projects are most often designed with a 70% penetration rate target. Therefore, approximately half of the customers in the "Low" decile are unlikely to connect to ESCOM or mini-grid service.

2. Assumes all future grid expansion customers are assessed the present-day ESCOM tariff.

Applying Expenditure Results

- Given that most electrification expansion programs are designed with approximately 70% penetration level, this level was applied to the ESCOM tariffs.
- When applied with current ESCOM residential tariffs, this yields average monthly consumption in kWh for each region.
    - Electricity consumption is applied to all unelectrified housing structures to evaluate total demand in kW using a regression formula[1] developed for rural electrification analysis for feeders in the model. Feeders are sized for 100% penetration rates.
- Electricity demand is clustered to determine the optimal location of MV/LV transformers
- A routing algorithm is then used to evaluate viable grid expansion projects, following the OSM road data for public rights-of-way.

Region	Monthly energy expenditures (US$/month)	Anticipated Consumption (kWh/month)
Northern	$3.82	60
Central	$3.00	47
Southern	$4.23	66

1. RUS Bulletin No. 45-2, United States Department of Agriculture Rural Utilities Service.

Elasticity of Demand for off-grid electricity service

The ESCOM residential tariff is $0.064/kWh for residential consumers. This tariff reflects national-level economies of scale and is subsidized by the government. For off-grid electrification, the costs of system operations are allocated to fewer users at a smaller scale, which requires a higher tariff for sustainable operation.

- Mini-grids typically have higher financing costs and shorter-term debt than public utility infrastructure, which also increases the cost of electricity service. Therefore, mini-grid tariffs are assumed to be higher, in the range of USD $0.45/kWh and the associated monthly electricity consumption is 12 kWh/month-consumer, based on WTP survey results and associated tariff levels.
- Solar Home Systems (SHS) typically charge monthly fees for service rather than direct consumption-based tariffs for end users. These costs depend on the SHS size and the provider's prices, however a MTF[1] Tier 1 system is commonly USD $12/month or higher, and based on discussions with SHS vendors, Tier 2 systems can exceed $25/month, which exceeds the WTP based on the survey results in all three regions. Therefore, SHS affordability will require subsidies for Low decile customers.

Region	Monthly energy expenditures (US$/month)	Anticipated ESCOM Consumption (kWh/month)	Anticipated mini-grid Consumption[2] (kWh/month)
Northern	$3.82	60	8.5
Central	$3.00	47	6.7
Southern	$4.23	66	9.4

Table 2. Mini-grid consumption was estimated at 12 kWh/month in all regions, however grants or subsidies may be necessary to close the affordability gap.

1. Further inputs on the Multi-Tier Framework (MTF) is provided in the Annex.

2. Derived from the willingness to pay divided by the anticipated mini-grid tariff.

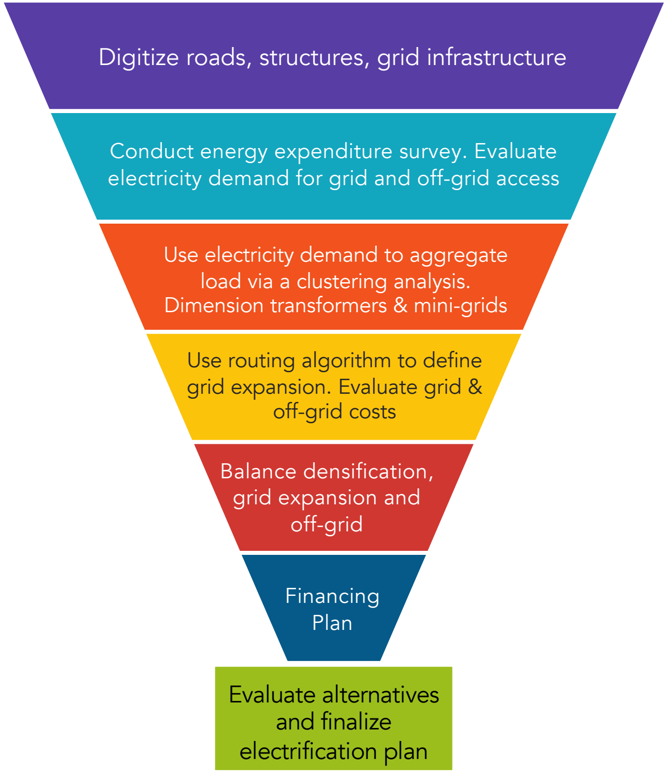
MALAWI IEP – ELECTRIFICATION

Methodology for Geospatial Electrification Analysis

SUSTAINABLE ENERGY FOR ALL

UNITY AND FREEDOM

Steps in Electrification Analysis



STEP 1: DATA COLLECTION

- Define & collect data from ESCOM, DoE, other stakeholders
- Collect structure, road, population & cost data
- Integrate data into geospatial platform

STEP 2: ENERGY EXPENDITURE SURVEY

- Collect data from northern, central and southern regions. Evaluate expenditure levels
- Using ESCOM tariff and projected mini-grid tariff, estimate grid and off-grid demand
- Use demand estimates to inform clustering analysis

STEP 3: CLUSTERING: AGGREGATE DEMAND IN SPECIFIC GEOGRAPHIC AREAS

- Clustering is used to aggregate demand and to dimension transformers for grid expansion and distributed generation for mini-grids
- Clustering is evaluated nation-wide using housing structure locations and demand estimates

STEP 4: DEFINE GRID AND OFF-GRID PROJECTS

- Routing algorithm is used to define LV networks and then to define MV pathways
- Project characteristics are aggregated for each project and consumers and costs are evaluated
- Results are collated in database

STEP 5: PROJECT COST ANALYSIS AND BALANCING OF ON-GRID/OFF-GRID PORTFOLIO

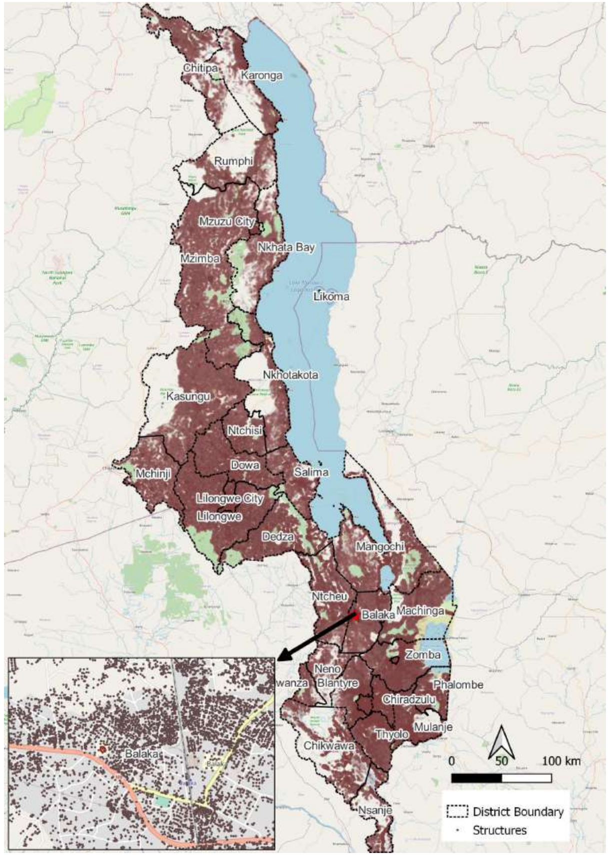
- Compile complete list of grid densification, grid expansion and off-grid costs
- Organize results by region & district
- Draft implementation plan

Modeling Assumptions for Grid Densification and Expansion

- The base case analysis was conducted in accordance with current ESCOM construction design and cost parameters for MV lines, LV lines, customer connections, and customer metering. Two additional sensitivity cases were also analyzed to examine the impact of lower-cost electrification practices. These include:
  1. Impact of international competitive bidding (ICB) for ESCOM procurement with no change in design.
  2. Impact of using lower-cost design standards for rural areas where loads are significantly lower than in urban areas.
- Demand projections were aggregated to define grid expansion and mini-grid projects using 2015 census data that is projected to 2022 using
  1. 2015 household size for each district
  2. Population growth projections for each district
  3. Digitized structure data derived from Google Open Buildings database to geo-locate loads.
- Consumption estimates were derived from energy expenditure surveys undertaken for each of three regions. Consumption was assumed to be uniform across each region, based on the survey data taken from a representative sample of consumers.
- Densification analysis assumes uniform cost of connecting consumers within 600 meters of ESCOM transformers at a cost of US$476 per consumer. This figure will be explained in more detail on slide 45.
- Grid expansion costs were evaluated on a project-by-project basis after identifying MV feeder extensions, transformer sizes (by evaluating load for each housing cluster), LV circuit lengths (calculated by routing algorithm), and number of service connections.

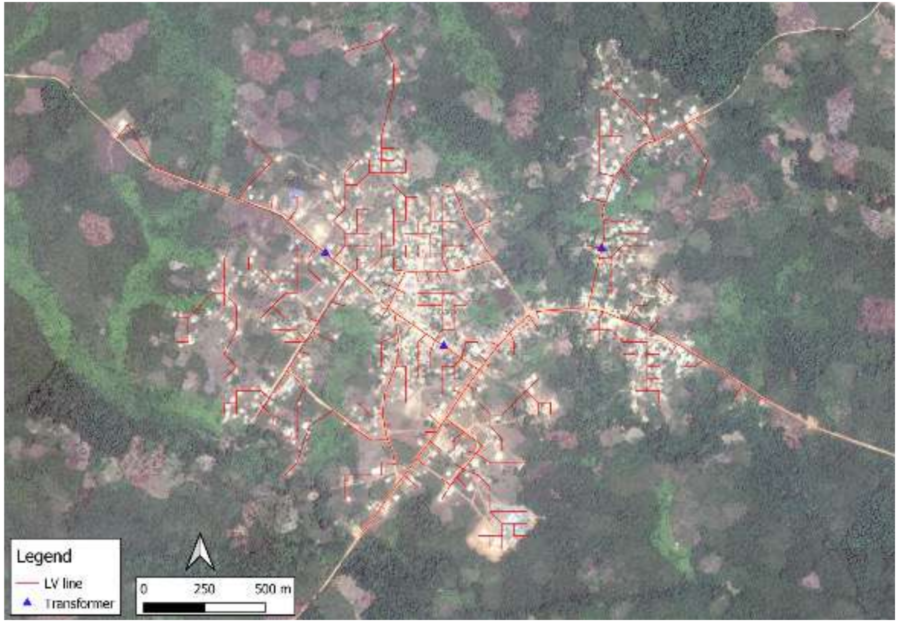
Digitization of Housing Structures

- Housing structure data was derived from Google Open Buildings
- A total of 5,440,893 structures were identified and digitized
- National Statistics Office data projects 4,474,000 households in Malawi in 2030, based on 2018 census data.
- Structure-to-housing ratio of 0.83 was used in the electrification analysis, as a scaling factor to align the total number of buildings/structures in the geospatial model with national population data.



Routing Algorithm: Defining Distribution Line Alignments

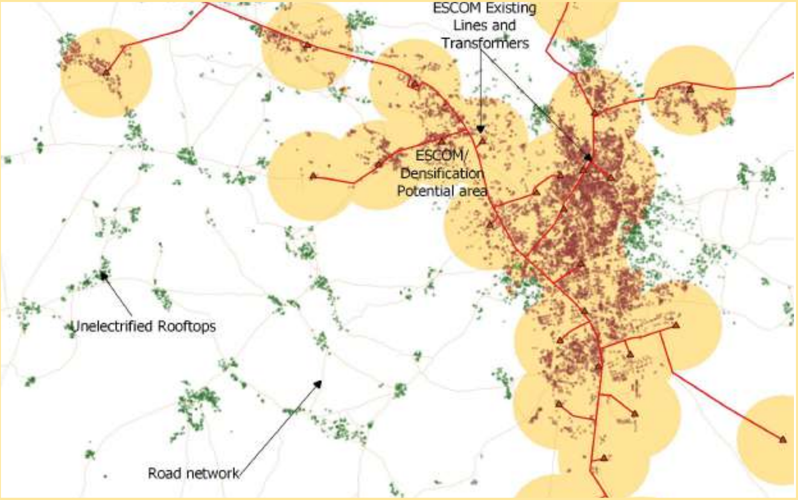
- Distribution lines follow existing roads to facilitate maintenance and ease in operation. To define the pathways that MV and LV lines will follow, a contiguous road atlas is needed.
- MV and LV line alignments are defined by interconnecting load centers identified and evaluated using the cluster algorithm to optimize distribution coverage
- Use of the routing algorithm ensures:
  - Coverage of all community/population cluster areas
  - Distribution system layout follows existing rights of way.
  - When line alignments follow roads, it ensures the MV- and LV-lines are laid out in an orderly fashion.



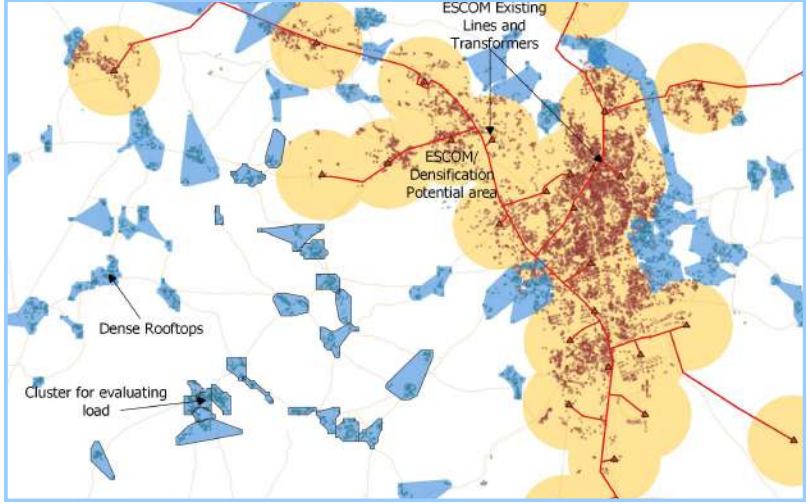
Routing Algorithm: Defining Distribution Line Alignments (2)

- A density-based spatial clustering algorithm is used to group data points representing households into geographic clusters. This analysis is guided by the energy expenditure survey results and the current practice of the utility.
- After assessing the cluster area and anticipated load, transformer locations and capacities are defined with maximum service radius from the centroid of each cluster.

