Malawi Integrated Energy Plan

An Overview

Electrification Report

October 10th , 2022

IN PARTNERSHIP WITH:

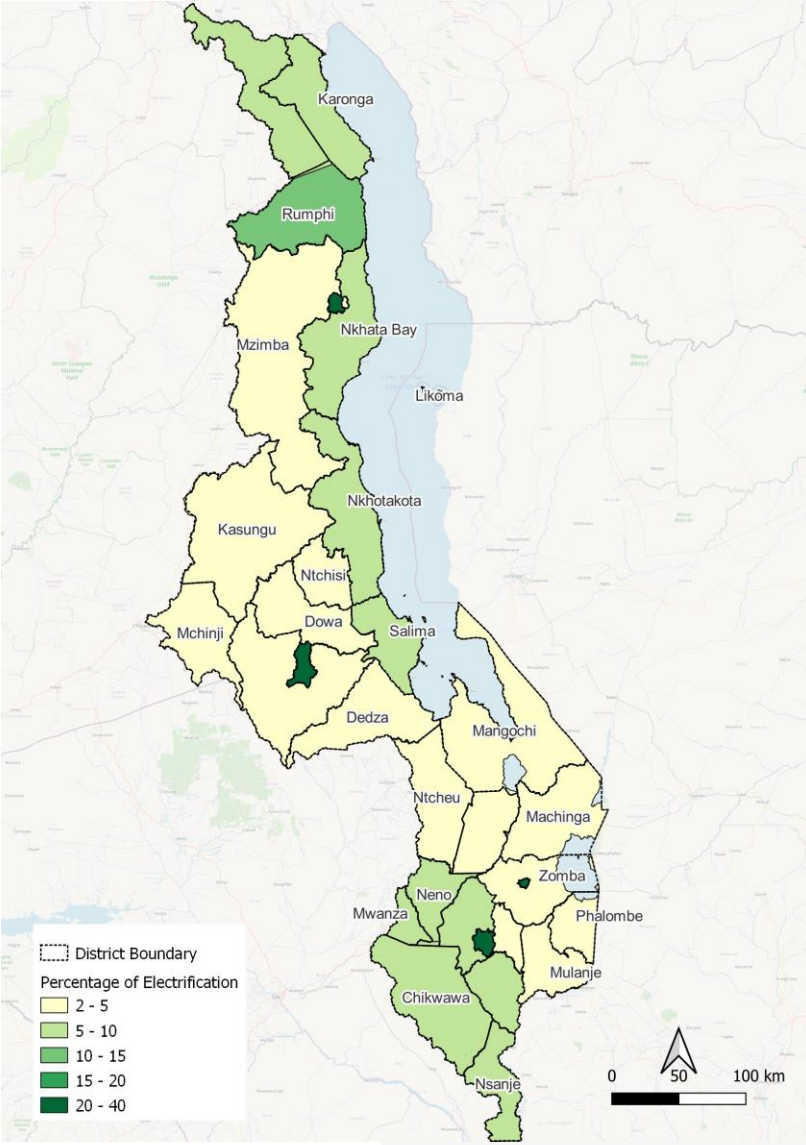
Global Energy Alliance for People and Planet

CONFIDENTIAL AND PROPRIETARY
Any use of this material without specific permission is strictly prohibited

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)



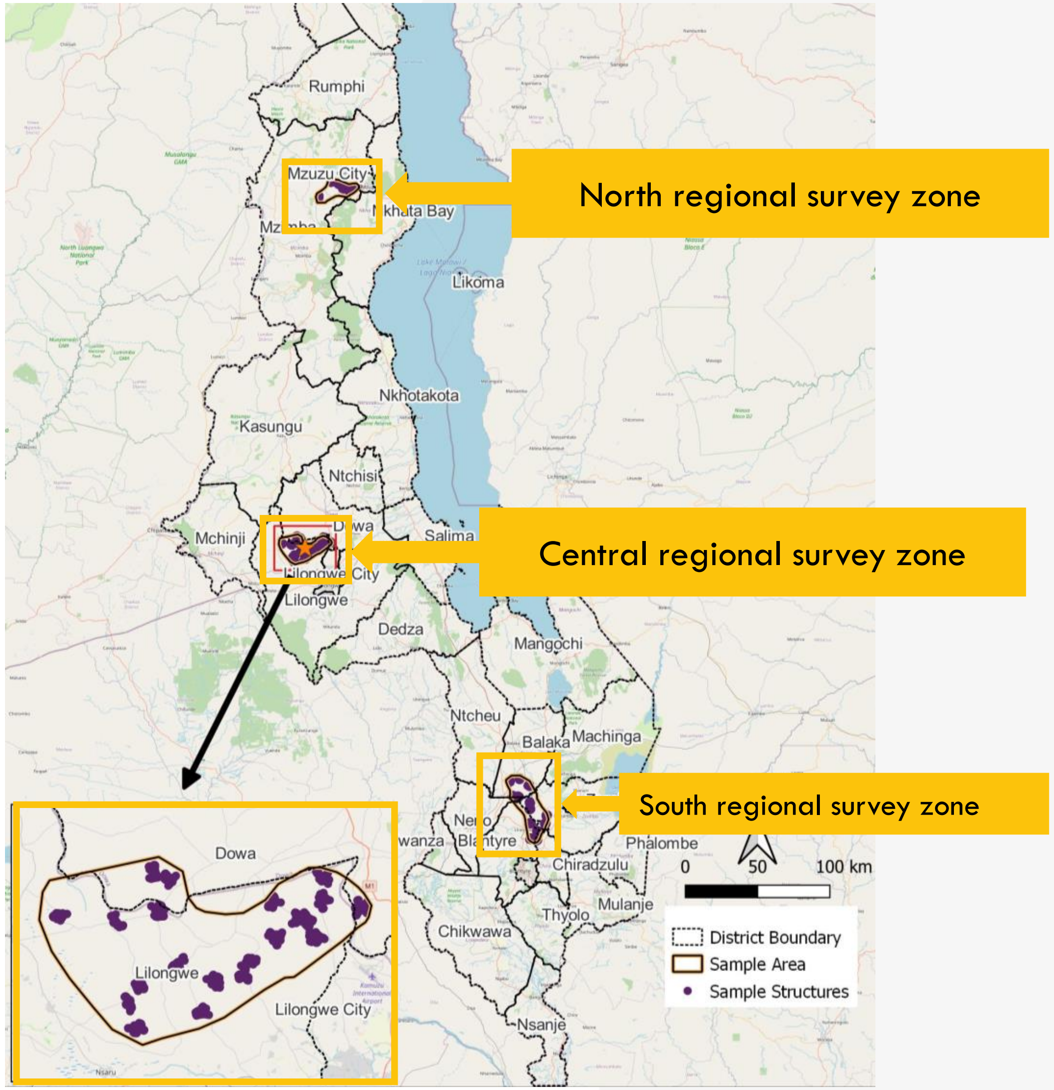
Energy Expenditure Survey

An energy expenditure survey was carried out to evaluate electricity consumption/demand for newly connected consumers.

