Nigeria Integrated Energy Plan

Geospatial Model for Universal Electrification of Nigeria

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In partnership with

Acronyms

Term	Definition
BUA	Built-Up Areas
Capex	Capital expenses
DISCOs	Electricity Distribution Companies
Dx	Distribution
FGN	Federal Government of Nigeria
GRID3	Geo-Referenced Infrastructure and Demographic Data for Development
GW	Gigawatts
GWh	Gigawatt-hour
Gx	Generation
HA	Hectare
HH	Household
HRSL	High Resolution Settlement Layer
IEP	Integrated Energy Plan
IRR	Internal Rate of Return

SUSTAINABLE ENERGY FOR ALL

Acronyms

Term	Definition
IRR	Investors Rate of Return
kW	Kilowatt
kWh	Kilowatt-hour
LCOE	Levelized Cost of Energy
MG	Mini-grid
NERC	Nigeria Electricity Regulatory Commission
NGN	Nigerian Naira
NPV	Net Present Value
REA	Rural Electrification Agency
SEforALL	Sustainable Energy for All
SHS	Solar Home System
SSA	Small Settlement Area
USD	US Dollar
WACC	Weighted Average Cost of Capital

Executive Summary (1/3)

Context

In 2019, the Federal Government of Nigeria (FGN), through the Rural Electrification Agency (REA), developed a geospatial model to determine the least-cost solution to achieving 100% electrification by 2024 and 2030. SEforALL has prioritized the development of Integrated Energy Plan towards the achievement of Sustainable Development Goal 7 to 'Ensure access to affordable, reliable, sustainable and modern energy for all'. **This geospatial model strives to update the analysis developed in 2019 and will form the foundation of an updated Integrated Energy Plan (IEP).**

How the model works

The model layers demand, generation capacity and cost data from various sources, and adopts a 5-step process to generate the least-cost technology by household:

1. **Defining un-electrified households and clustering these into 'settlements':** the model finds an electrification rate of 60%, which is comparable to external sources (60% - REA and 55% - World Bank). Using population growth assumptions, this leaves 19.3 Mn unelectrified households (106 Mn people) by 2030, which are divided as follow:
   - Rural settlements are defined as settlements with fewer than 10,000 people, and account for 99.6 Mn people (18.1 Mn households)
     - 'Standalone' areas (sub-set of rural areas), with fewer than 1 household per hectare, account for 26.7 Mn people (4.6 Mn households). These are automatically assigned solar home system (SHS) technology given the expense to connect such isolated households to a grid or mini-grid
   - Urban settlements are defined as settlements with more than 10,000 people, and account for 6.6 Mn people (1.2 Mn households)
2. **Calculating unmet household demand as a function of pre-determined demand tiers, income level and migration across tiers over time** (i.e., increase in settlement income and consumption). Consumption levels are determined using the Energy Sector Management Assistance Program (ESMAP) definitions of Tier Two (224 kWh p.a.), Tier Three (695 kWh p.a.) and Tier Four (1,800 kWh p.a.) demand. Fraym's geospatial consumer class data-set is overlaid to group the population into consumer classes where each consumer class has an estimate of annual household spend. Consumer classes are mapped to demand tiers based on assumed share of their annual income that could be allocated to purchasing the required appliances for the different ESMAP tiers. Consumption demand is grown over time based on household surveys (across 3,000 respondents in the DRC, Tanzania and Nigeria). These surveys indicate a migration of 11% of households from Tier 2 to Tier 3 every five years, and a migration of 5% of households from Tier 3 to Tier 4 every five years. This provides a view on future demand growth linked to income growth
3. **Determining the energy generation potential across three technologies, namely grid extension, solar mini-grid and solar home systems.** The grid extension and mini-grid options are expected to meet all demand tiers, while solar home systems are currently only available in Nigeria to service Tier 2 and Tier 3 demand. The feasibility for solar mini-grid and SHS is determined using irradiation data, where the entire country is assumed to be conducive to solar generation with an annual irradiation range of 1,500 to 2,300 kWh/m^2

Executive Summary (2/3)

How the model works

4. **Defining the optimal technology solution per household by comparing the lifetime cost per household for each technology** (driven by distance from the grid, settlement density and aggregate demand in the settlement). A bottom-up cost is calculated for each technology based on five major cost categories: generation (capital and operating costs), distribution (capital and operating costs), household connection (i.e., metering and cabling), margins (inclusive of cost of capital) and appliances. The model uses a 20-year lifetime cost per connection per technology type to select the optimal technology per household. The costs of solar home systems and mini-grids change over time as technology costs adjust. For both solar mini-grid and solar home system, the cost of panels and batteries are projected to fall by 37 and 48 percent between 2021 and 2030
5. **Testing the sensitivity of the model to key input assumptions to understand the impact on the least-cost technology mix.** The model was sensitized against key value drivers including different assumption around mini-grid generation and grid reticulation costs

Insights for households

60% of the population in Nigeria is electrified, leaving 15.3 Mn households without access. This number is **expected to grow to 19.3m Mn households by 2030**. In 2030, the least-cost technology mix to provide universal access to these unelectrified households consists of:

- **5.4 Mn grid connections** (28% of total new connection) in 9.1k settlements **predominantly in dense urban areas in close proximity to existing grid infrastructure**
- **8.9 Mn mini-grid connections** (46% of total new connection) in 104.8k settlements (representing 104,829 mini grid systems) **predominantly in dense urban areas further from existing grid infrastructure**
- **5 Mn SHS connections** (26% of total) in 516k settlements **predominantly in sparse rural and standalone areas where Grid and Mini-Grids are not economically viable**
- **It would cost USD 25.8 Bn**, to achieve this universal access target by 2030. Of this amount, mini-grids comprise USD 10.4 Bn, or 40% of the total cost
- The model results were sensitized against solar home system, mini-grid capex cost and grid capex assumptions:
  - A 15% increase in SHS capex does not materially change the shares of least cost connection shares across technologies
  - A 15% increase in mini-grid capex results in a 17% reduction in mini-grids share of new connections in the 2030 least-cost technology mix
  - Conversely, a 15% decline in 2030 mini-grid capex results in 18% increase in mini-grids share of new connections in the 2030 least-cost technology mix
  - Increasing grid capex by 15% results in an 12% decrease in Grid share of connections in the 2030 least-cost technology mix
  - Conversely, a 15% reduction in grid reticulation capex results in a 18% increase in grid share of new connections in the 2030 least-cost technology mix
- **When public institutional loads (schools and hospitals)** are included, the number of **grid connections increases by ~1 Mn** at the expense of **mini-grids**
- **When productive load demand (Rice and Maize milling) is considered**, the number of **mini-grids** in the 2030 least-cost mix **increases by ~3.3k (representing 108,129 mini grid systems) accounting for an additional 200k connections**

Executive Summary (3/3)

Implications

- **Cost implication:** The total cost of universal electrification by 2030 will be USD 25.8 Bn of which USD 19.6 Bn will be an upfront investment. 19% of this investment (USD 4.9 Bn) will need to be financed through the Nigerian population in the form of SHS system purchases. The private sector will need to finance 50% (USD 12.8 Bn) of the investment through mini-grid developers and private capital raising by the distribution companies. The remaining 31% (USD 8.1 Bn) will need to be financed through the public sector through contributions to the distribution companies capital expenditure on grid expansion
- **A policy-driven choice to drive mini-grids for residential use needs to tackle two main risks: underutilization risk, and default risk**
  - While in 2030 (given the cost evolution) LCOEs of mini-grids are cost-competitive with diesel generation sets, the results in a short-term timeframe (2021) are less evident, implying mini-grids will need financing support. Applying a USD 350/connection subsidy to the sample mini-grid settlement results in a reduction in 2021 LCOE to USD 0.31-0.46/kWh, compared to USD 0.35-0.70/kWh for a diesel generation set
  - 40% the total cost of achieving universal electrification in 2030 (USD 25.8 Bn) is attributed to mini-grid (USD 10.4 Bn). The World Bank estimates the required subsidy for mini-grids to be viable is USD 350/connection. Assuming a USD 350/connection subsidy, the total cost to private developers to deploy the mini-grids would be USD 7.3 Bn, a 30% reduction
- **Productive-use demand has the potential to unlock the economic viability of mini-grids in rural agricultural settlements.** SHS does not support large productive-use (i.e. milling, grinding), which potentially limits the economic development opportunity. We assessed the impact of rice and maize milling electricity demand in rural unelectrified settlements on the least cost mix. The productive-use demand resulted in a decrease in costs per residential connection, which leads to an increase of ~3300 mini-grid settlements (~200k connections) in the least-cost technology mix
- **The model can also be used to help REA prioritize electrification sites as part of the Solar Power Naija programme which aims to deploy 5m electricity connections in Nigeria.** The 2030 least-cost technology mix consists of 5 Mn SHS connections, with all of these connections being in rural settlements. The model findings can be used to help REA identify electrification sites to deploy the target 5m SHS connections as part of the Solar Power Naija programme. Achieving this objective is expected to grow the local manufacturing industry by expanding the local solar technology value chain, potentially leading to the creation of 250k new jobs in the energy sector
- **Assessment of affordability indicates that while all grid connections in the least cost mix are expected to be able to afford their connection costs, 92% of SHS connections and 53% of mini-grid connections will have an affordability gap.** This gap amounts to USD 1.3 Bn in total or USD 266-370 per connection for SHS and USD 681 Mn or USD 145 per connection for mini-grids. The NEP has earmarked USD 288 Mn to subsidize mini-grid and SHS connections, a number which would need to significantly increase to achieve universal electrification by 2030

Context & Objectives

Summary of Key Findings

Appendix

Context and objectives

Context

- **In 2019**, the Federal Government of Nigeria (FGN), through the **Rural Electrification Agency (REA), developed a geospatial model to determine the least-cost solution** to achieving 100% electrification by 2024 and 2030
- The model revealed that 100% electrification by 2024 would result in 60% of new connections from solar home systems (SHS), 29% from grid extension and 11% of new connections from mini-grids
- **SEforALL has prioritized the development of Integrated Energy Plan towards the achievement of Sustainable Development Goal 7** to 'Ensure access to affordable, reliable, sustainable and modern energy for all'
- **Nigeria's IEP goes a long way towards being an exemplar of an Integrated Energy Plan, but has key limitations** that the FGN, in collaboration with SEforALL, now seeks to address:
  - Some of its data and analysis is outdated;
  - It is not yet a fully open-access tool usable by public and private sector actors;
  - It does not incorporate clean cooking.
- Thus, an **updated Nigerian Integrated Energy Plan** incorporating electrification, clean cooking and productive use will **play a vital role in assisting the FGN in determining the tactical implementation approach for the relevant interventions**