Grid Densification Algorithm: grid densification opportunity is defined by areas which can be electrified within the service radius of existing ESCOM transformers.



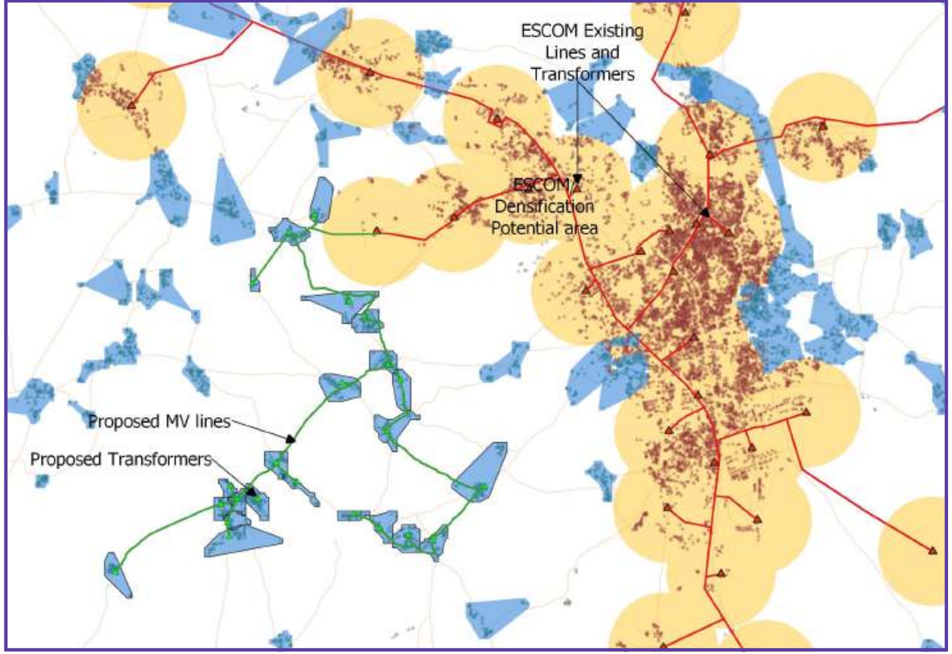
Clustering Algorithm: unelectrified structures beyond the densification boundaries are grouped into clusters for evaluation of grid expansion or off-grid electrification.



Routing Algorithm: Defining Distribution Line Alignments (3)

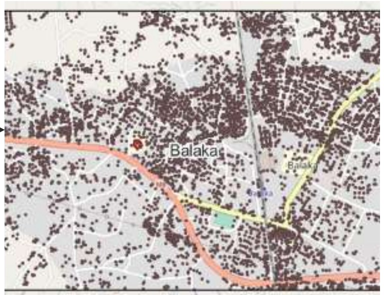
- Once clusters have been defined, the load centers are evaluated for grid expansion through the routing algorithm. Proposed MV line extensions are routed from existing network along the national road network to reach surrounding customer clusters, optimized to ensure shortest path and lowest cost.
- With each structure added to the simulated MV expansion, the routing algorithm calculates the cumulative grid expansion cost – including all customers served by the proposed MV line extension – and evaluates the average distribution cost per consumer associated with the project.
- As the routing algorithm expands to reach clusters with lower population density, the distribution costs per connection rise above a pre-defined cost threshold which represents the breakeven cost of mini-grid electrification.
- Transformer sizes, conductor ratings, and voltage levels are assigned to each project according to demand of the cluster, distance from the existing grid and voltage of existing system

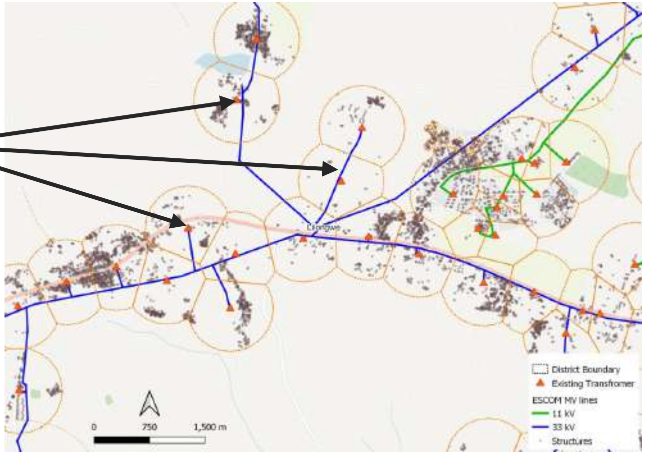
Routing Algorithm: population clusters are added to grid expansion projects until further incremental MV extension becomes cost prohibitive. Clusters beyond the grid extension project routing are evaluated for off-grid electrification modalities.



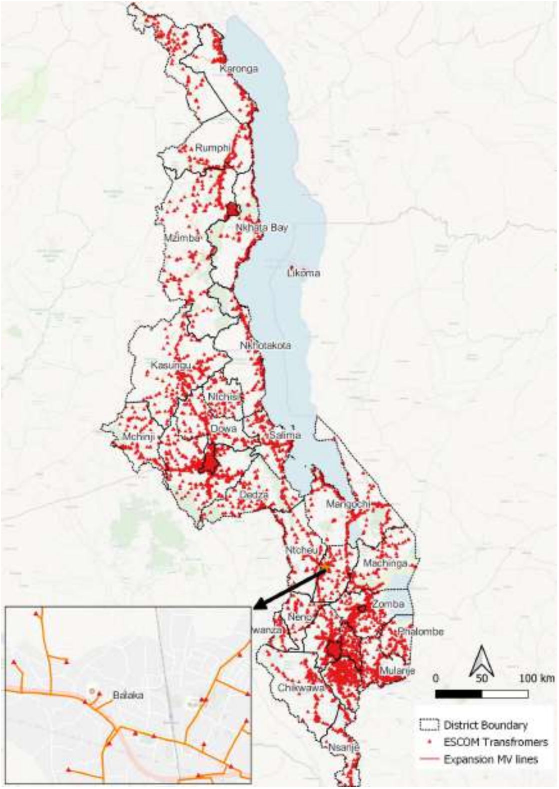
Densification Analysis

- Densification analysis uses housing structure, ESCOM network and ESCOM commercial data to evaluate densification potential
- The densification potential for a given areas includes the total housing structures within 600 meters of distribution transformers, excluding existing consumers equals densification potential. The 600-meter assumption is based on acceptable voltage drop in the LV network, considering grid reliability.
- All ESCOM transformers were evaluated in the densification analysis



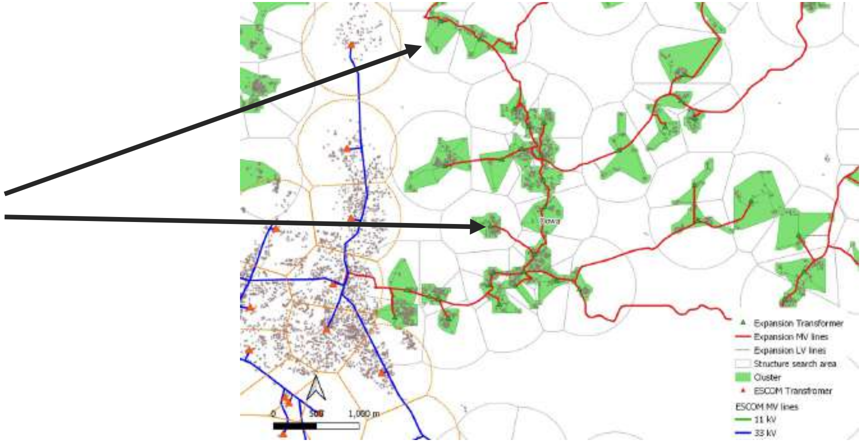


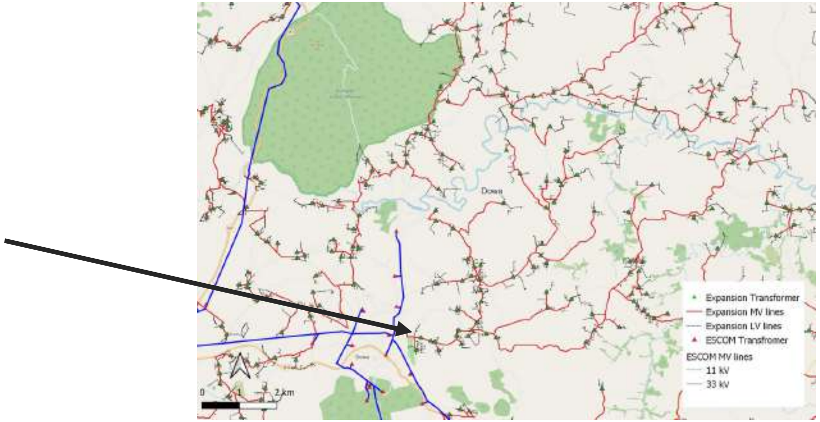
EXISTING ESCOM TRANSFORMERS BY REGION



Expansion Analysis

- Expansion analysis relies on results of clustering to identify demand & transformer placements
- Transformers are interconnected with MV via the routing algorithm explained previously
- Projects characteristics recorded in the geodatabase are then evaluated for cost, consumers served and evaluated against selection criteria
- Selection normally focuses on projects that have highest potential impact at lowest cost, but implementation also will need to be balanced across regions and districts





Mini-Grid potential and development targets

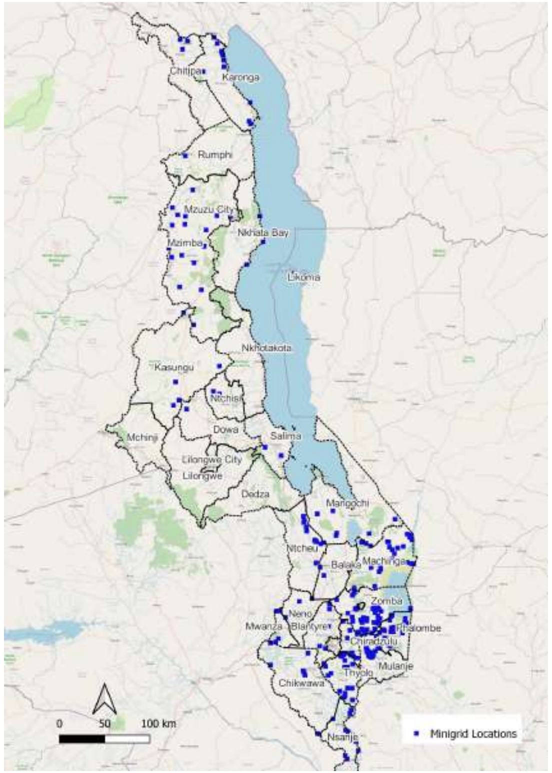
A total of 1,688 LV new mini-grids were identified and evaluated in the geospatial plan in addition to the ten pilot mini-grids currently under development.

Many of the 1,688 mini-grids are clustered close to one another that may result in consolidation into MV mini-grid clusters.

A summary of the mini-grid potential is provided in the table below, corresponding to the map at right.

Row Labels	Number of Mini-Grids	Sum of Total CAPEX	Sum of Potential Consumers	Average of Cost per consumer
Central	541	$157,512,522	91,355	$1,409
Northern	616	$158,869,634	81,392	$1,569
Southern	531	$174,988,476	109,360	$1,302
Grand Total	**1688**	**$491,370,631**	**282,107**	**$1,434**

PROPOSED MINI-GRID LOCATIONS



MALAWI IEP – ELECTRIFICATION

Least-cost Electrification Analysis and Results

ESCOM Construction Costs vs. Other Regional Costs

- ESCOM costs are found to be significantly higher than grid expansion costs in other countries in East Africa
- The expansion analysis was undertaken using ESCOM costs to evaluate program costs as the base case
- Data from EDM[1] /Mozambique using international competitive bidding was used to evaluate cost savings potential for electrification program implementation
- A third case was evaluated using lower-cost strategies for grid expansion to low-density rural areas

Construction Element	Materials	ESCOM	Mozambique ICB[2]	Low Cost
MV 33 kV	**AAAC 100mm2**	**$43,097**	**$32,643**	**$32,643**
	AAAC 50mm2	$37,476	$28,297	$28,297
	AAAC 35mm2 Ph-Ph			$21,513
Transformers	315kVA three phase	$5,368	$5,368	$5,368
	200kVA three phase	$4,481	$4,481	$4,481
	100kVA three phase	$3,835	$3,835	$3,835
	50 kVA three phase	$2,112	$2,112	$2,112
	25 kVA	$3,251	$3,251	$3,251
LV	4x100mm2 AAC	$23,084	$14,000	$12,500
Services	Single ph service	150	$85	$85
	Three ph service	433	$135	$135
Meters	Single ph service	88	$65	$65
	Three ph service	187	$100	$100

Note: Costs in US Dollars.

[1]. Electricidade de Moçambique (EDM)

[2]. International Competitive bidding (ICB), a scenario assuming cost reductions due to the introduction of international competitive bidding.

Densification Analysis Results by Region

Densification costs include:

- Service drop & meter ($238)
- Allowance of 10 meters of LV ($230.84)
- Allowance for partial transformer (1/150th cost - $6.70)
- Total estimated cost USD $476/consumer
- Total potential: 1.2 million consumers
- Total cost: US$574.4 million

Region	Densification Potential Total Connections	Total Cost USD
Northern	121,352	$57,736,781
Central	496,201	$236,082,025
Southern	589,795	$280,612,222
Total	1,207,348	$574,431,028

Note1: Costs in US Dollars.

Note2: Consumers refers to total number of household connections.