The surveys were undertaken in off-grid zones which were 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.

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 6-12 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 MTF[1] Tier 1 system is commonly USD $12/month or higher, 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.

ESCOM Database and Projected Demand

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):

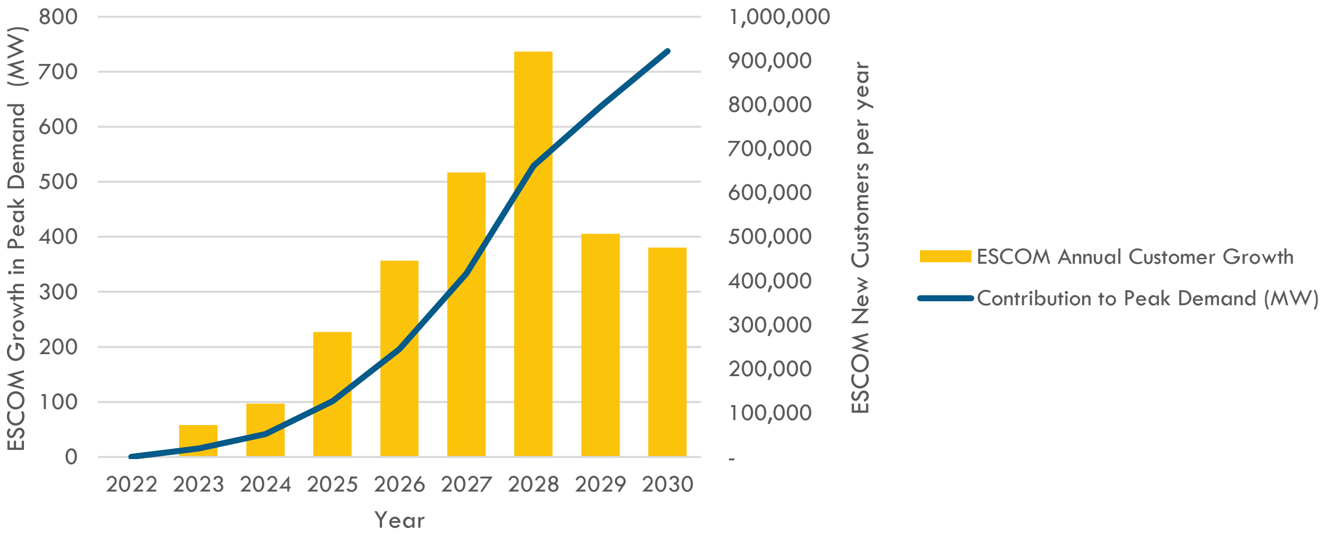
- 9,521 km MV line
- 5,733 MV/LV transformers

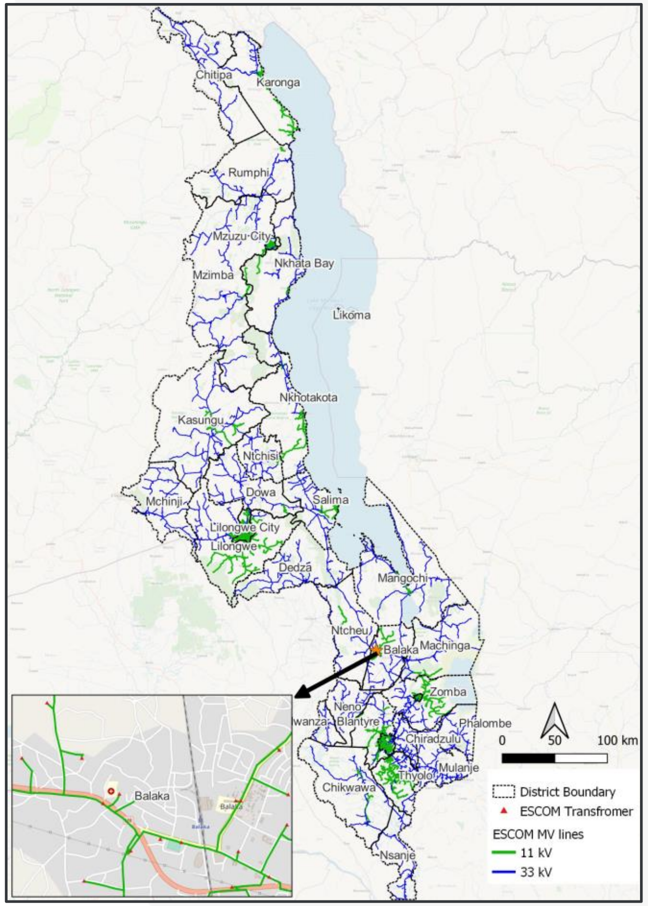
Updated ESCOM data (2022):

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

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.

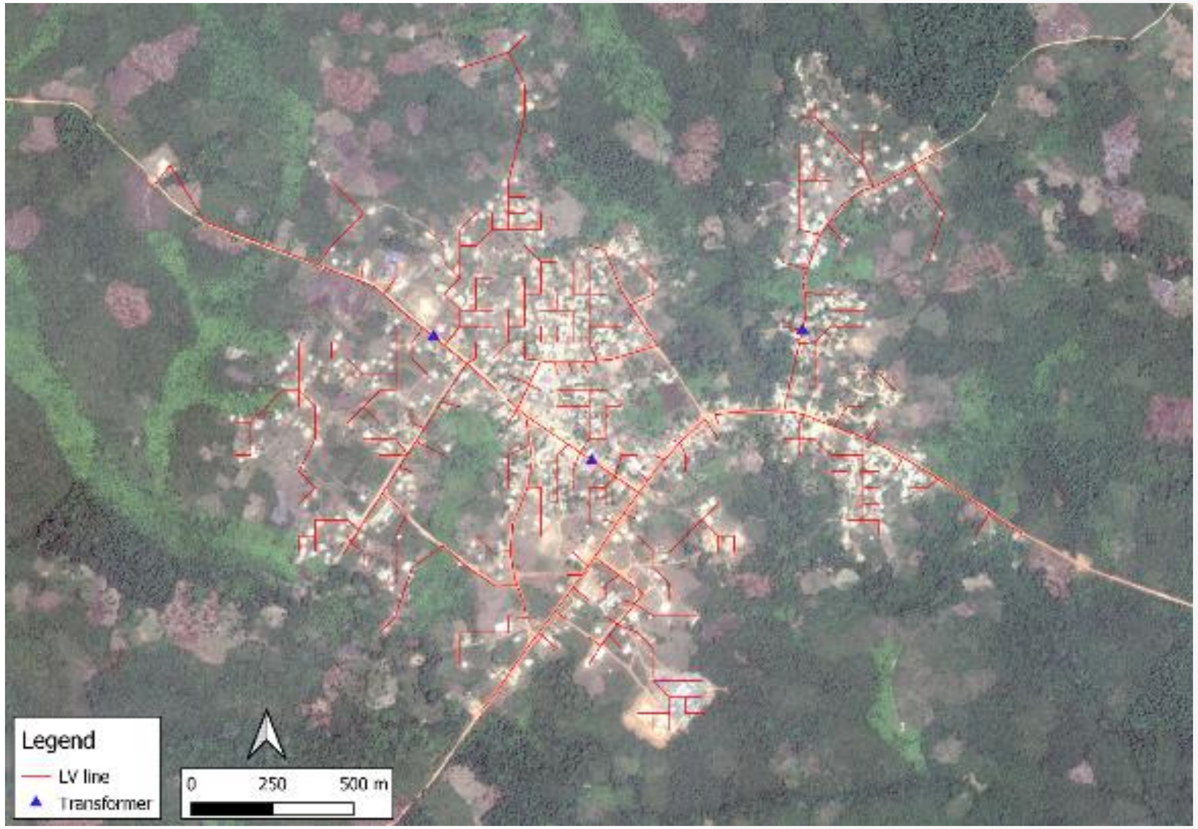
Projected growth of ESCOM Customers and Demand