Objectives of this project

- **To develop an updated and enhanced Integrated Energy Plan (IEP)** for Nigeria, 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 is accessible** and usable by external stakeholders

Overview of the least-cost electrification analysis

Objectives

Estimate the energy demand of the unelectrified population in Nigeria

- Model identifies area without access to electricity and projects required energy demand based on household characteristics

Determine the least-cost technology mix and required investment to achieve universal electrification

- Least-cost analysis determines the least-cost electrification method for each settlement between grid connection, mini-grid construction and Solar Home System deployment based on an estimation of the lifetime connection cost for each technology

Understand implications of expanding clean cooking

- Some settlements may require an upgrade from SHS to mini-grid connections based on aggregated clean cooking demand

What it will inform

Support the Solar Naija project objective to deploy 5m SHS and Mini-grid connections by identifying prospective locations

Inform the Nigeria Electrification Project (NEP) driven by REA in collaboration with World Bank and AfDB[1] by identifying priority areas for Mini-grid development

Help REA and Discos identify priority areas for grid extension

Key stakeholders

SUSTAINABLE ENERGY FOR ALL · REA · FEDERAL MINISTRY OF POWER

Other stakeholders: Discos, TCN[2], donors and private sector players

1. African Development Bank
2. Transmission Company Nigeria

The aim of this model is to provide a perspective on the least-cost solution to achieving 100% electrification in Nigeria by 2030

Decisions it can inform…

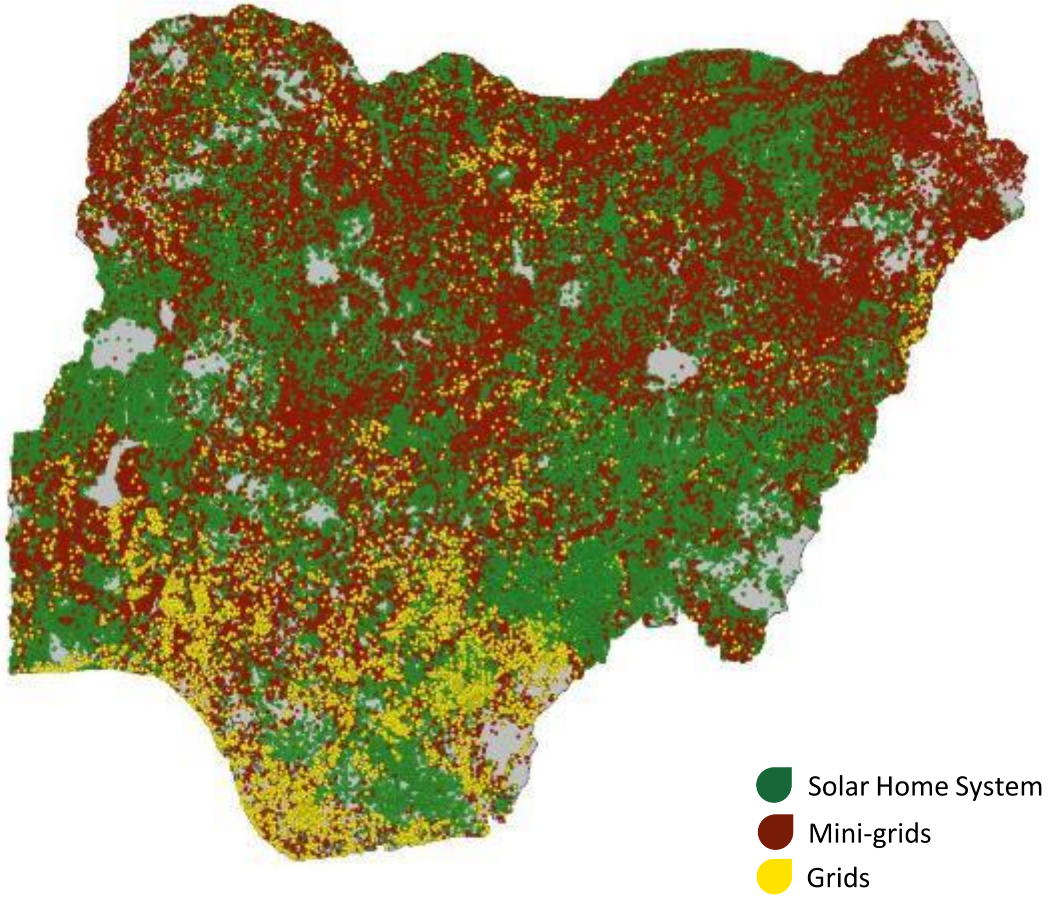
- Least-cost technology mix to electrify households (by 2030)
- Associated costs, budget implications and prioritization of sites for each technology type
- Optimised least-cost mix for settlements with no existing connection to electricity