Densification Costs by District

Region	Districts	Current ESCOM Connections	Densification Potential (Connections)	Total Cost (USD)
Northern	Chitipa	6,391	7,681	3,654,448
Northern	Karonga	12,511	26,367	12,544,651
Northern	Nkhata Bay	8,697	10,782	5,129,834
Northern	Rumphi	7,954	11,454	5,449,558
Northern	Mzimba	15,321	22,391	10,652,958
Northern	Likoma	1,307	2,212	1,052,640
Northern	Mzuzu City	27,758	36,913	17,562,208
Central	Kasungu	13,756	32,698	15,557,167
Central	Nkhotakota	10,182	23,704	11,278,034
Central	Ntchisi	5,043	10,868	5,170,626
Central	Dowa	12,258	31,918	15,186,107
Central	Salima	14,057	39,044	18,576,321
Central	Lilongwe	23,820	89,207	42,442,723
Central	Mchinji	9,863	29,882	14,217,166
Central	Dedza	12,148	35,548	16,912,818
Central	Ntcheu	14,870	27,342	13,008,761
Central	Lilongwe City	101,774	165,135	78,567,594
Southern	Mangochi	24,874	82,635	39,316,007
Southern	Machinga	11,629	40,392	19,217,501

(Continued)

Region	Districts	Current ESCOM Connections	Densification Potential (Connections)	Total Cost (USD)
Southern	Zomba	13,487	42,563	20,250,763
Southern	Chiradzulu	7,073	29,185	13,885,407
Southern	Blantyre	18,164	38,487	18,311,443
Southern	Mwanza	6,299	9,276	4,413,218
Southern	Thyolo	16,506	52,747	25,095,884
Southern	Mulanje	13,519	41,359	19,677,833
Southern	Phalombe	6,595	24,084	11,458,711
Southern	Chikwawa	12,972	36,096	17,173,861
Southern	Nsanje	7,980	23,022	10,953,323
Southern	Balaka	12,846	23,800	11,323,325
Southern	Neno	4,322	7,354	3,498,780
Southern	Zomba City	13,008	16,475	7,838,501
Southern	Blantyre City	93,236	132,553	63,065,977
		560,220	**1,203,172**	**572,444,146**

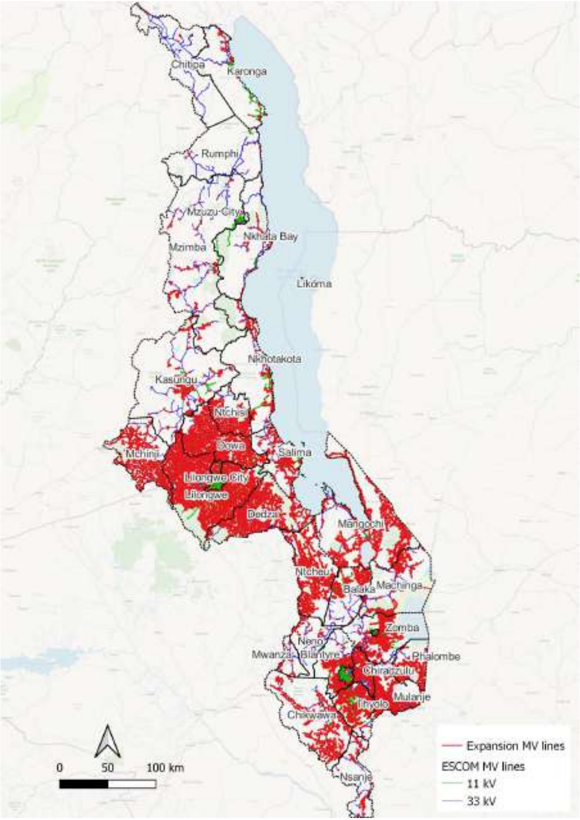
Grid Expansion All Regions

Three different scenarios were evaluated for the 2,152 identified projects each of which consists of MV and LV circuits expanded from existing ESCOM infrastructure:

- Scenario 1: Business as usual (BAU) based on current ESCOM cost data.
- Scenario 2: Modified costs for International Competitive Bidding (ICB) case (page 51)
- Scenario 3: Modified costs using low-cost design principles (page 53)
  - Low-cost design includes phase-to-phase 33 kV laterals and 2 x 35mm2 ABC LV

For all three scenarios:

- Assumed MV feeder extensions greater than 20 km use AAAC 100mm2 conductor
- MV feeder extensions less than 20 km use AAAC 50mm2 conductor
- Transformers assigned by calculated load from ESCOM design standard



Grid Expansion by Region: Scenario 1 – BAU

ESCOM Procurement Practices:

- Small-scale procurement on local market
- AAC 100mm2 feeders for MV > 20 km extensions
- AAC 50mm2 feeders for MV< 20 km extensions
- AAC 4 x 100mm2 LV
- Total potential: 2.2 million consumers
- Total estimated cost: US$ 3.1 billion

Region	Projects	Consumers	Total Cost
Northern	228	41,173	69,190,685
Central	893	1,275,771	1,664,803,126
Southern	1,031	887,944	1,371,331,609
Total	**2,152**	**2,204,888**	**3,105,325,420**

Note1: Costs in US Dollars.

Note2: Consumers refers to total number of household connections.

Grid Expansion by District: Scenario 1 - BAU

Region	Districts	Projects	Consumers	MV km	LV(km)	Trans Cost	MV Cost	LV Cost	Services Cost	Total Cost
Southern	Balaka	57	34,960	143	1,504	2,429,619	22,122,244	34,725,017	14,043,347	73,320,226
Southern	Blantyre	62	40,109	193	1,691	2,903,000	29,300,855	39,031,376	16,963,577	88,198,808
Southern	Blantyre City	15	7,613	15	187	307,761	3,001,875	4,324,161	2,432,896	10,066,694
Southern	Chikwawa	94	79,476	436	3,033	7,362,979	49,182,763	70,015,531	31,990,716	158,551,990
Southern	Chiradzulu	77	57,881	232	1,962	6,554,235	33,158,937	45,288,755	22,249,692	107,251,620
Northern	Chitipa	15	894	1	68	122,399	468,129	1,569,593	499,604	2,659,724
Central	Dedza	126	174,370	664	4,126	11,512,947	80,786,577	95,252,653	64,956,101	252,508,278
Central	Dowa	91	146,493	782	4,444	11,427,753	93,456,251	102,590,359	62,391,382	269,865,746
Northern	Karonga	34	6,121	24	310	475,550	3,437,310	7,147,960	2,421,256	13,482,076
Central	Kasungu	84	30,710	159	1,457	2,143,797	21,327,907	33,644,639	13,508,506	70,624,848
Central	Lilongwe	176	317,655	1,307	7,740	13,789,012	167,164,906	178,675,774	124,144,102	483,773,793
Central	Lilongwe City	26	44,176	106	852	919,971	13,338,745	19,663,861	14,445,421	48,367,998
Southern	Machinga	84	45,818	161	1,427	3,510,299	22,566,195	32,939,983	14,181,776	73,198,252
Southern	Mangochi	135	150,981	719	4,051	12,159,624	74,717,619	93,509,974	49,560,237	229,947,454
Central	Mchinji	99	88,194	354	2,489	5,713,457	47,859,112	57,457,841	30,378,014	141,408,423
Southern	Mulanje	99	103,425	415	3,089	10,640,266	54,298,396	71,307,523	38,710,834	174,957,019
Southern	Mwanza	24	4,316	14	159	478,868	2,102,480	3,676,508	1,508,880	7,766,736
Northern	Mzimba	94	11,654	85	663	1,547,348	9,229,109	15,303,452	5,977,633	32,057,542
Northern	Mzuzu City	6	1,109	4	48	74,589	606,021	1,098,960	408,681	2,188,250
Southern	Neno	29	7,650	23	261	683,516	4,718,830	6,014,650	3,227,922	14,644,918
Northern	Nkhata Bay	59	6,458	15	347	824,281	4,030,209	8,008,073	3,100,189	15,962,752
Central	Nkhotakota	54	23,283	91	974	1,203,839	15,498,092	22,478,879	9,298,365	48,479,174
Southern	Nsanje	43	18,512	63	779	1,811,096	9,138,877	17,973,080	7,104,888	36,027,941
Central	Ntcheu	104	118,258	519	3,403	7,099,817	60,430,469	78,556,696	47,702,137	193,789,120
Central	Ntchisi	60	50,233	213	1,570	3,989,244	30,106,758	36,245,792	20,669,710	91,011,503
Southern	Phalombe	66	52,540	208	1,891	5,834,041	27,947,871	43,648,213	19,454,992	96,885,116
Northern	Rumphi	20	1,165	3	69	147,164	547,073	1,599,935	546,167	2,840,340
Central	Salima	73	44,517	112	1,271	2,217,557	19,535,026	29,342,225	13,879,434	64,974,242
Southern	Thyolo	131	87,296	321	2,699	5,250,734	48,488,699	62,295,147	28,040,445	144,075,026
Southern	Zomba	112	75,837	359	3,022	4,848,146	48,940,364	69,771,528	29,076,778	152,636,816
Southern	Zomba City	3	2,486	9	70	70,311	1,309,402	1,612,210	811,070	3,802,994
	Totals	**2,037**	**1,755,866**	**7,382**	**52,563**	**123,134,763**	**948,567,331**	**1,213,386,613**	**663,796,903**	**2,948,885,610**

Note: Costs in US Dollars.

Grid Expansion by Region: Scenario 2 - ICB

ICB Procurement:

- ICB used for multiple large lots of all materials
- AAC 100mm2 feeders for MV extensions > 20 km
- AAC 50mm2 feeders for MV extensions < 20 km
- AAC ABC 2 x 35mm2 LV
- Total potential: 2.2 million consumers
- Total estimated cost: US$ 2.1 billion

Region	Projects	Consumers	Total Cost
Northern	228	41,173	338,046,815
Central	893	1,275,771	844,043,933
Southern	1,031	887,944	935,507,595
Total	**2,152**	**2,204,888**	**2,117,598,343**

Note: Costs in US Dollars.

Grid Expansion by District: Scenario 2 - ICB

Region	Districts	Projects	Consumers	MV km	LV (km)	Trans Cost	MV Cost	LV Cost	Services Cost	Total Cost
Central	Dedza	126	206.464	664	4.126	11.512.947	61.016.315	57.768.174	42.697.297	172.994.733
Central	Dowa	91	198.312	782	4.444	11.427.753	70.610.725	20.404.569	41.011.442	47.531.973
Central	Kasungu	84	42.937	159	1.457	2.143.797	16.104.123	108.362.055	8.879.484	330.025.806
Central	Lilongwe	176	394.594	1.307	7.740	13.789.012	126.271.664	11.925.603	81.603.075	32.414.714
Central	Lilongwe City	26	45.915	106	852	919.971	10.073.797	34.846.636	9.495.343	96.674.393
Central	Mchinji	99	96.557	354	2.489	5.713.457	36.146.059	13.632.836	19.968.241	32.650.914
Central	Nkhotakota	54	29.555	91	974	1.203.839	11.702.188	47.642.525	6.112.052	131.751.399
Central	Ntcheu	104	151.622	519	3.403	7.099.817	45.653.229	21.982.099	31.355.828	62.293.190
Central	Ntchisi	60	65.699	213	1.570	3.989.244	22.735.121	17.795.271	13.586.726	43.886.500
Central	Salima	73	44.116	112	1.271	2.217.557	14.750.367	951.916	9.123.305	1.756.188
Northern	Chitipa	15	1.588	1	68	122.399	353.471	62.218.296	328.403	185.268.216
Northern	Karonga	34	7.696	24	310	475.550	2.595.420	4.335.046	1.591.553	8.997.568
Northern	Mzimba	94	19.000	85	663	1.547.348	6.968.649	9.281.133	3.929.250	21.726.380
Northern	Mzuzu City	6	1.299	4	48	74.589	457.590	666.489	268.637	1.467.305
Northern	Nkhata Bay	59	9.854	15	347	824.281	3.043.101	4.856.681	2.037.833	10.761.896
Northern	Rumphi	20	1.736	3	69	147.164	413.080	970.318	359.009	1.889.572
Southern	Balaka	57	44.637	143	1.504	2.429.619	16.706.430	21.059.790	9.231.049	49.426.887
Southern	Blantyre	62	53.919	193	1.691	2.903.000	22.126.845	23.671.481	11.150.591	59.851.916
Southern	Blantyre City	15	7.733	15	187	307.761	2.266.634	2.622.488	1.599.205	6.796.088
Southern	Chikwawa	94	101.683	436	3.033	7.362.979	37.148.336	42.462.538	21.028.311	108.002.164
Southern	Chiradzulu	77	70.721	232	1.962	6.554.235	25.037.412	27.466.413	14.625.288	73.683.349
Southern	Machinga	84	45.077	161	1.427	3.510.299	17.039.120	19.977.214	9.322.042	49.848.676
Southern	Mangochi	135	157.528	719	4.051	12.159.624	56.452.860	56.711.286	32.577.204	157.900.974
Southern	Mulanje	99	123.043	415	3.089	10.640.266	41.001.908	43.246.096	25.445.615	120.333.886
Southern	Mwanza	24	4.796	14	159	478.868	1.587.525	2.229.703	991.825	5.287.922
Southern	Neno	29	10.260	23	261	683.516	3.563.060	3.647.724	2.121.795	10.016.095
Southern	Nsanje	43	22.583	63	779	1.811.096	6.900.517	10.900.190	4.670.224	24.282.027
Southern	Phalombe	66	61.838	208	1.891	5.834.041	21.102.677	26.471.468	12.788.261	66.196.447
Southern	Thyolo	131	89.127	321	2.699	5.250.734	36.614.771	37.780.333	18.431.698	98.077.536
Southern	Zomba	112	92.421	359	3.022	4.848.146	36.958.117	42.314.557	19.112.905	103.233.725
Southern	Zomba City	3	2.578	9	70	70.311	988.694	977.762	533.137	2.569.904
	Totals	**2.152**	**2.204.888**	**7.750**	**55.656**	**128.053.220**	**754.389.805**	**779.178.691**	**455.976.627**	**2.117.598.343**

Note: Costs in US Dollars.