Routing Algorithm: Defining Distribution Line Alignments (1)

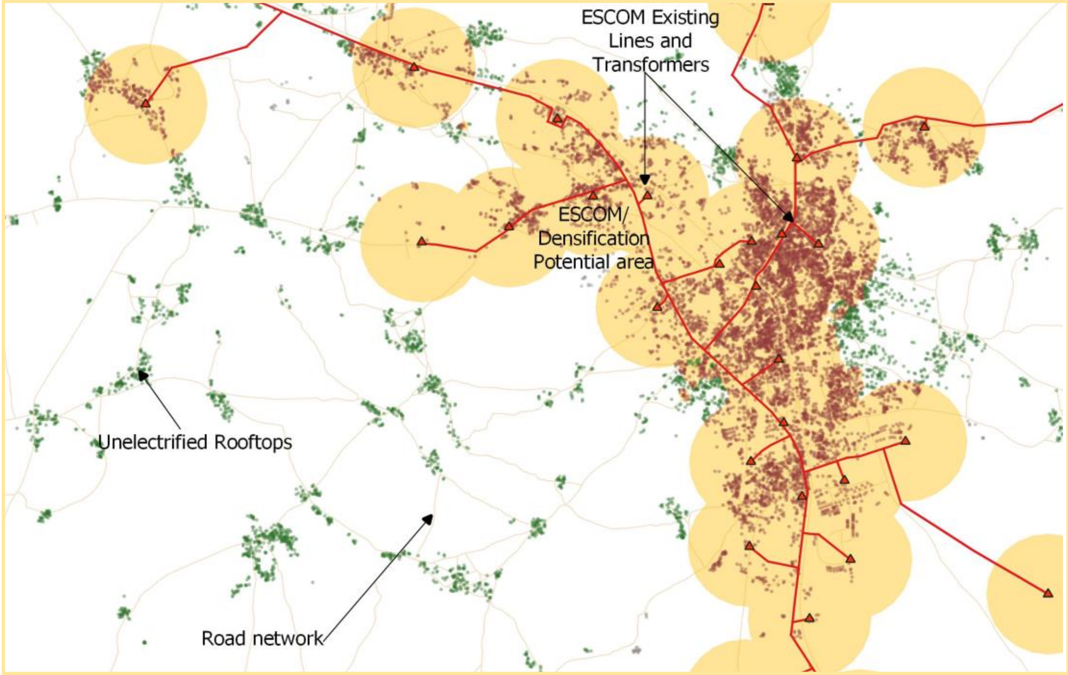
- Distribution lines follow existing roads to facilitate maintenance and ease in operation. To define the pathways that MV and LV lines will follow, a contiguous road atlas is needed.
- MV and LV line alignments are defined by interconnecting load centers identified and evaluated using the cluster algorithm 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.



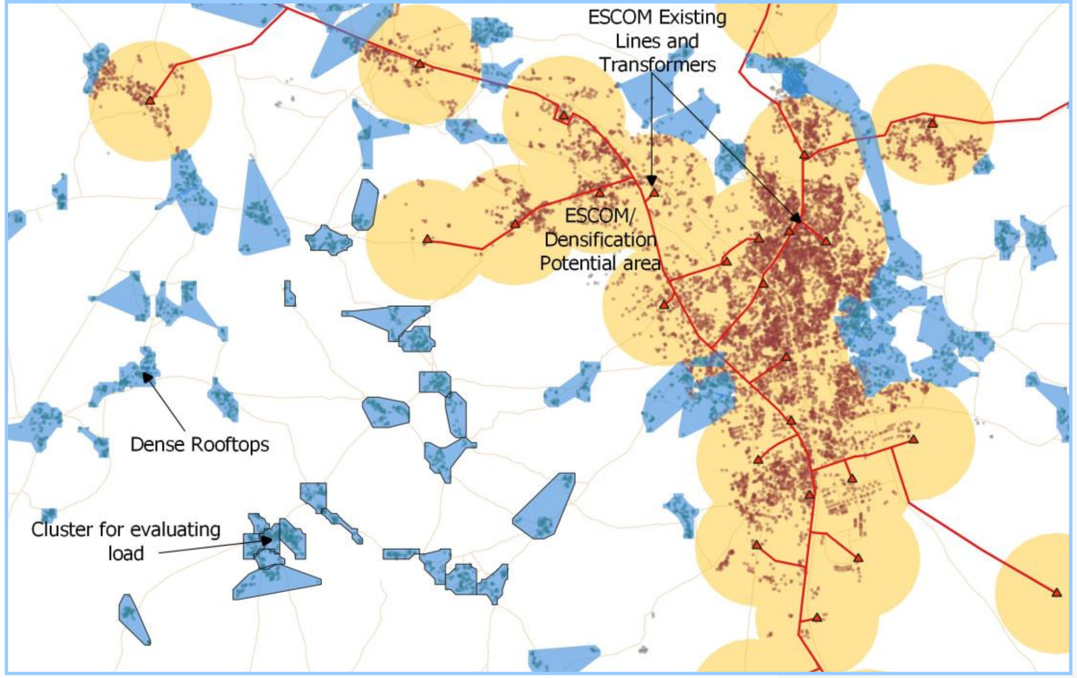
Routing algorithm: Defining Distribution Line Alignments (2)

- 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.