Decisions it cannot inform…

- The model does not provide any technical recommendations (e.g., where to place transmission lines or sub-stations)
- Does not validate the economic viability of connecting sites for technology providers
- Does not assess the quality of connection of households already connected to a power source

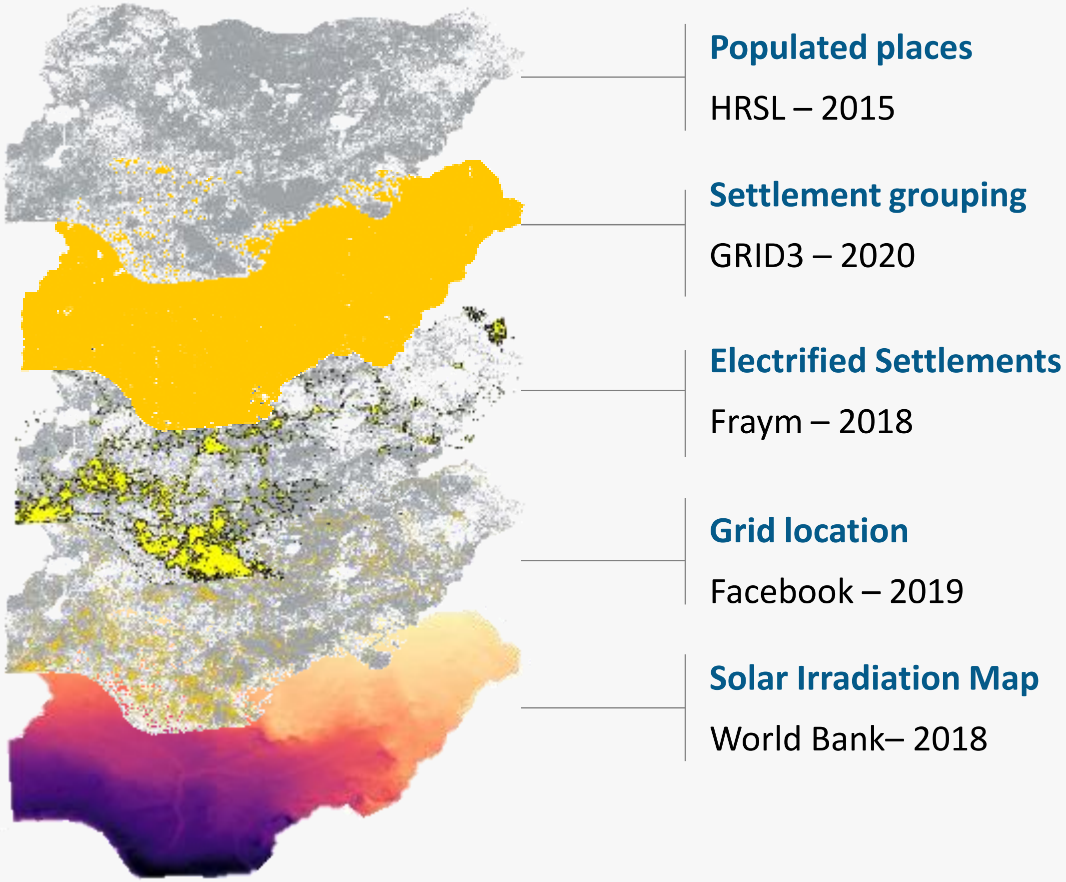
The model determines the least-cost technology mix which can be used …

Geospatial model output: Least-cost mix (2030)



… to electrify the currently unelectrified population

Inputs: demand, generation capacity, and cost data



Built environment datasets (e.g., road network, mobile coverage, etc.) to be included in visualization platform

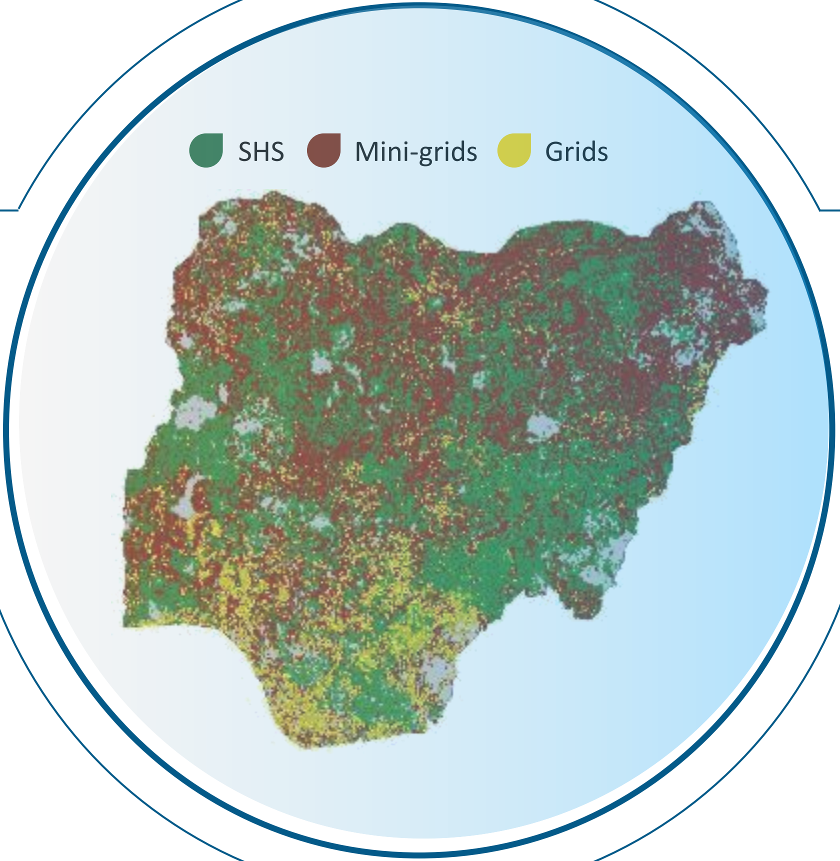
Source: Columbia University (HRSL, 2015), Geo-Referenced Infrastructure and Demographic Data for Development (GRID3, 2020), Fraym – Access to Electricity (2018), Facebook – Electricity Grid Mapping (2019), The World Bank – Global Solar Atlas 2018