Grid Expansion by Region: Scenario 3 – Low-cost

Low-Cost Attributes:

- AAC 100mm2 feeders for MV > 20 km extensions
- AAC 50mm2 feeders for MV < 20 km extensions
- Phase-to-phase 33 kV laterals
- ICB cost estimates for large-scale procurement
- AAC ABC 2 x 35mm2 ABC LV
- Total potential: 2.2 million consumers
- Total estimated cost: US$ 1.8 billion

Region	Projects	Consumers	Total Cost
Northern	228	41,173	44,171,160
Central	893	1,275,771	1,066,721,510
Southern	1,031	887,944	880,578,471
Total	**2,152**	**2,204,888**	**1,991,471,141**

Note: Costs in US Dollars.

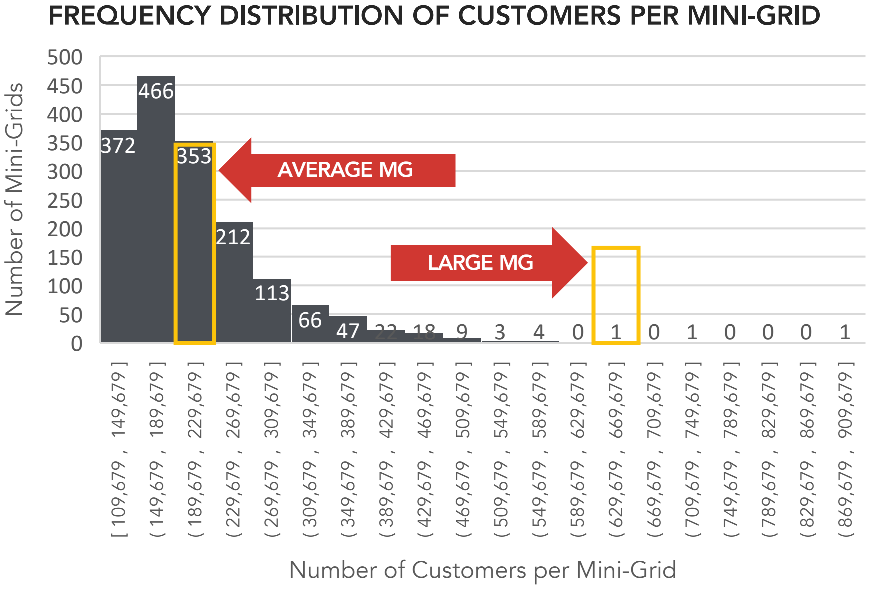
Grid Expansion by District: Scenario 3 – Low-cost

Region	Districts	Projects	Consumers	MV km	LV (km)	Trans Cost	MV Cost	LV Cost	Services Cost	Total Cost
Central	Dedza	126	206.464	664	4.126	11.512.947	51.061.908	57.768.174	42.697.297	163.040.326
Central	Dowa	91	198.312	782	4.444	11.427.753	59.441.849	62.218.296	41.011.442	174.099.341
Central	Kasungu	84	42.937	159	1.457	2.143.797	13.320.229	20.404.569	8.879.484	44.748.079
Central	Lilongwe	176	394.594	1.307	7.740	13.789.012	105.378.269	108.362.055	81.603.075	309.132.411
Central	Lilongwe City	26	45.915	106	852	919.971	8.401.579	11.925.603	9.495.343	30.742.496
Central	Mchinji	99	96.557	354	2.489	5.713.457	29.973.017	34.846.636	19.968.241	90.501.351
Central	Nkhotakota	54	29.555	91	974	1.203.839	9.512.113	13.632.836	6.112.052	30.460.840
Central	Ntcheu	104	151.622	519	3.403	7.099.817	38.474.502	47.642.525	31.355.828	124.572.672
Central	Ntchisi	60	65.699	213	1.570	3.989.244	18.756.373	21.982.099	13.586.726	58.314.442
Central	Salima	73	44.116	112	1.271	2.217.557	11.973.421	17.795.271	9.123.305	41.109.554
Northern	Chitipa	15	1.588	1	68	122.399	272.137	951.916	328.403	1.674.854
Northern	Karonga	34	7.696	24	310	475.550	2.133.562	4.335.046	1.591.553	8.535.710
Northern	Mzimba	94	19.000	85	663	1.547.348	5.872.915	9.281.133	3.929.250	20.630.646
Northern	Mzuzu City	6	1.299	4	48	74.589	374.328	666.489	268.637	1.384.043
Northern	Nkhata Bay	59	9.854	15	347	824.281	2.415.641	4.856.681	2.037.833	10.134.436
Northern	Rumphi	20	1.736	3	69	147.164	334.980	970.318	359.009	1.811.471
Southern	Balaka	57	44.637	143	1.504	2.429.619	13.696.647	21.059.790	9.231.049	46.417.104
Southern	Blantyre	62	53.919	193	1.691	2.903.000	18.157.881	23.671.481	11.150.591	55.882.952
Southern	Blantyre City	15	7.733	15	187	307.761	1.823.606	2.622.488	1.599.205	6.353.059
Southern	Chikwawa	94	101.683	436	3.033	7.362.979	31.322.153	42.462.538	21.028.311	102.175.982
Southern	Chiradzulu	77	70.721	232	1.962	6.554.235	20.609.120	27.466.413	14.625.288	69.255.057
Southern	Machinga	84	45.077	161	1.427	3.510.299	14.043.560	19.977.214	9.322.042	46.853.115
Southern	Mangochi	135	157.528	719	4.051	12.159.624	48.158.870	56.711.286	32.577.204	149.606.984
Southern	Mulanje	99	123.043	415	3.089	10.640.266	34.017.089	43.246.096	25.445.615	113.349.066
Southern	Mwanza	24	4.796	14	159	478.868	1.304.752	2.229.703	991.825	5.005.148
Southern	Neno	29	10.260	23	261	683.516	2.866.506	3.647.724	2.121.795	9.319.542
Southern	Nsanje	43	22.583	63	779	1.811.096	5.676.183	10.900.190	4.670.224	23.057.693
Southern	Phalombe	66	61.838	208	1.891	5.834.041	17.457.026	26.471.468	12.788.261	62.550.796
Southern	Thyolo	131	89.127	321	2.699	5.250.734	30.040.771	37.780.333	18.431.698	91.503.536
Southern	Zomba	112	92.421	359	3.022	4.848.146	30.580.197	42.314.557	19.112.905	96.855.805
Southern	Zomba City	3	2.578	9	70	70.311	811.420	977.762	533.137	2.392.631
	Totals	**2.152**	**2.204.888**	**7.750**	**55.656**	**128.053.220**	**628.262.603**	**779.178.691**	**455.976.627**	**1.991.471.141**

Mini-grid and Solar Home Systems (SHS) – Technical Assumptions

Key assumptions used to evaluate mini-grid potential in the geospatial electrification plan include:

- Mini-Grids were evaluated where grid expansion capital costs exceed $1,300 USD per connection. When marginal grid expansion costs increase beyond 5-10 years of cumulative residential energy expenditures, rural consumers can often be served sooner and more affordably by decentralized mini-grid infrastructure development in local communities.
- Mini-grids are included up to a maximum capital cost of $2,000 USD per consumer, which represents an estimated upper threshold for financially viable mini-grids in electrification analysis.[1] If costs per connection exceed $2,000 USD per consumer, the consumers exceeding this threshold will be served with SHS.
- All mini-grids are modeled twice: once as solar photovoltaic-battery charging systems with supplemental diesel generation and again as a fully renewable mini-grid with larger solar and battery arrays to eliminate diesel generation entirely.

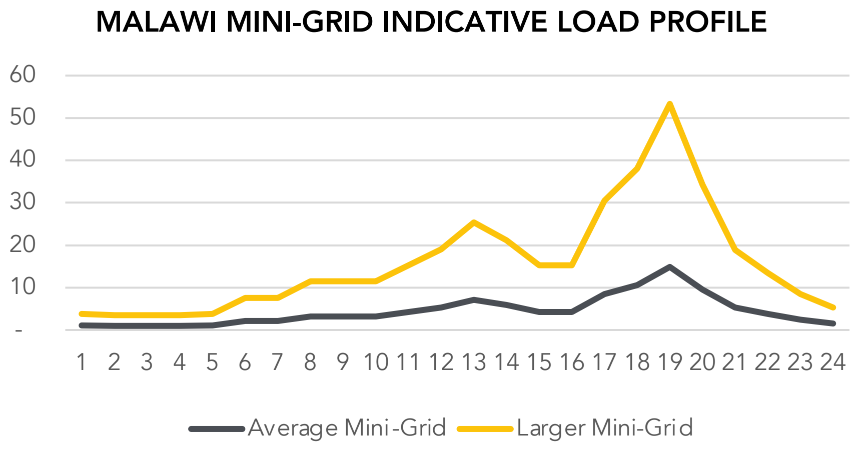


[1] Cross Boundary, 2018. https://www.greentechmedia.com/articles/read/minigrids-are-the-cheapest-way-to-electrify-100-million-africans-today

Mini-grid and Solar Home Systems (SHS) – Technical Assumptions

Key assumptions used to evaluate mini-grid potential in the geospatial electrification plan include:

- Low voltage distribution networks are better suited to maintenance by local technicians in remote areas. Service areas were therefore limited to a 1.5 km radius from the powerhouse to maintain power quality. It may be preferable to consider use of medium voltage networks to aggregate multiple adjacent mini-grids and optimize power generation sizing and cost over larger customer populations.
- For purposes of this analysis, mini-grids were identified and evaluated with a minimum of 100 consumers for each mini-grid service area.
- Solar Home Systems (SHS) are modeled as Tier-1 and Tier-2 compliant systems



	Average	Large
MG_ID	1244	666
Region	Northern	Southern
District	Mzimba	Machinga
Year 10 Connections	212	732
Year 10 Consumption (kWh/yr)	38,795	139,036
Year 10 Peak Demand (kW)	16	54

Mini-Grid Financial Assumptions

Mini-grid characteristics were evaluated in HOMER Pro for selected mini-grid sizes. The analyses were evaluated to provide 24-hour power using year 10 demand, assuming 12 kWh/month per household, and a minimum renewable fraction of 75% in the base case as well as a sensitivity case with 100% renewable fraction.

- All mini-grids were evaluated using low-cost LV standards with associated costs for feeders, services, and meters.
- Unit cost assumptions are based on recent price data for mini-grid projects in Democratic Republic of Congo using lower shipping and logistics costs to reflect conditions in Malawi.
- The mini-grid topology includes a hybrid generation system with fixed-tilt PV panels, containerized battery system, diesel generator, mini-grid controller, and metering server. The control mode of the mini-grids is illustrated in the figures at right. Solar energy serves load directly during daylight hours while also charging the battery to maximum state of charge (SOC) in the afternoon. Once the battery is fully discharged, diesel generators support overnight loads to deliver 24/7 energy access to all customers with 12% operating reserve. Model results include solar array size, battery capacity, diesel generator capacity and capital & operating costs.

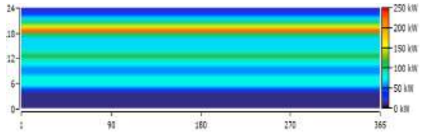
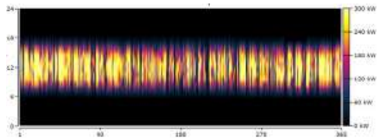
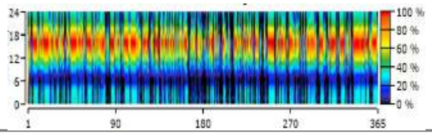
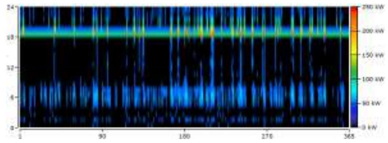
Data	Indicative HOMER Results
Load (kW)	
Solar Generation (kW)	
Battery State of Charge (%)	
Diesel Generation (kW)	

Figure 2: Illustration of generation and load characteristics in HOMER analysis.

Mini-Grid Financial Assumptions (continued)

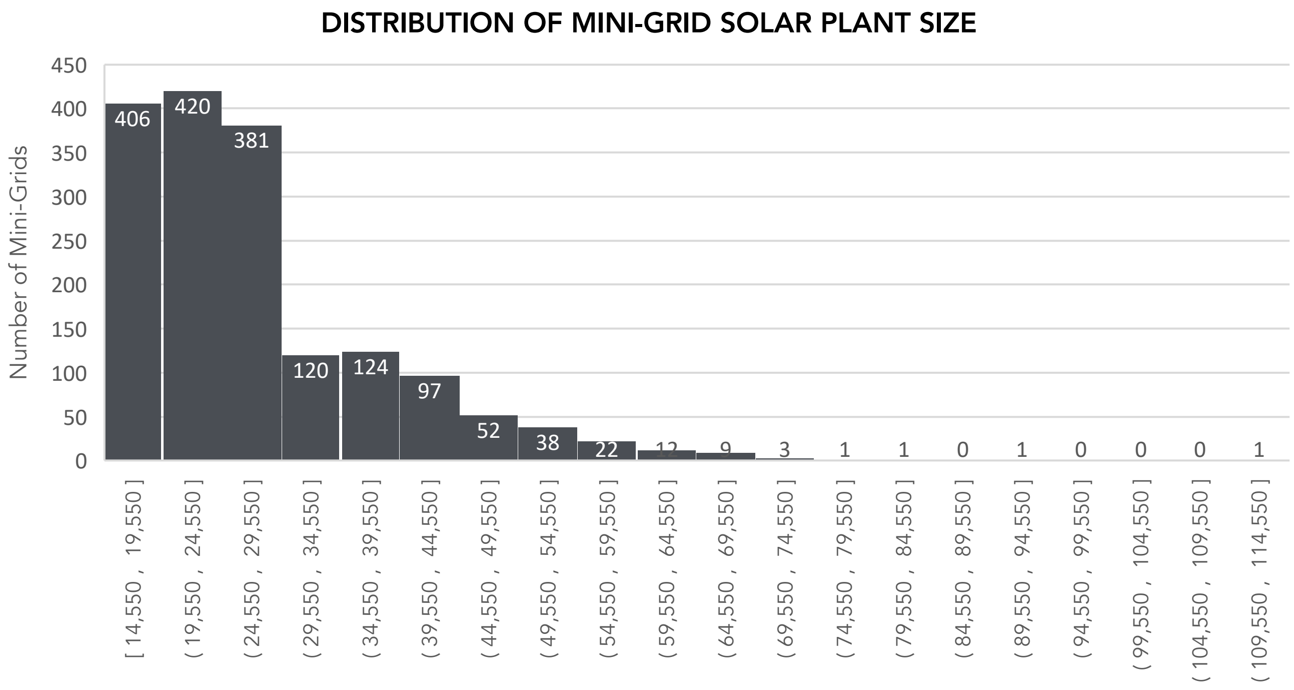
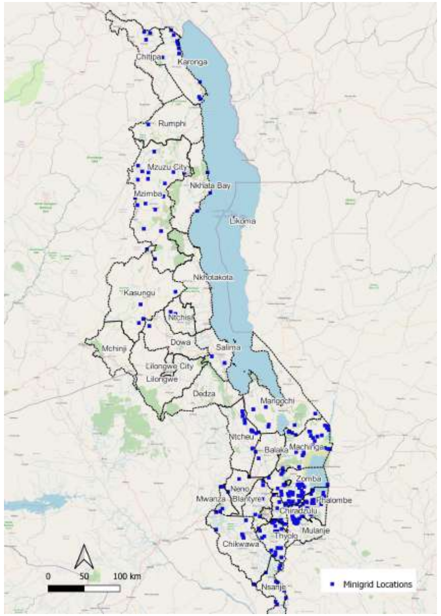


Figure 1: Solar Plant Size (kW DC) for mini-grids in the analysis.