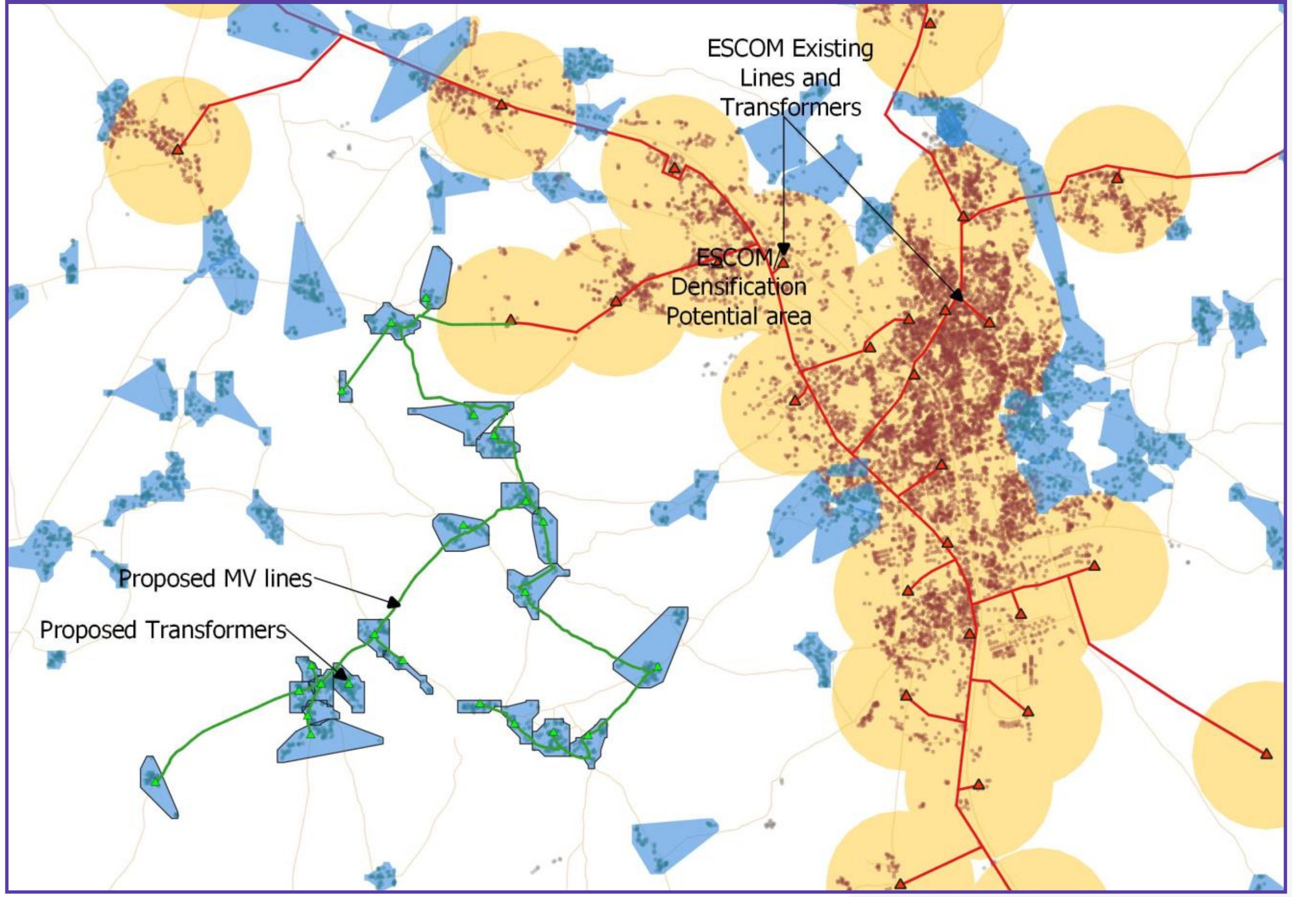
Clustering Algorithm: unelectrified structures beyond the densification boundaries are grouped into clusters for evaluation of grid expansion or off-grid electrification.



Routing algorithm: Defining distribution line alignments (3)

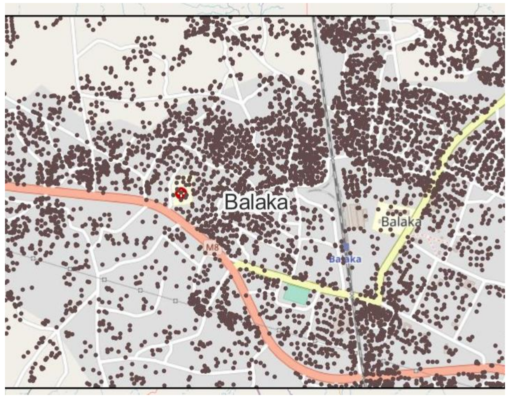
- Once clusters have been defined, the load centers are evaluated for grid expansion through the routing algorithm. Proposed MV line extensions are routed from existing network along the national road network to reach surrounding customer clusters, optimized to ensure shortest path and lowest cost.
- 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

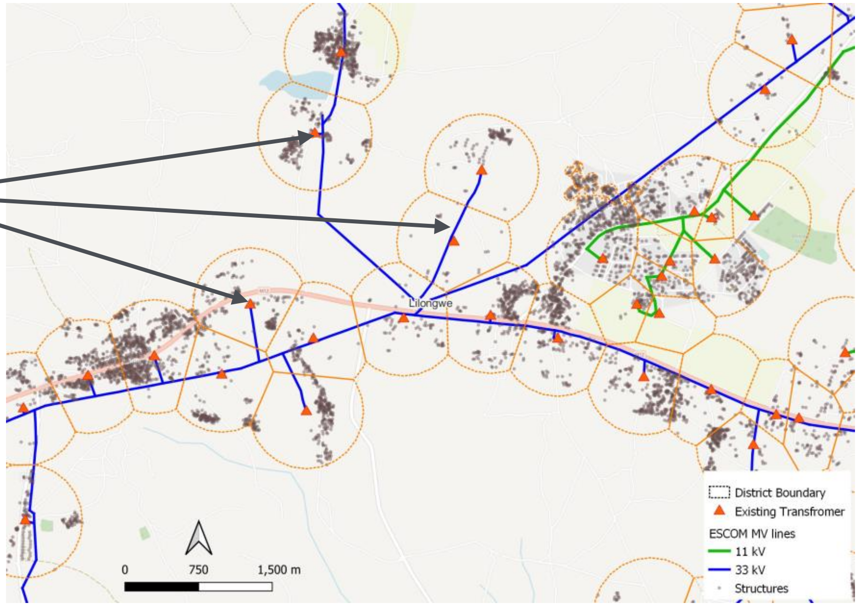
Routing Algorithm: population clusters are added to grid expansion projects until further incremental MV extension becomes cost prohibitive. Clusters beyond the grid extension project routing are evaluated for off-grid electrification modalities.