The overall electrification picture for Nigeria in 2030

5 Mn
Solar home systems connections, mostly in sparsely populated areas

5.4 Mn
Grid connections in densely populated areas within close proximity of existing grid infrastructure

8.9 Mn
Mini-grid connections (104.8k mini-grids) in densely populated areas further from existing grid infrastructure



USD 25.8 Bn
Total nominal investment needed for universal access

8400 GWh p.a. & 3.6 GW
Total electricity supplied to unelectrified residential households

106 Mn & 19.3 Mn
Additional people and residential households reached respectively

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The least-cost approach to universal electrification in Nigeria will cost USD 25.8 Bn, and will result in 5Mn SHS and 8.9Mn mini-grid connections

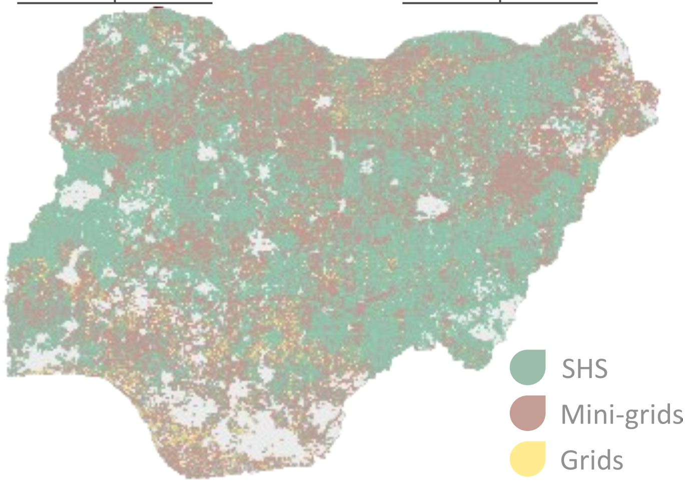
Snapshot of universal electrification (2030)

USD 25.8 Bn
Total investment needed for universal access

5 Mn
Solar home system connections, mostly in sparsely populated areas

8.9 Mn
Mini-grid connections in densely populated areas far from the grid

5.4 Mn
Grid connections in densely populated areas in close proximity to the grid



Key implications of this work

A. **The total cost to achieve universal access in 2030 is USD 25.8 Bn, of which USD 20 Bn will be an upfront investment** to which multiple stakeholders must contribute

B. **A policy driven choice to drive more mini-grids** would need to be **weighed against default risk and underutilization risk**