Mini-Grid Planning Results

The Table on the right illustrates the total number of mini-grids by district and by region as well as the total consumers (household connections) and anticipated CAPEX investment per region and district.



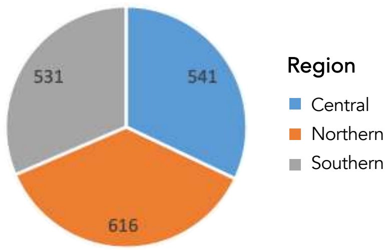
Region	District	Number of Mini-Grids	Total CAPEX (USD)	Potential Consumers	Average CAPEX per consumer (USD)
Central		**541**	**$ 157,512,522**	**91,355**	**$ 1,409**
	Dedza	1	$ 263,250	188	$ 1,105
	Dowa	31	$ 8,898,838	5,780	$ 1,246
	Kasungu	319	$ 89,684,238	49,297	$ 1,471
	Lilongwe	2	$ 316,723	264	$ 952
	Mchinji	35	$ 10,373,548	6,993	$ 1,190
	Nkhotakota	33	$ 10,430,294	5,412	$ 1,575
	Ntcheu	50	$ 15,997,433	9,419	$ 1,397
	Ntchisi	30	$ 8,593,111	5,245	$ 1,345
	Salima	40	$ 12,955,086	8,757	$ 1,196
Northern		**616**	**$ 158,869,634**	**81,392**	**$ 1,569**
	Chitipa	35	$ 9,218,044	4,379	$ 1,678
	Karonga	23	$ 7,577,078	4,028	$ 1,512
	Mzimba	490	$ 123,059,989	63,657	$ 1,553
	Nkhata Bay	36	$ 9,733,674	4,773	$ 1,658
	Rumphi	32	$ 9,280,849	4,554	$ 1,636
Southern		**531**	**$ 174,988,476**	**109,360**	**$ 1,302**
	Balaka	53	$ 16,153,328	8,647	$ 1,493
	Blantyre	39	$ 12,283,735	6,441	$ 1,535
	Chikwawa	34	$ 9,057,433	5,834	$ 1,260
	Machinga	130	$ 45,755,742	29,563	$ 1,249
	Mangochi	82	$ 25,134,474	16,316	$ 1,239
	Mulanje	28	$ 10,724,577	6,852	$ 1,290
	Mwanza	13	$ 3,789,128	2,744	$ 1,102
	Neno	16	$ 4,299,822	2,634	$ 1,342
	Nsanje	29	$ 8,496,322	5,337	$ 1,261
	Phalombe	25	$ 10,896,114	7,311	$ 1,204
	Thyolo	33	$ 11,621,652	7,258	$ 1,292
	Zomba	49	$ 16,776,149	10,420	$ 1,310
Grand Total		**1688**	**$ 491,370,631**	**282,107**	**$ 1,434**

Mini-Grid Planning Results

The number of mini-grids is relatively balanced between the North, South, and Central regions, whereas the Northern region has the lowest population and the highest number of mini-grids, which is a reflection of its lower population density and less attractive opportunity for grid expansion and densification.

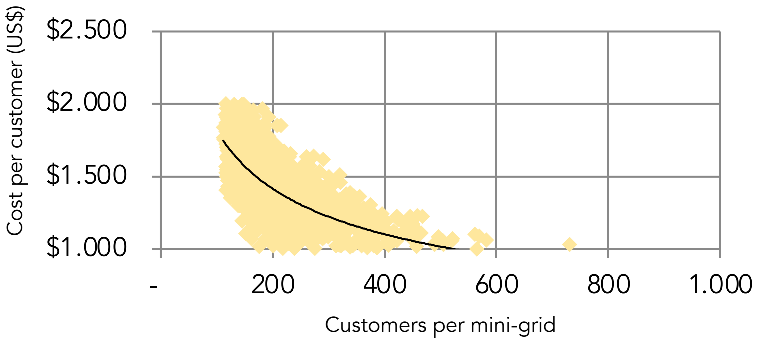
The vast majority of sites have solar power requirements below 30 kW, which is widely seen as an economic viability threshold within the mini-grid sector. The very small mini-grid candidates will likely require customized subsidies to attract private sector investment and reach economies of scale.

NUMBER OF MINI-GRIDS

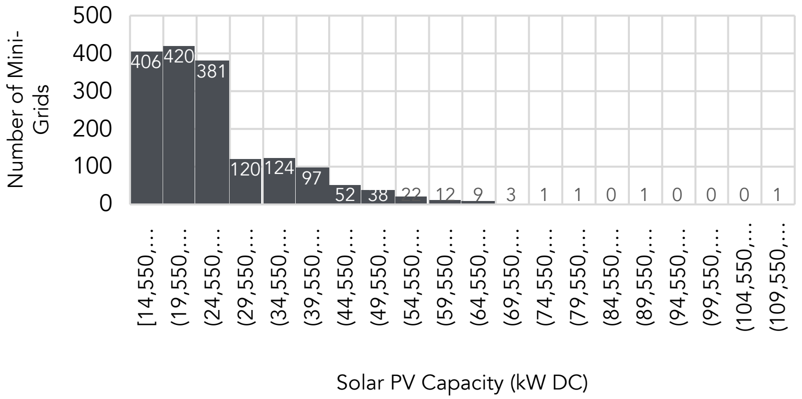


Out of 1,688 mini-grids in the analysis, 1,207 of the mini-grids (72%) have PV plant sizes of 30 kW or less.

MINI-GRID ECONOMIES OF SCALE



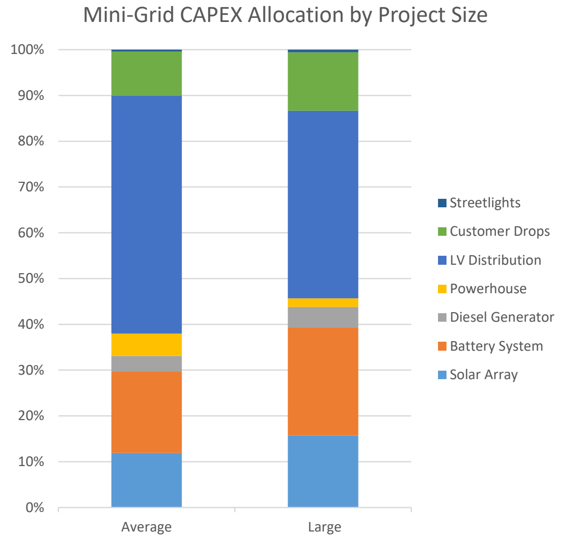
DISTRIBUTION OF MINI-GRID SOLAR PLANT SIZE



Mini-Grid Results: Capital Cost Observations

- Relative contributions to mini-grid capital costs for distribution, generation, storage and other cost components vary somewhat by size as shown in the bar graph to the right.
- Due to the relatively high cost of distribution construction, distribution costs for smaller mini-grids average ~50% of total capital cost, dropping to ~40 for larger mini-grids.
- Both average and large mini-grids have a footprint no larger than 1.5km radius meaning that larger mini-grids have a higher population density with lower distribution cost per served consumer.
- The table on the right illustrates that as mini-grid size increases, mini-grid cost per consumer becomes much more cost-competitive with grid expansion projects, which were capped at $1300 per customer connection. Therefore, large mini-grids offer lower costs ($1032 per connection), including 24-hour generation and distribution, than the distribution-only costs of grid expansion in large mini-grid areas. Nevertheless, average mini-grids have connection costs roughly comparable ($1355 per connection) to grid expansion.
- That said, tariffs to consumers will be significantly higher for mini-grids than ESCOM service – even with competitive capital costs. Therefore, subsidy programs, including results-based financing (RBF), may be implemented to incentivize rapid deployment of mini-grids with tariffs more comparable to the ESCOM tariff.

Mini-Grid Type	**Average**	**Large**
Year 10 Connections	**212**	**732**
MG_ID	1281	703
Solar Array	$ 34,221	$118,953
Battery System	$ 51,074	$177,533
Diesel Generator	$ 9,856	$ 34,260
Powerhouse	$ 14,000	$ 14,000
LV Distribution	$149,273	$309,486
Customer Drops	$ 27,912	$ 96,504
Streetlights	$ 1,160	$ 4,205
Total	$287,496	$754,941
CAPEX per Connection	**$ 1,355**	**$ 1,032**
Distribution CAPEX/connection	$ 840.76	$ 560.71
Generation CAPEX/connection	$ 514.56	$ 471.25



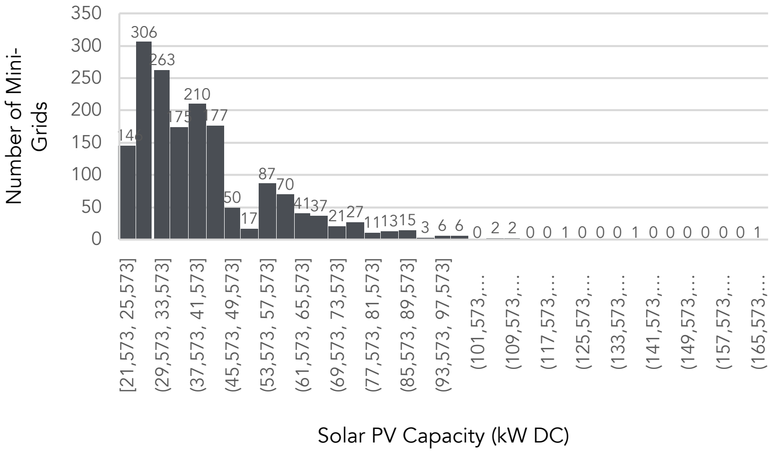
Mini-Grid Results: Sensitivity Case A – No Diesel Generation

To improve the environmental performance of the mini-grids and eliminate greenhouse gas (GHG) emissions associated with rural electrification service, all mini-grids were also analyzed with 100% renewable energy. In this sensitivity scenario, the solar array and battery bank sizing was increased to serve the full load of the mini-grid on a 24-hour basis, without any contributions from a diesel generator.

In order to accommodate the fully renewable operation within a reasonable system construction cost, the analysis was performed in HOMER Pro to allow for up to 10% annual capacity shortage. Therefore, the model allows for outages during days when the solar resource is insufficient to meet the system demand.

While most mini-grid developers are not designing fully renewable mini-grid systems, due to the additional CAPEX for larger solar and battery systems, there are some project investors who prefer exclusively renewable energy systems. Elimination of diesel generators may become more prevalent as unit costs continue to decline for solar panels and batteries over time.

DISTRIBUTION OF MINI-GRID SOLAR PLANT SIZE (RF = 100%)



SIMULATION RESULTS:

- In order to eliminate diesel generation with no more than 10% annual capacity shortage:
    - Solar PV capacity increases by 23% in average mini-grids and 37% in large mini-grids
    - Battery capacity increases by 18% in average mini-grids and 28% in large mini-grids
- Even after accounting for cost savings from eliminating the diesel generators in all projects, the net cost of the mini-grid component of universal electrification plan increases by 14% overall and the average cost per connection increases from USD $1,375 to $1,565.
- The number of mini-grids that can be served with a solar capacity of 30 kW or less is reduced from 1,207 (72%) to 452 (27%)

Mini-Grid Results: Sensitivity Case B – Utilize Medium Voltage in Mini-Grids

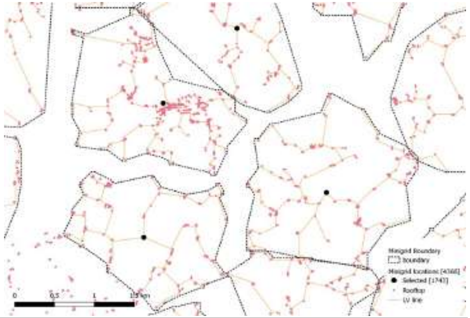
As a second sensitivity case, the geospatial model was re-simulated allowing for medium voltage (MV) connections between mini-grids.

- Advantage: using MV conductors and transformers allows for consolidation of multiple LV population clusters into a single mini-grid which achieves economies of scale in generation sizing, distribution network construction, and system operating costs. The MV mini-grids would use the same construction standards as the national grid.
- Disadvantage: utilizing MV power systems in remote areas requires training and staffing competent technicians who can operate and maintain these systems safely, since MV equipment is extremely dangerous. Additionally, the incremental cost of transformers and MV lines adds 10-20% to the distribution CAPEX of MV mini-grids.