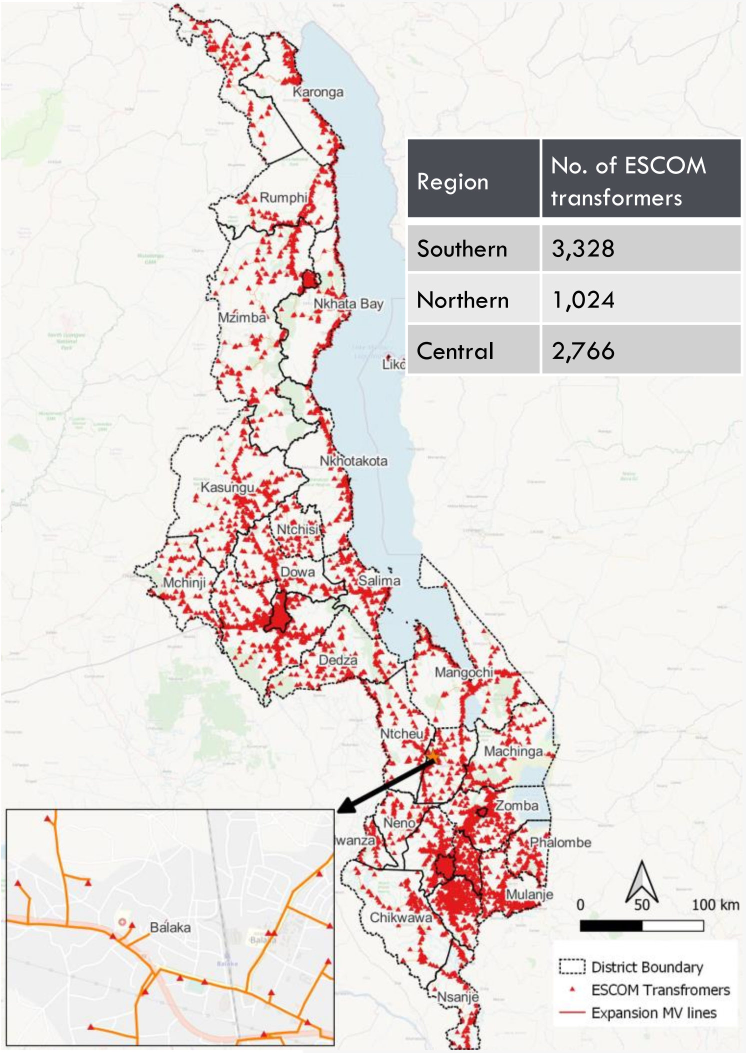
Densification Analysis

- Densification analysis uses housing structure, ESCOM network and ESCOM commercial data to evaluate densification potential
- Total housing structures within 600 meters of distribution transformers, less existing consumers equals densification potential. The 600 meter assumption is based on acceptable voltage drop in the LV network.
- All ESCOM transformers were evaluated in the densification analysis





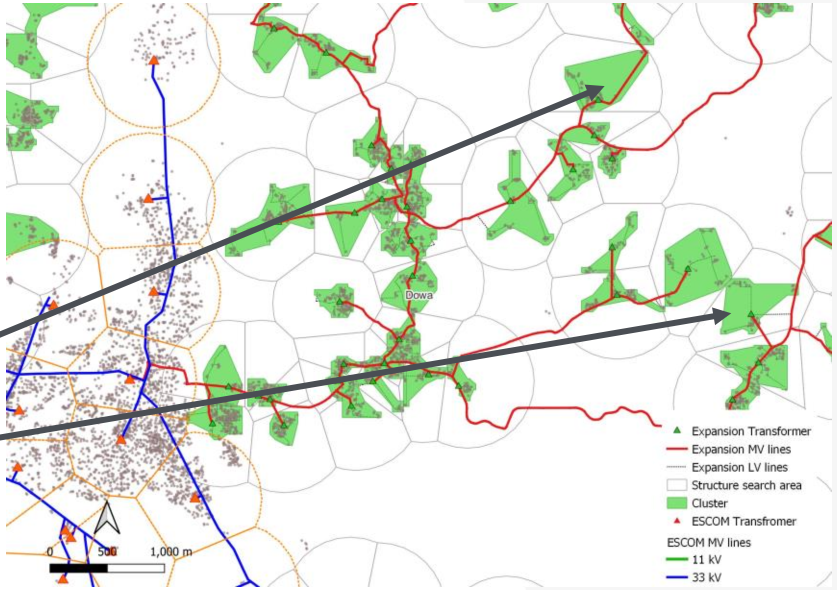
EXISTING ESCOM TRANSFORMERS BY REGION

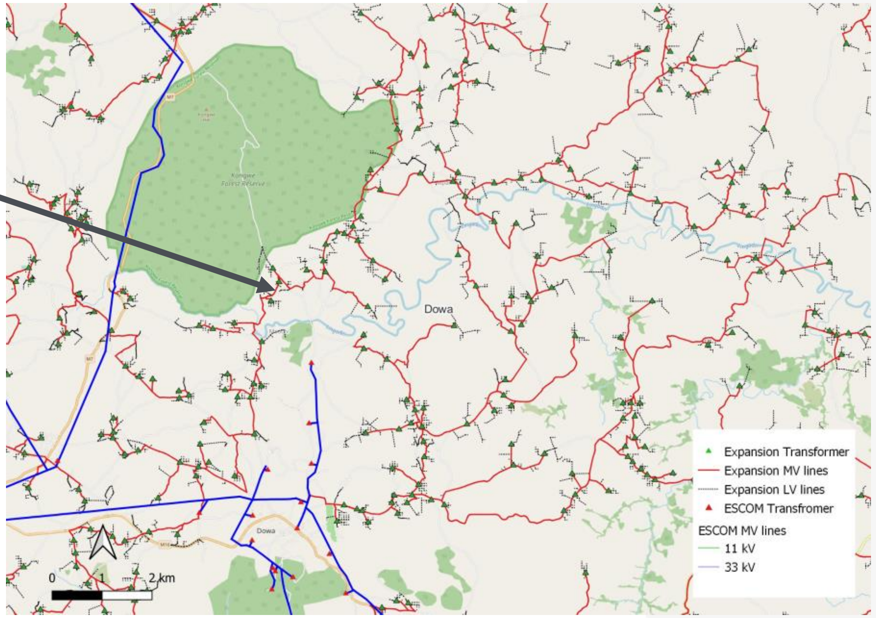


Region	No. of ESCOM transformers
Southern	3,328
Northern	1,024
Central	2,766

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





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	315 kVA three phase	$5,368	$5,368	$5,368
	200 kVA three phase	$4,481	$4,481	$4,481
	100 kVA 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 meter	88	$65	$65
	Three ph meter	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)
- 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.

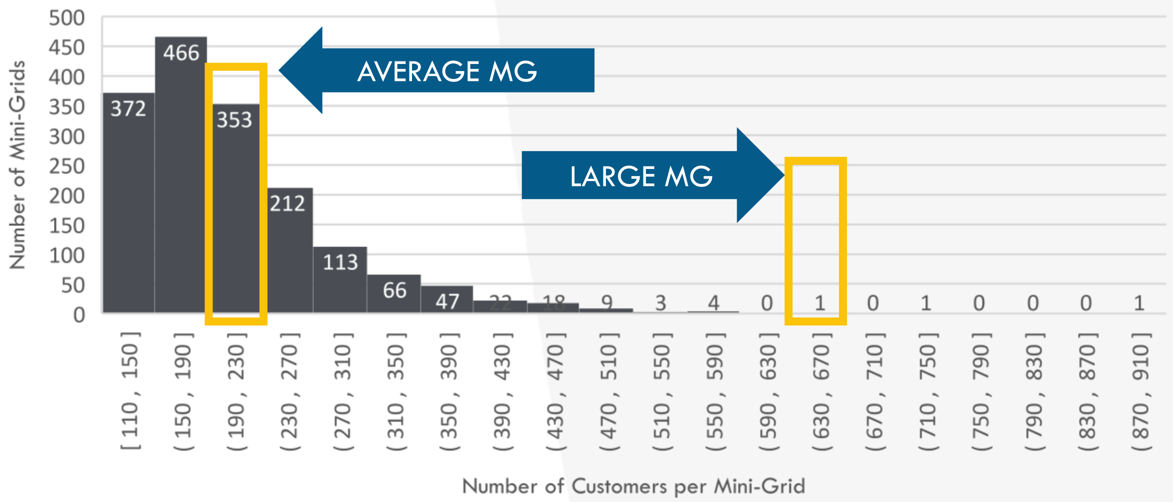
Note2: Consumers refers to total number of household connections.