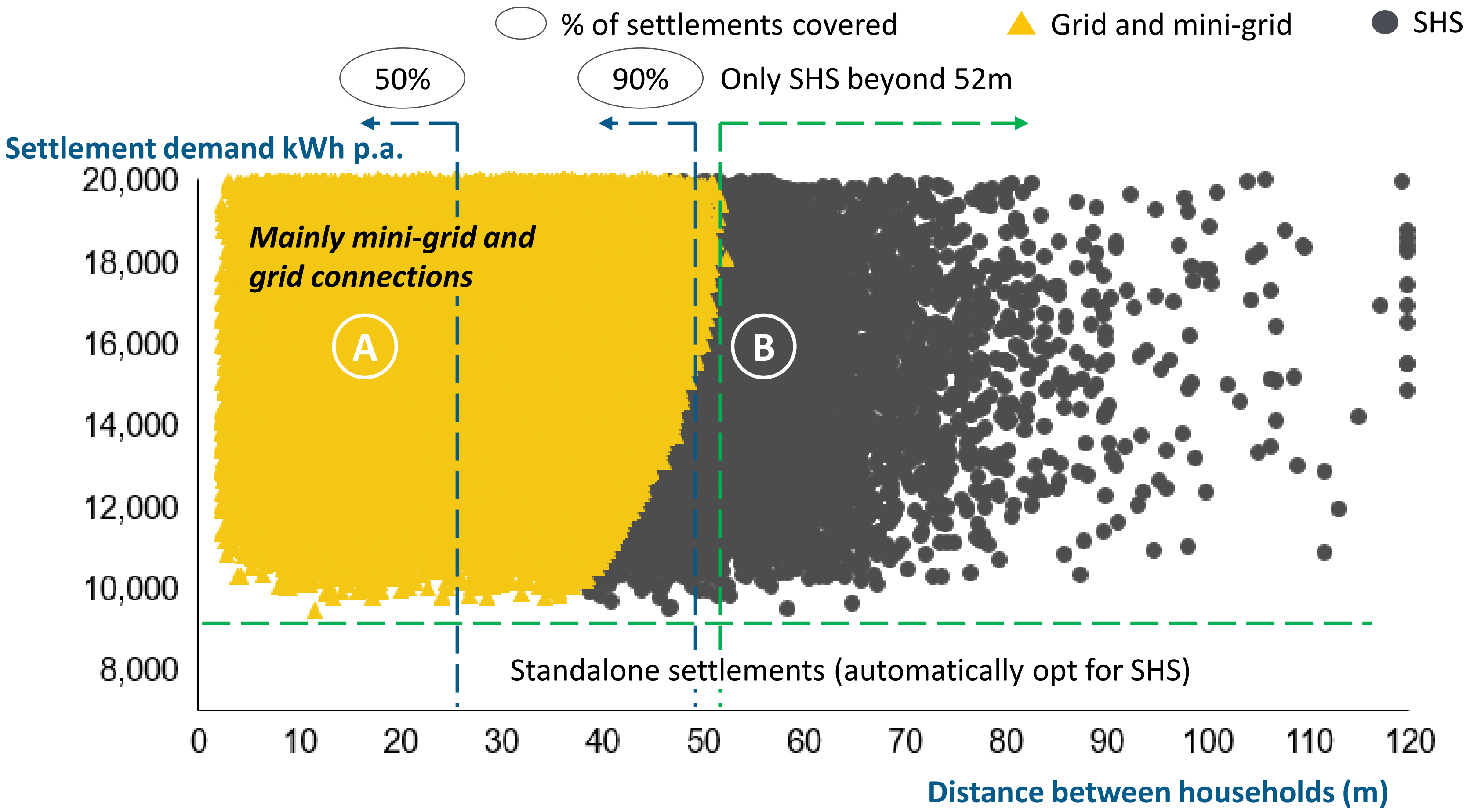
C. **Productive-use has the potential to improve economic viability of mini-grid** development in agricultural settlements

D. **We have identified ~5m SHS sites, in line with the Solar Power Naija program** aim to deploy 5m SHS connections

E. **We predict there will be an affordability gap for 92%** of SHS connections and **53%** mini-grid connections

The intersection between settlement demand and population density drives the decision between mini-grid and SHS

Unelectrified settlements, (represented by each point on the graph) by choice of least cost technology (2030)



Share of new connections (2030), %

26% **Solar home systems** are least-cost for settlements with low demand (<9.4kWh) or in sparsely populated areas (i.e., distance between households >52m)

74% **Grids and mini-grids** are optimal in settlements with denser populations (i.e., distance between households <52m) and higher demand (>9.4kWh).

SOURCE: Geospatial model (2021)

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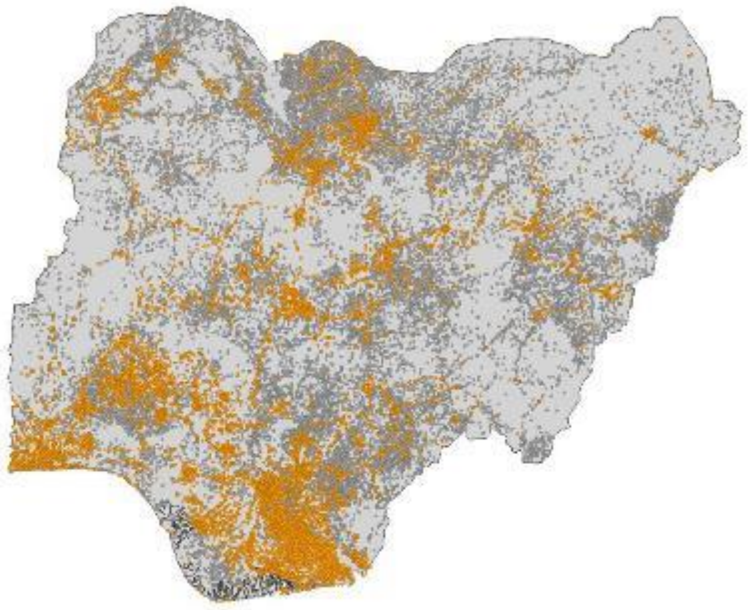
We overlaid the institution location data with the electrification settlement layer to identify unelectrified settlements with institutions