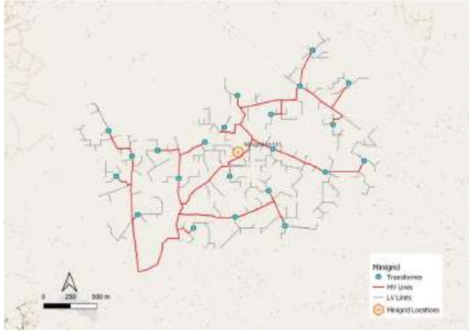
SIMULATION RESULTS:

- Out of 1,688 LV mini-grids, 669 (40%) were in isolated areas and unable to be combined with any other mini-grid. These systems still have the same characteristics as in the base case. The average customer connections per isolated mini-grid is 153.
- The remaining 1,019 LV mini-grids (60%) were able to be consolidated into a total of 103 MV mini-grids with a range of 5-19 transformers per grid. The average customer connections per consolidated mini-grid is 1,747.
- Therefore, if rural mini-grid operators can be trained in MV system operations, substantial consolidation is possible.

Example of co-located LV Mini-Grids operating on a standalone basis with separate generation plants.



Example of clustered LV mini-grids aggregated into an MV mini-grid with transformers and a common generation plant.



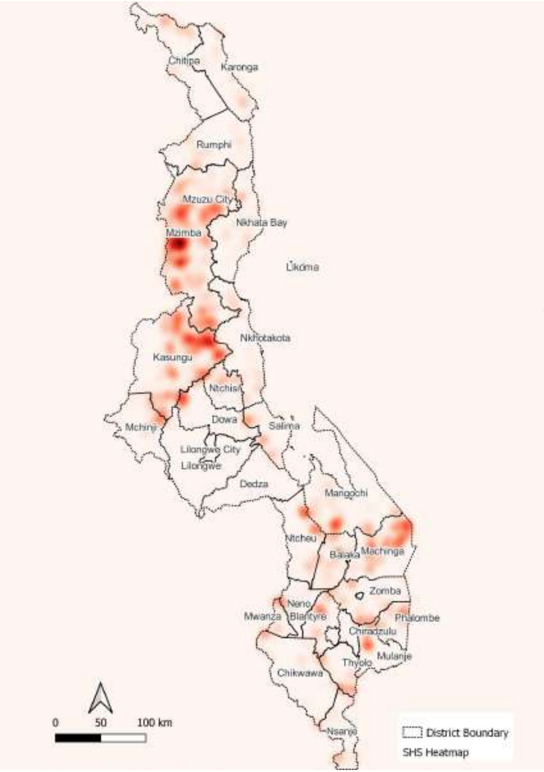
Solar home system (SHS) potential

The solar home system (SHS) potential is shown by region and district in the table at right. All SHS in the model are Tier 1 and Tier 2.

Solar solutions were considered in areas that cannot be served by grid densification, grid expansion and mini-grid service.

Affordability limitations will need to be considered to define incentives and, in some cases, consumer subsidies.

Some households and businesses may choose to purchase SHS to increase reliability of grid service if load shedding is frequent and problematic. These elective purchases are not represented in the electrification analysis.



Region	District	Total Systems
Northern	Chitipa	37,590
Northern	Karonga	41,052
Northern	Nkhata Bay	29,495
Northern	Rumphi	30,244
Northern	Mzimba	108,677
Northern	Likoma	160
Northern	Mzuzu City	2,476
Central	Kasungu	81,267
Central	Nkhotakota	30,853
Central	Ntchisi	11,796
Central	Dowa	8,822
Central	Salima	21,783
Central	Lilongwe	16,034
Central	Mchinji	20,762
Central	Dedza	3,464
Central	Ntcheu	11,825
Central	Lilongwe City	-
Southern	Mangochi	32,355
Southern	Machinga	71,676
Southern	Zomba	61,990
Southern	Chiradzulu	9,864
Southern	Blantyre	26,992
Southern	Mwanza	13,833
Southern	Thyolo	34,774
Southern	Mulanje	20,247
Southern	Phalombe	25,347
Southern	Chikwawa	12,957
Southern	Nsanje	19,086
Southern	Balaka	39,529
Southern	Neno	14,075
Southern	Zomba City	-
Southern	Blantyre City	-
		839,024

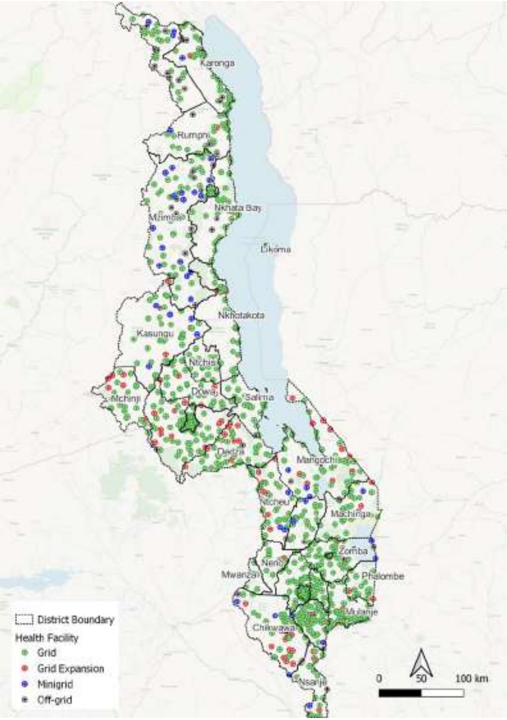
Electrification of Public Facilities – Health Clinics

- Nationwide health facility data was provided by the ministry of health and analyzed in the cold chain analysis to determine electrification status and approximate electrical demand.
- Health facilities were identified in the geospatial planning models and illustrated according to electrification modality in the 2030 universal electrification scenario.
- Results of health facility electrification planning are as follows:

Electrification Modality	Number of Health Facilities
ESCOM Grid	869
Grid Expansion	83
Mini-Grid	53
Standalone Solar (SHS)	53

Note that the standalone solar solutions for health clinics are significantly larger than those for residential consumers. These sizing and cost assumptions are further explained in the Malawi IEP cold chain report.

MAWALI HEALTH CLINIC ELECTRIFICATION RESULTS

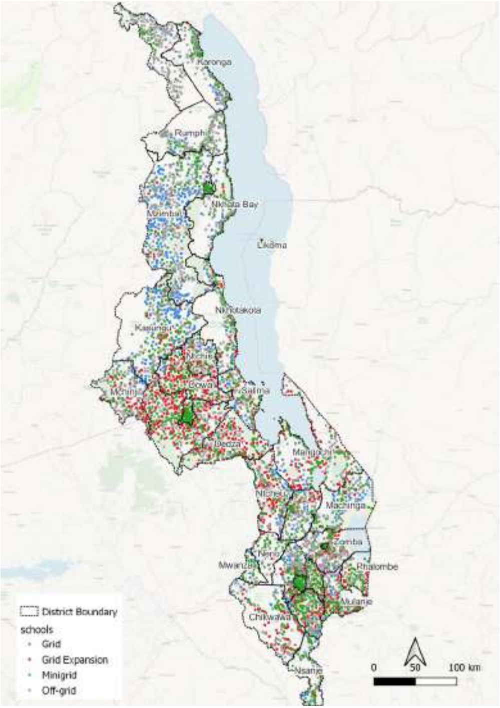


Electrification of Public Facilities – Schools

- Nationwide primary and secondary school data was gathered from public datasets.
- Schools were identified in the geospatial planning models and illustrated according to electrification modality in the 2030 universal electrification scenario.
- Results of school electrification planning are as follows:

Electrification Modality	Number of Schools
ESCOM Grid	3,123
Grid Expansion	961
Mini-Grid	617
Standalone Solar (SHS)	2,422

MAWALI SCHOOL ELECTRIFICATION RESULTS



Note that the standalone solar solutions for schools may need to be larger than those for residential consumers. These sizing and cost assumptions will require further refinement in future analyses.

MALAWI IEP – ELECTRIFICATION

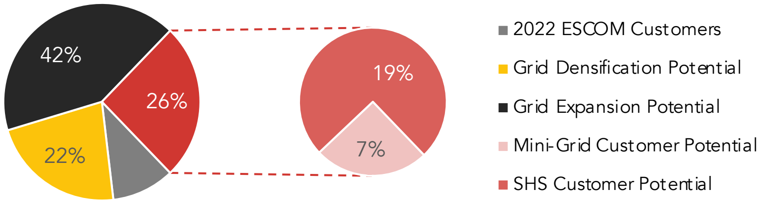
Implementation Recomendations

Universal Access by 2030

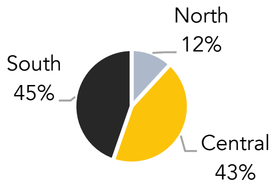
Region	2022 ESCOM Customers	Grid Densification Potential	Grid Expansion Potential	Mini-Grid Customer Potential	SHS Customer Potential	Total
North	79,939	117,799	33,910	100,727	309,010	641,385
Central	217,771	485,346	1,284,440	113,057	255,685	2,356,299
South	262,510	600,028	951,554	135,339	473,640	2,423,070
Total	**560,220**	**1,203,172**	**2,269,903**	**349,123**	**1,038,336**	**5,420,754**

- To increase access from 12.5% of today's population (4.5 million households) to universal access by 2030 (with a total population of 5.5 million households), 42% of new consumers will be connected via grid expansion and 22% will be connected via densification.
- Off-grid electrification will account for 26% of the electrification plan of which 7% represent mini-grid expansion and 19% via standalone solar solutions.
- The regional division of electrification expansion (including grid and off-grid) shows the majority of connections in south and central regions (45% and 43%, respectively) with 12% in the north.

2030 UNIVERSAL ELECTRIFICATION PLANNING RESULTS

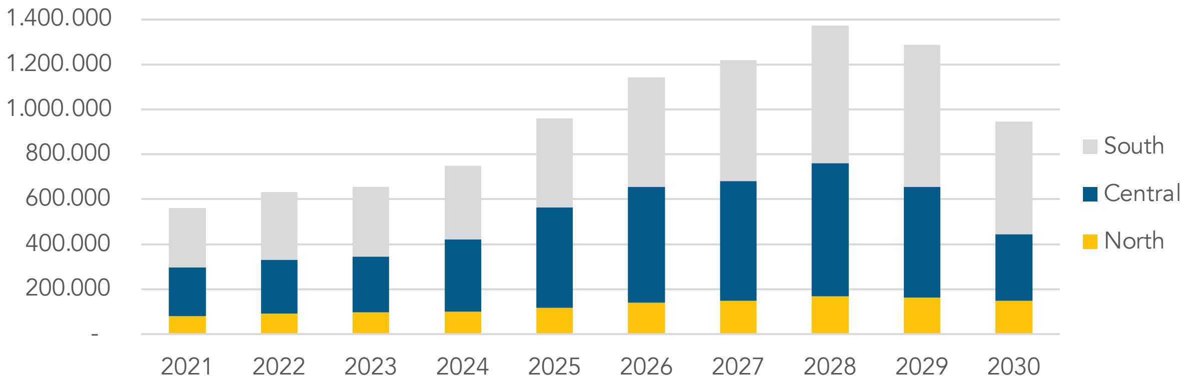


TOTAL CUSTOMERS BY REGION



2030 Full Access – Implementation Plan by Region

ELECTRIFICATION IMPLEMENTATION PLAN BY REGION

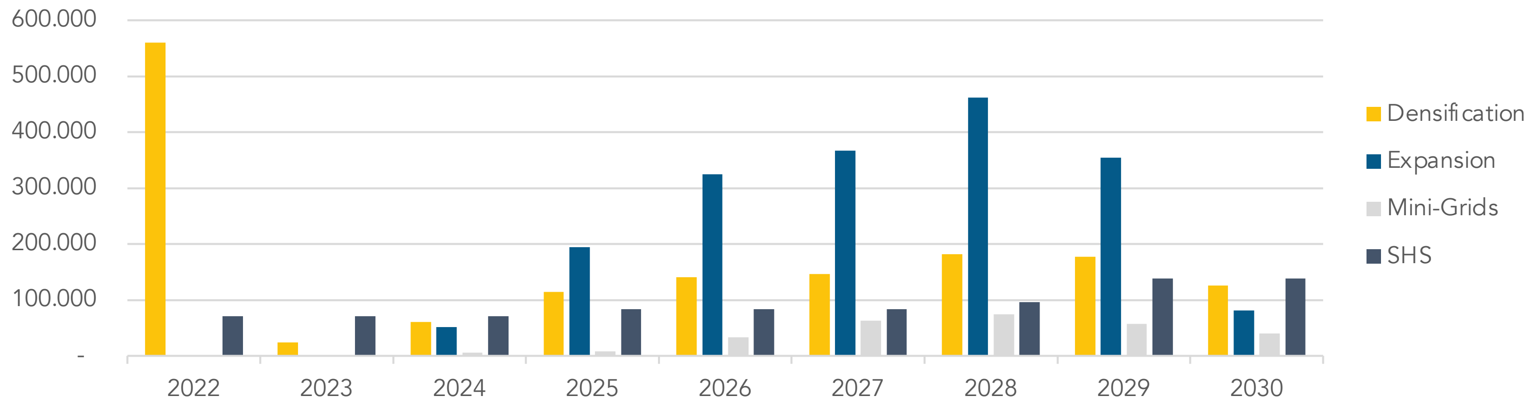


Region	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	Total
North	79,939	61,802	24,737	34,757	50,201	65,645	90,381	109,428	74,129	50,365	**641,385**
Central	217,771	51,137	53,904	87,873	213,029	338,185	428,689	578,411	210,880	176,419	**2,356,299**
South	262,510	94,728	64,799	98,651	170,049	241,448	350,452	482,764	343,663	314,006	**2,423,070**
Total	**560,220**	**207,667**	**143,439**	**221,282**	**433,280**	**645,278**	**869,523**	**1,170,603**	**628,672**	**540,790**	**5,420,754**

Note: the 560,220 ESCOM consumers in 2021 reflect the data in the ESCOM customer database.