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.

Frequency Distribution of Customers per Mini-Grid

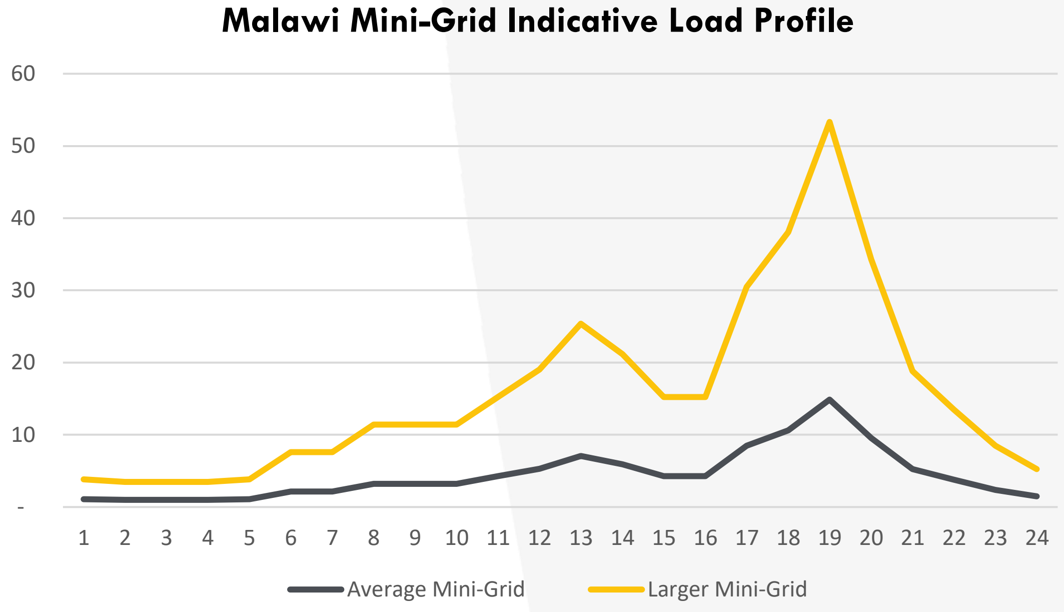


1. Cross Boundary, 2018. https://www.greentechmedia.com/articles/read/minigrids-are-the-cheapest-way-to-electrify-100-million-africans-today

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 System (SHS)s are modeled as Tier-1 and Tier-2 compliant systems



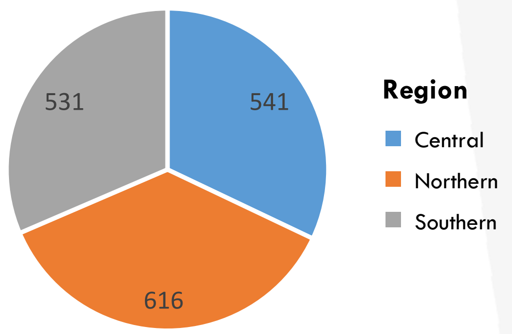
	Average	Large
MG_ID	1244	666
Region	Northern	Southern
District	Mzimba	Machinga
Year 10 Connections	212	732
Year 10 Consumption (kWh/yr)	38,795	139,036
Year 10 Peak Demand (kW)	16	54

Mini-Grid 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.

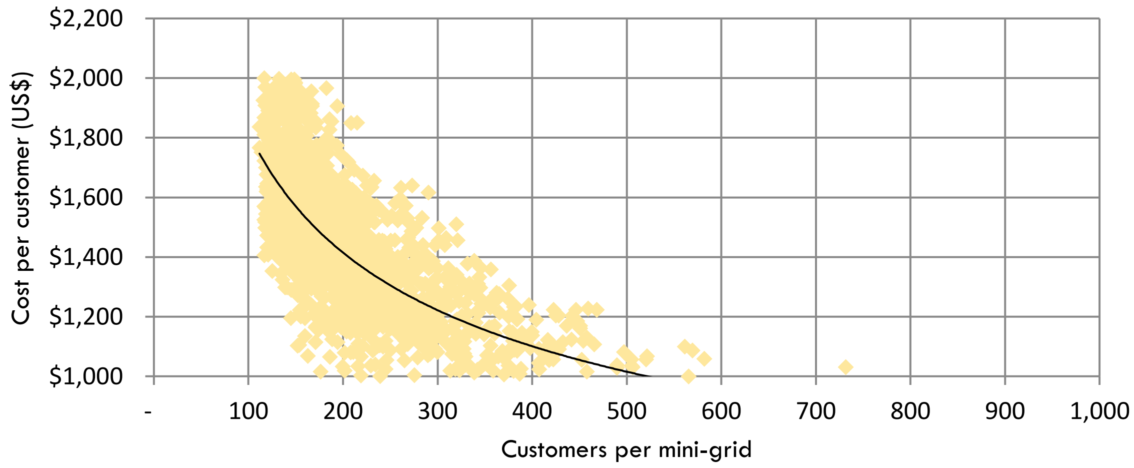
The vast majority of sites have solar power requirements below 30 kW, which is widely seen as an economic viability threshold within the mini-grid sector. The very small mini-grid candidates will likely require customized subsidies to attract private sector investment and reach economies of scale.

Number of Mini-Grids

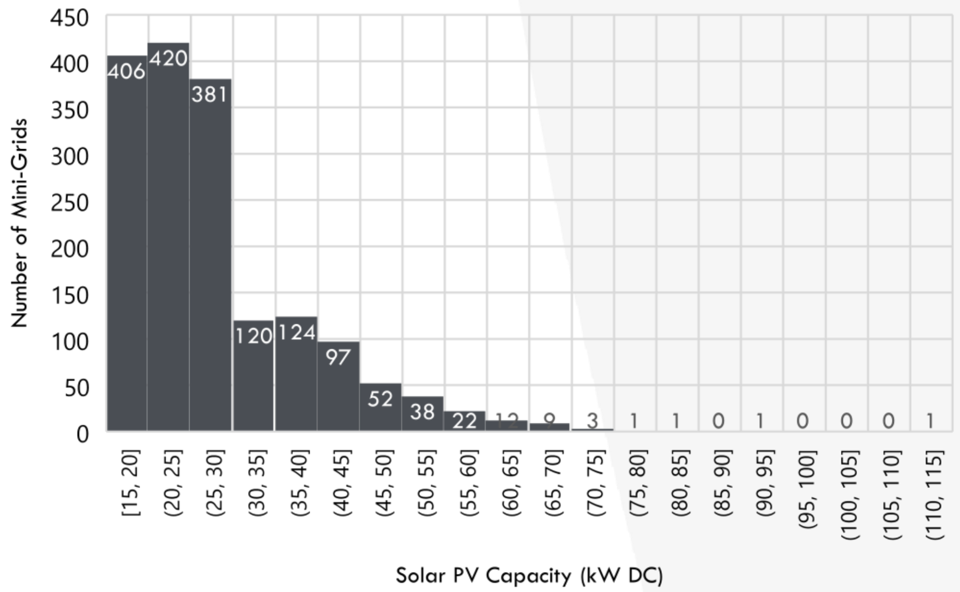


Out of 1,688 mini-grids in the analysis, 1,207 of the mini-grids (72%) have PV plant sizes of 30 kW or less.

Mini-Grid Economies of Scale



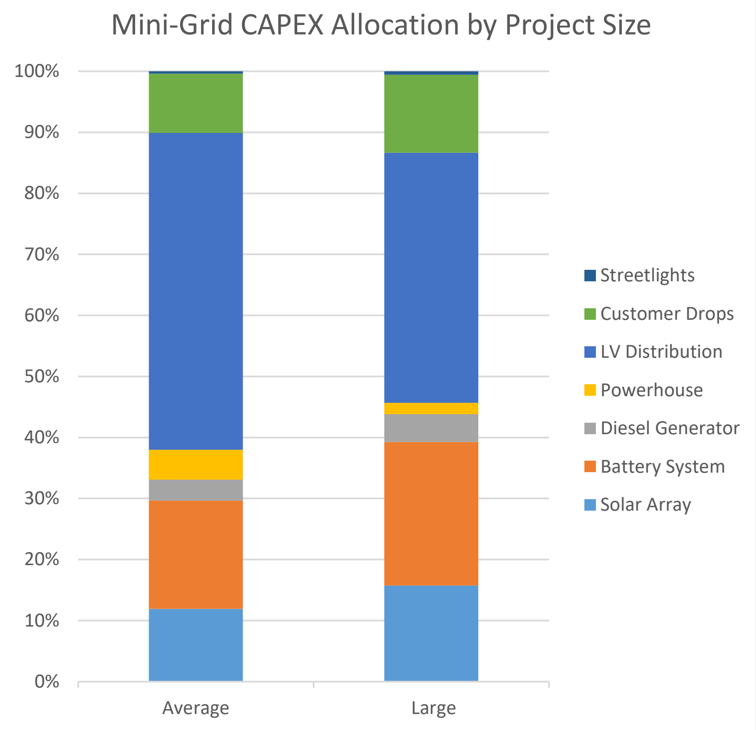
Distribution of Mini-Grid Solar Plant Size



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 below 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



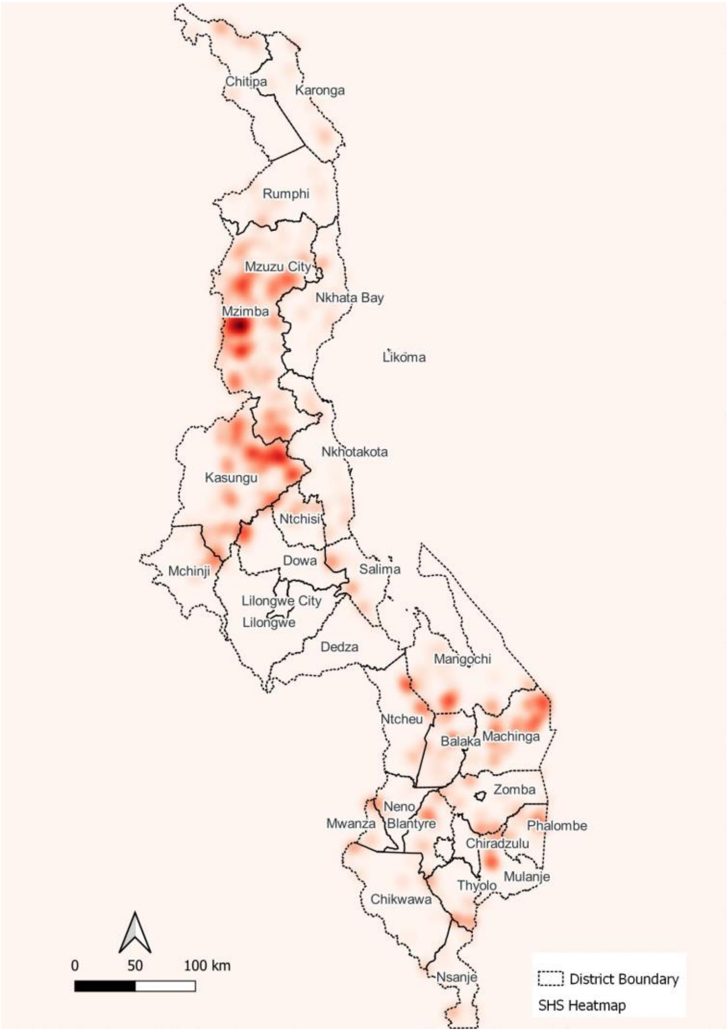
Solar home system (SHS) potential

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.

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

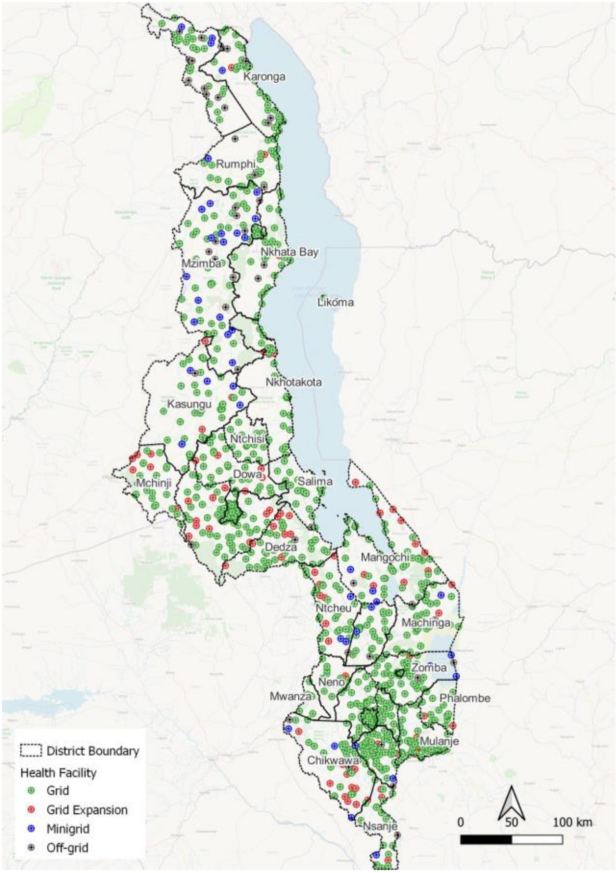
Electrification of Public Facilities

- 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.
- Similar analysis was conducted for electrification status of schools throughout Malawi.