2030 Full Access – Implementation Plan by Modality

ELECTRIFICATION IMPLEMENTATION PLAN BY MODALITY



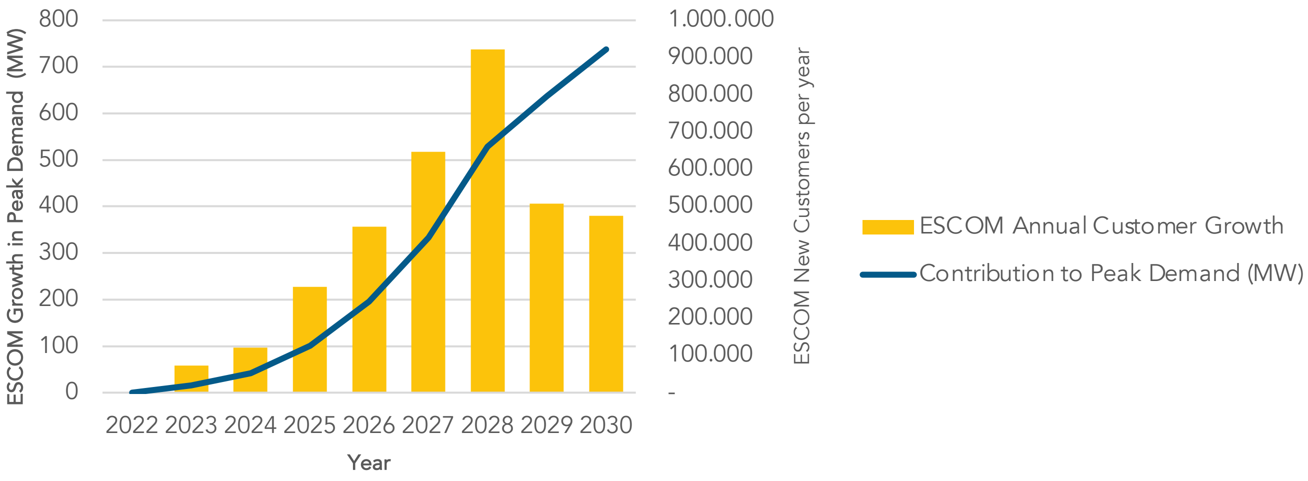
Modality	2022	2023	2024	2025	2026	2027	2028	2029	2030	Total
Densification	560,220	60,159	96,254	120,317	144,381	180,476	240,634	240,634	120,317	**1,763,392**
Expansion	-	12,450	24,900	163,137	301,374	466,114	680,655	266,260	355,013	**2,269,903**
Mini-Grids	-	8,531	17,061	45,992	74,923	67,182	93,564	17,945	23,926	**349,123**
SHS	207,667	62,300	83,067	103,834	124,600	155,750	155,750	103,834	41,533	**1,038,336**
Total	**767,887**	**143,439**	**221,282**	**433,280**	**645,278**	**869,523**	**1,170,603**	**628,672**	**540,790**	**5,420,754**

Note: the “densification” connections in 2022 represents existing ESCOM grid customers at the time of the analysis.

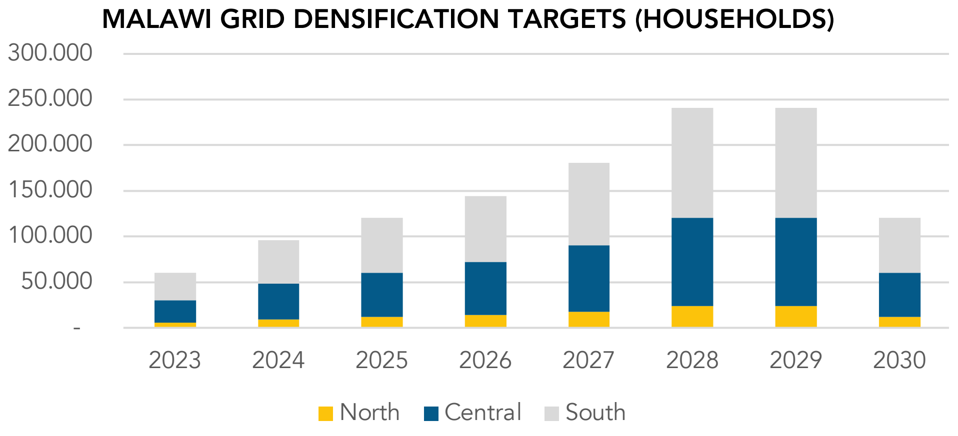
ESCOM Demand Projection

Demand will grow each year as customers are connected through grid densification and expansion. The chart below shows growth in demand along as a function of growth in new consumers through 2030. Additional generation capacity in the national generation-transmission system will be needed to keep pace with demand over the full access timeline.

GROWTH OF ESCOM CUSTOMERS AND DEMAND



Malawi Grid Densification Targets



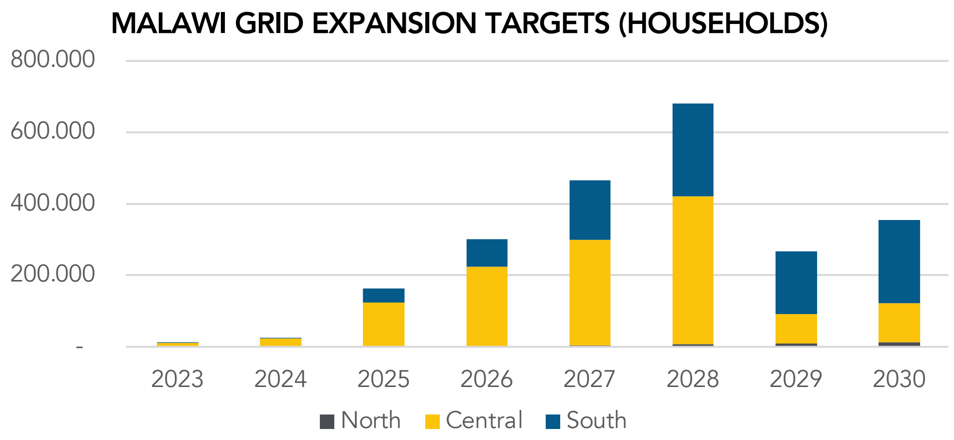
Densification Plan									
Year	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**Total**
North	5%	8%	10%	12%	15%	20%	20%	10%	100%
Central	5%	8%	10%	12%	15%	20%	20%	10%	100%
South	5%	8%	10%	12%	15%	20%	20%	10%	100%
Year	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**Total**
North	5,890	9,424	11,780	14,136	17,670	23,560	23,560	11,780	117,799
Central	24,267	38,828	48,535	58,241	72,802	97,069	97,069	48,535	485,346
South	30,001	48,002	60,003	72,003	90,004	120,006	120,006	60,003	600,028
Total	**60,159**	**96,254**	**120,317**	**144,381**	**180,476**	**240,634**	**240,634**	**120,317**	**1,203,172**

The units in the chart and table are customer connections (households) and not population.

Grid densification refers to customers connected to ESCOM within in each region of ESCOM service.

1. The ESCOM geospatial database showed 560,220 customers in 2022. The 2023 targets assume ESCOM rate of expansion continues in 2023 to achieve 5% access in 2023, uniformly distributed across all three regions. ESCOM will need to increase commercial staff to manage the volume of new consumers from densification and grid expansion.
2. In 2024 and 2025 the rate of densification will gradually increase as materials are procured and capacity is increased.
3. The densification program peaks in years 2027-2029 as ESCOM financial resources are secured and financing is defined to address affordability issues for low-income consumers.
4. Population growth will require continued densification in 2029-2030, as the program tapers off by reaching universal electrification access.

Malawi Grid Expansion Targets



Expansion Plan									
Year	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**Totals**
North	0%	0%	1%	3%	12%	22%	26%	35%	100%
Central	1%	2%	10%	17%	23%	32%	6%	9%	100%
South	0%	0%	4%	8%	17%	27%	18%	24%	100%
Year	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**Totals**
North	29	58	461	865	4,111	7,473	8,963	11,950	33,910
Central	11,367	22,735	123,427	224,119	295,726	412,803	83,256	111,008	1,284,440
South	1,054	2,108	39,249	76,391	166,278	260,379	174,041	232,054	951,554
Total	**12,450**	**24,900**	**163,137**	**301,374**	**466,114**	**680,655**	**266,260**	**355,013**	**2,269,903**

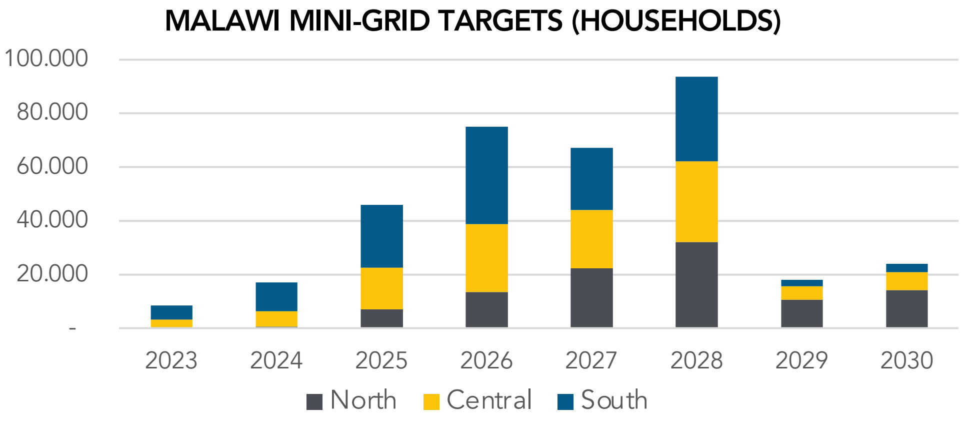
The units in the chart and table are customer connections (households) and not population.

Grid expansion refers to the extension of MV service to reach unserved communities and housing clusters. This requires extension of feeders and transformer placements to previously unelectrified areas.

1. Design/procurement will take ~12-18 months to initiate grid expansion. This is the reason for the slow rate of progress in 2022-2024.
2. The Malawi Energy Access Program financed by the World Bank will allocate $105 million to finance approximately 110,000 new connections over the next 5 years. The expansion plan reflects achieving this goal by 2025.
3. The construction of the national grid expansion program is recommended to be subdivided into three lots that will be implemented successively using international competitive procurement to achieve lower cost results. The full portfolio of grid expansion projects will be prioritized according to the cost effectiveness of each project, so that the lowest cost projects with the highest impact are in Lot 1, and therefore first to be implemented. The lots are assigned as follows:
    - Lot 1: 2023-2026, < $1000 per connection
    - Lot 2: 2025-2028, between $1000-$1500 per connection
    - Lot 3: 2027-2030, > $1500 per connection

    Each lot includes projects from all three regions and is intended to be awarded to a distribution contractor to accelerate deployment. Each lot will be implemented with a ramp-up period over the first two years, including bid evaluation, contract award, procurement of materials, and contractor mobilization. The majority of connections will be energized in the final two years of each successive lot.

Malawi Mini-Grid Targets



Mini-grid Plan									
Year	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**Totals**
North	0%	1%	7%	13%	22%	32%	11%	14%	100%
Central	3%	5%	14%	22%	19%	27%	4%	6%	100%
South	4%	8%	17%	27%	17%	23%	2%	2%	100%
Year	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**Totals**
North	277	555	7,059	13,563	22,249	32,044	10,706	14,274	100,727
Central	2,928	5,856	15,500	25,143	21,808	30,186	4,987	6,649	113,057
South	5,325	10,650	23,433	36,216	23,125	31,333	2,252	3,003	135,339
Total	**8,531**	**17,061**	**45,992**	**74,923**	**67,182**	**93,564**	**17,945**	**23,926**	**349,123**

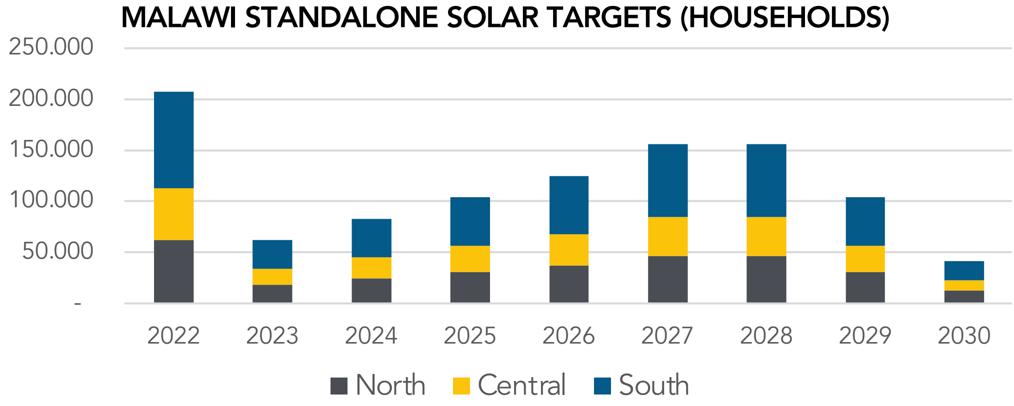
The units in the chart and table are customer connections (households) and not population.

Mini-grids are in early stages of development in Malawi and are beginning to see increased interest. Multiple development partners are supporting mini-grid expansion.

1. The World Bank has announced a pilot program of 10 mini-grids that will be funded in the near term. These projects are included in the geospatial plan. They are likely to be commissioned in 2024. The locations of these mini-grids are shown in the following page.
2. Financing for mini-grids will be needed to support implementation by private mini-grid developers. The rate of implementation will largely depend upon GoM's ability to provide co-financing to lower investment requirements and developers' ability to raise equity and debt for these mini-grids. The projections assume capital will be available. The table and graph project likely rate of implementation if both parties are successful in raising capital for these projects.
3. Similar to the grid expansion implementation plan, the mini-grid program is divided into three lots and prioritized by lowest cost and highest impact. The three lots of mini-grid projects are defined as follows:
   - Lot 1: 2023-2026, < $1200 per connection
   - Lot 2: 2025-2028, between $1200-$1600 per connection
   - Lot 3: 2027-2030, > $1600 per connection

The mini-grid lots are not envisioned to be assigned by ESCOM or the MOE, but instead, they are meant to represent the evolution of private sector developers implementing the most financially viable projects first and then moving on to more arginal projects that will require higher subsidies in the later years of the program.