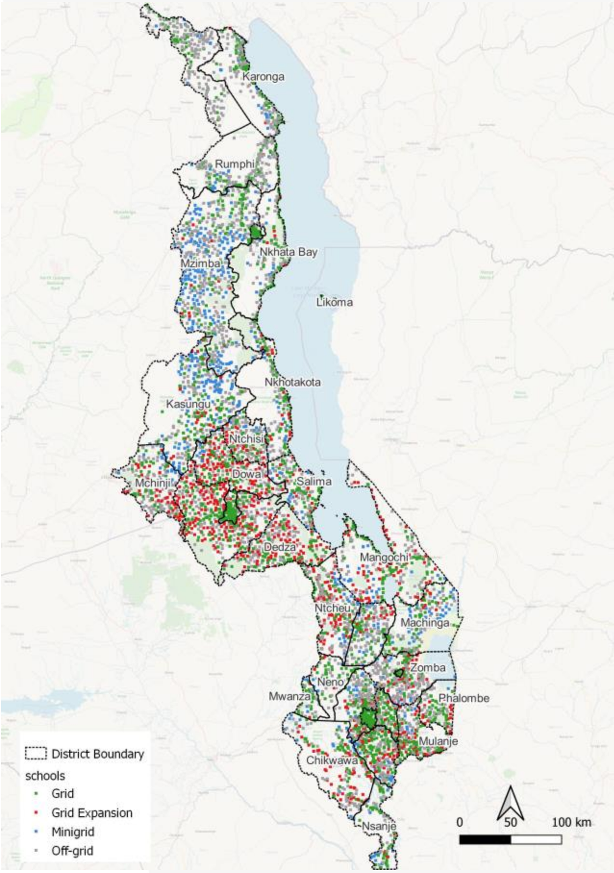
Results of public facility electrification planning are as follows:

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

HEALTH CLINIC ELECTRIFICATION RESULTS



SCHOOL ELECTRIFICATION RESULTS



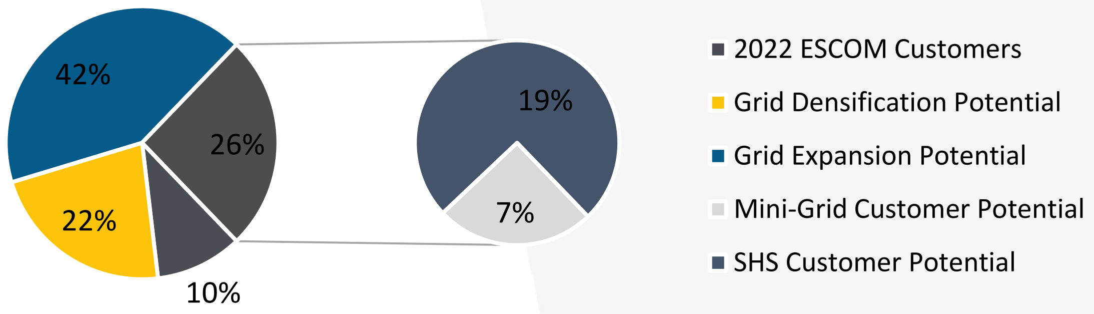
Note that the standalone solar solutions for schools may need to be larger than those for residential consumers. These sizing and cost assumptions will require further refinement in future analyses.

Universal Access by 2030

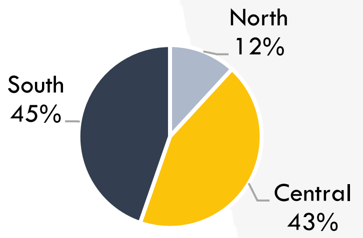
Region	2022 ESCOM Customers	Grid Densification Potential	Grid Expansion Potential	Mini-Grid Customer Potential	SHS Customer Potential	Total
North	79,939	117,799	33,910	100,727	309,010	641,385
Central	217,771	485,346	1,284,440	113,057	255,685	2,356,299
South	262,510	600,028	951,554	135,339	473,640	2,423,070
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



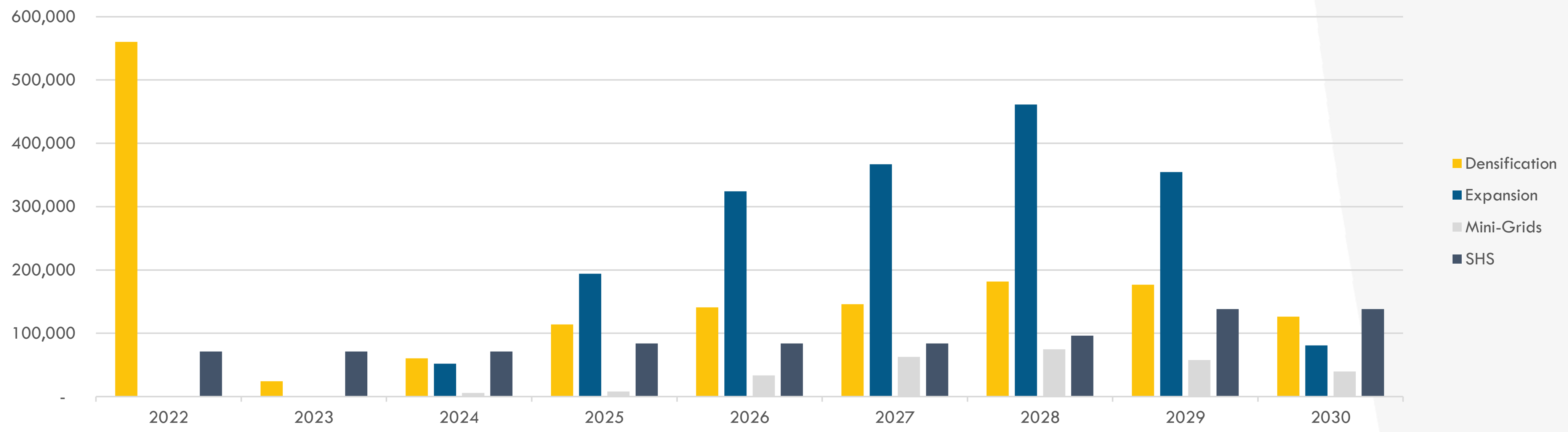
TOTAL CUSTOMERS BY REGION



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

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.

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.

Conclusions

- 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 (42% Expansion, 22% densification)
- 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.
- 72% of mini-grid 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.
- When eliminating all diesel use for mini-grids the total net cost increases by 14% overall and the average cost per connection increased 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%)
- While the cost per connection for mini-grids, especially larger ones, has the potential to be lower than for grid extensions, the tariffs to consumers will likely 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.

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