Malawi Standalone Solar Targets



SHS Plan										
Year	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**Total**
North	20%	6%	8%	10%	12%	15%	15%	10%	4%	100%
Central	20%	6%	8%	10%	12%	15%	15%	10%	4%	100%
South	20%	6%	8%	10%	12%	15%	15%	10%	4%	100%
Year	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**Total**
North	61,802	18,541	24,721	30,901	37,081	46,352	46,352	30,901	12,360	309,010
Central	51,137	15,341	20,455	25,569	30,682	38,353	38,353	25,569	10,227	255,685
South	94,728	28,418	37,891	47,364	56,837	71,046	71,046	47,364	18,946	473,640
Total	**207,667**	**62,300**	**83,067**	**103,834**	**124,600**	**155,750**	**155,750**	**103,834**	**41,533**	**1,038,336**

The units in the chart and table are customer connections (households) and not population.

* The 2022 installation total represents the existing SHS installation totals as reported by USAID.

Solar home system (SHS) service providers have made significant progress in market expansion, reporting installation of 50,000 systems per quarter in 2021. Many of the systems are being deployed in urban and peri-urban areas where population density can promote higher sales volume. Therefore, the SHS that have been deployed to date are likely to be allocated to households who are existing ESCOM customers or whose optimal electrification modality is grid densification or grid expansion, based on their proximity to existing infrastructure. Nevertheless, these existing SHS are represented in the 2022 column of the table below.

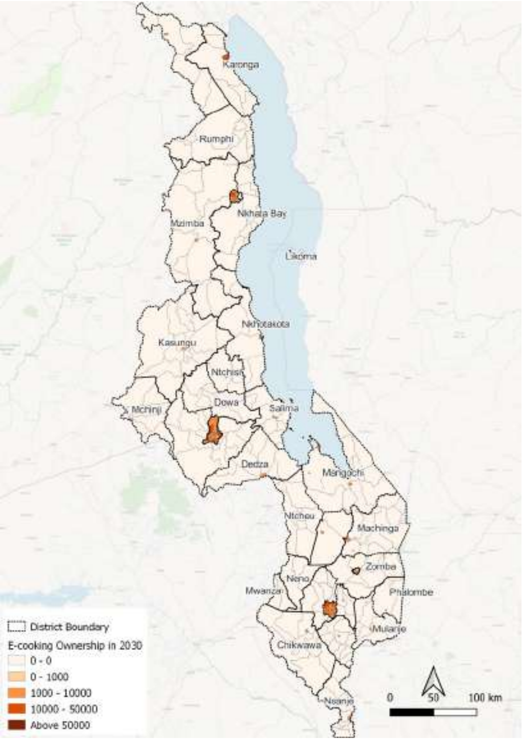
Over time, incentives will be needed to encourage service providers to expand into rural, off-grid areas as densification and grid expansion progress is made.

In addition, subsidies will likely be needed to address affordability issues in lower-income rural areas to achieve off-grid electrification goals.

Note that the anticipated lifespan of a Tier 2 SHS kit is 3-5 years. The connection forecasts presented in this slide are for first-time energy access only. In other words, SHS replacement would be the responsibility of the end-user and not funded by the national electrification program.

Implications of E-Cooking on Electrification Planning

E-COOKING STOVE OWNERSHIP (2030)



- Households eligible for e-cooking usage, based on electricity access are projected to increase from an estimated 92,000 today to 522,000 in 2030. This represents 15% of urban households using only e-cooking and 42% of urban households that use a mix of improved charcoal and e-cooking solutions.
- Total energy use for e-cooking increases from 184 GWh / year in 2022 to 1,099 GWh / year in 2030. While this number accounts for efficiency differences between stove types and stove stacking behaviors, the numbers do not reflect differences in energy use behaviors (e.g., meal preferences, using less energy to heat water, purchasing ready-to-go items in the city that don't require energy in the home) between urban vs. rural and hence should be used as an order of magnitude estimate.
- The total increase in electricity demand due to e-cooking utilization will result in increased energy consumption in urban and peri-urban areas. These increases are anticipated to be accommodated within the proposed grid densification and grid expansion capacity of the ESCOM network. Nevertheless, e-cooking adoption may lead to changes in daily and seasonal load profile during mealtimes as well as increased generation requirements for the national grid.

Presently, the market for electric cooking (e-cooking) in Malawi is severely constrained by the level of electricity access, quality of service, supply of e-cooking appliances, and affordability of electricity for cooking. Therefore, presently e-cooking accounts for a very small percentage of all cooking in urban areas, and very little cooking activities in rural areas.

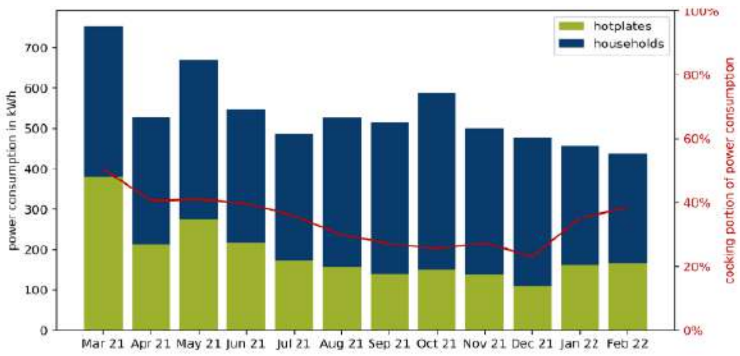
The Malawi Cleaner Cooking Compact envisions only 10% electricity access in Malawi by 2030 with a target of 15% of urban households utilizing e-cooking in their homes.

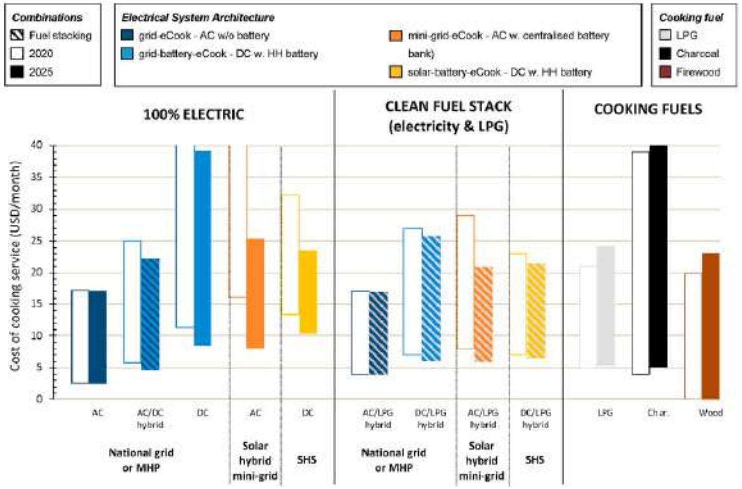
With the Malawi IEP projection of 100% electricity access by 2030, e-cooking opportunities will be more widespread, leading to increased adoption of e-cooking, particularly in urban areas.

The increased e-cooking will contribute to increased electricity consumption and higher peak demand correlating with evening mealtimes. These results will, in turn, impact electrification planning.

Off-Grid E-cooking Potential

- In the Malawi Cleaner Cooking Compact, there is no target for e-cooking among non-urban households. This is largely due to the perceived high cost of e-cooking on elevated mini-grid tariffs. Some emerging opportunities for off-grid e-cooking do exist, however.
- Based on a recent study from 2021-2022, e-cooking on a mini-grid in Malawi varied from 22% - 50% of total household energy consumption. In order to accelerate off-grid e-cooking, it would be possible to subsidize incremental increases to mini-grid generation infrastructure to support clean cooking demand and/or to modify mini-grid tariffs for e-cooking users.
- Another innovation in Malawi is a standalone solar kit optimized for e-cooking. The SHS utilizes Lithium-Ion Titanate (LTO) battery to provide more rapid charging/discharging with less degradation and better performance in higher temperatures. The costs of SHS E-cooking remains higher than many conventional fuels, but will decline over time. Pricing for high-performance batteries, such as LTO, is also expected to decrease and may become accessible for low-income off-grid customers.





1. Earles et al. "Opportunities and challenges for eCooking on mini-grids in Malawi: case study insight." Atmosfair and University of Strathclyde, Glasgow, UK, 2022.

2. Leary et al. "Battery-supported e-cooking: A transformative opportunity for 2.6billion people who still cook with biomass." Energy Policy, vol 159, 2021.

MALAWI IEP – ELECTRIFICATION

Financing Requirements

Electrification Financing Requirements

	Public Sector, Government, and Development Partner Financing			Private Sector and End-User Co-Financing	
Electrification Modality	Base Case: BAU[1.] GoM Financing Requirements (USD)	Sensitivity 1: ICB[2.] GoM Financing Requirements (USD)	Sensitivity 2: Low-Cost[3.] GoM Financing Requirements (USD)	Off-Grid Funding by Private Sector Developers (USD)	Connection Fees Paid by End-Use Consumer Grid & (USD)
Densification	$464,562,316	$464,562,316	$464,562,316	-	$109,868,712
Grid expansion	$ 2,938,414,330	$ 1,950,687,253	$ 1,824,560,052	-	$166,911,090
Mini-grids	$196,548,240	$196,548,240	$196,548,240	$287,769,674	$ 7,052,686
Standalone solar (Tier 2)[1]	$ 90,854,403	$ 90,854,403	$ 90,854,403	$250,758,152	$ 20,766,721
Total	**$ 3,629,729,750**	**$ 2,642,002,673**	**$ 2,515,875,471**	**$387,613,528**	**$304,808,087**

[1] **Note:** The SHS figures are based on Tier 2 SHS systems for an average cost of $350 per household. As a sensitivity analysis, Tier 1 systems would reduce the overall cost of the program by approximately 47% based on indicative supplier cost data.

MALAWI IEP – ELECTRIFICATION

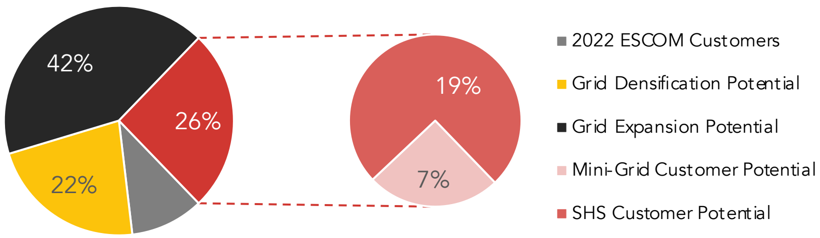
Conclusions

Conclusions

Region	2022 ESCOM Customers	Grid Densification Potential	Grid Expansion Potential	Mini-Grid Customer Potential	SHS Customer Potential	Total
North	79,939	117,799	33,910	100,727	309,010	641,385
Central	217,771	485,346	1,284,440	113,057	255,685	2,356,299
South	262,510	600,028	951,554	135,339	473,640	2,423,070
Total	**560,220**	**1,203,172**	**2,269,903**	**349,123**	**1,038,336**	**5,420,754**

- The electrification analysis illustrates very significant investments are needed in grid and off-grid electrification technologies to achieve universal access. Grid connections comprise 64% of the projected new consumer growth.
- Moreover, ESCOM construction standards were defined to serve an urban environment with higher load densities than will be seen in rural areas. A lower-cost rural standard will support much lower costs in conjunction with use of international competitive bidding.
- Off-grid solutions will play a significant role in the electrification expansion plan by servicing approximately 26% of the market (19% SHS, 7% MGs). This figure could expand significantly if grid densification and expansion financing is not secured.

2030 UNIVERSAL ELECTRIFICATION PLANNING RESULTS



MALAWI IEP – ELECTRIFICATION

Annex

ESMAP Multi Tier Framework (MTF)

ATTRIBUTES		TIER 0	TIER 1	TIER 2	TIER 3[b]	TIER 4	TIER 5
Capacity	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
	Services		Lighting of 1,000 lmhr per day	Electrical lighting, air circulation, television, and phone charging are possible			
Availability[a]	Daily Availability	Less than 4 hours	At least 4 hours		At least 8 hours	At least 16 hours	At least 23 hours
	Evening Availability	Less than 1 hour	At least 1 hour	At least 2 hours	At least 3 hours	At least 4 hours	
Reliability		More than 14 disruptions per week			At most 14 disruptions per week or At most 3 disruptions per week with total duration of more than 2 hours"	(> 3 to 14 disruptions / week) or ≤ 3 disruptions / week with > 2 hours of outage	At most 3 disruptions per week with total duration of less than 2 hours
Quality		Household experiences voltage problems that damage appliances				Voltage problems do not affect the use of desired appliances	
Affordability		Cost of a standard consumption package of 365 kWh per year is more than 5% of household income			Cost of a standard consumption package of 365 kWh per year is less than 5% of household income		
Formality		No bill payments made for the use of electricity				Bill is paid to the utility, prepaid card seller, or authorized representative	
Health and Safety		Serious or fatal accidents due to electricity connection				Absence of past accidents	

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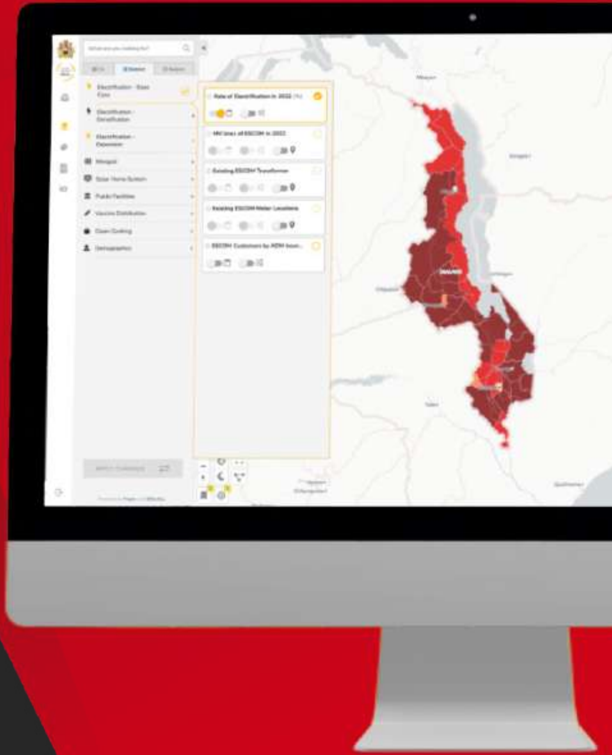

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