Electrification status of healthcare facilities

Electrified healthcare facilities

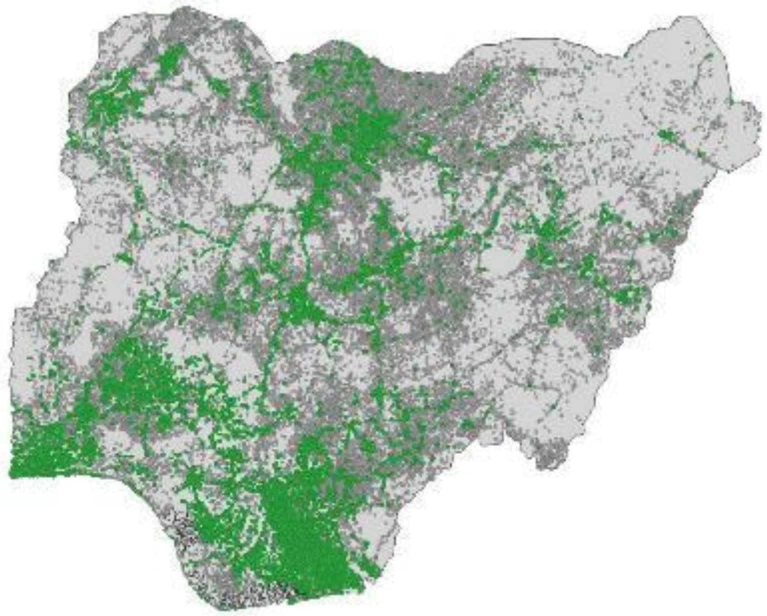
Unelectrified healthcare facilities



Electrification status of schools

Electrified schools

Unelectrified schools



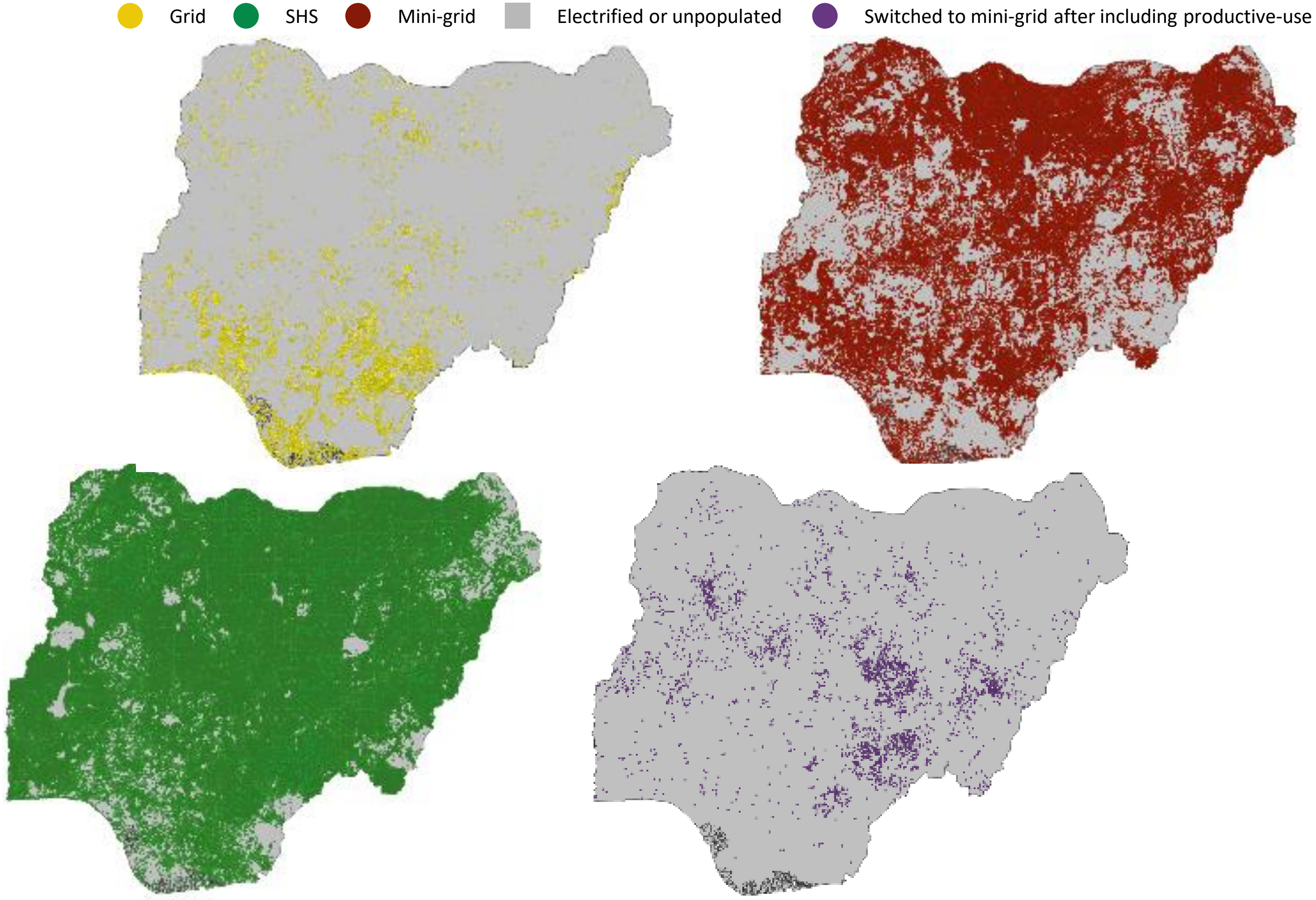
Key insights:

- ~40% of healthcare facilities in Nigeria are unelectrified (18.6k out of 46k)
- ~48% of schools in Nigeria are unelectrified (36.8k out of 76k)
- These unelectrified institutions are located within the 630k unelectrified settlements
- It is possible that facilities designated as electrified are only partially or under – electrified

Source: eHealth Africa (2021) https://data.ehealthafrica.org/datasets, Fraym (2018)

When productive-use demand is considered, the number of mini-grid connections increases by ~200k in 2030

2030 least-cost technology mix including milling productive-use



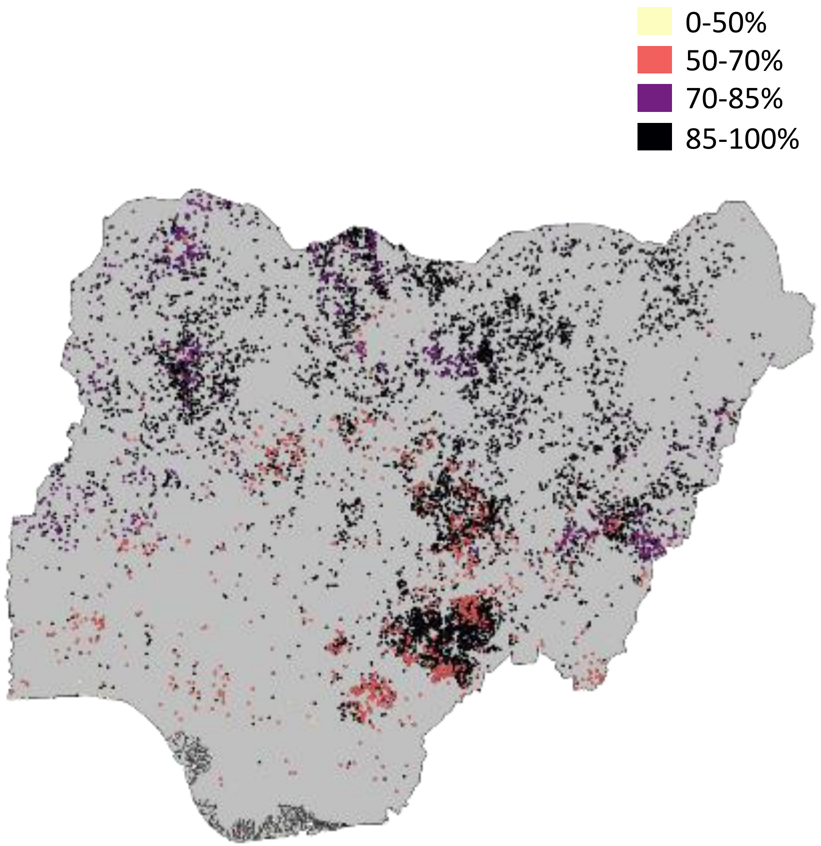
Number of settlements that can switch to mini-grid	3,389
Number of new mini-grid connections	194,870
Average reduction in least cost per connection for new mini-grids (%)[1]	9%
Average mini-grid cost reduction per connection for new mini-grids (%)	12%
Total productive-use energy demand (GWh)	~106

1. Cost reduction compared to mini-grid cost considering only residential demand

Source: Geospatial model (2021)

The SHS affordability gap is estimated at USD 1.3Bn which could be addressed through a subsidy of USD 266-370/connection

Households that cannot pay for SHS, %



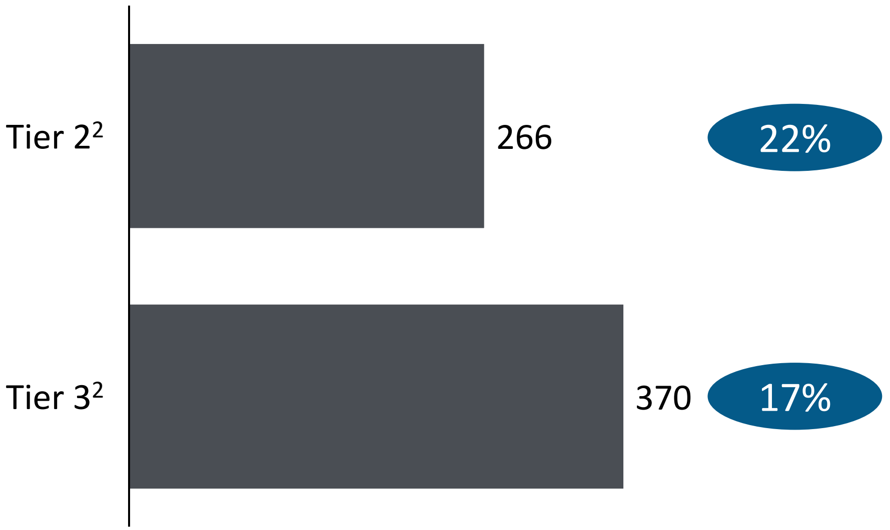
Investment required to close affordability gap, USD

USD 1.3Bn

Investment to close gap

Affordability gap per connection, USD

X% % of SHS costs



Key Insights:

Settlements in the North have a large number of households that cannot afford SHS

An investment of ~USD 1.3Bn is required to make SHS affordable to consumers

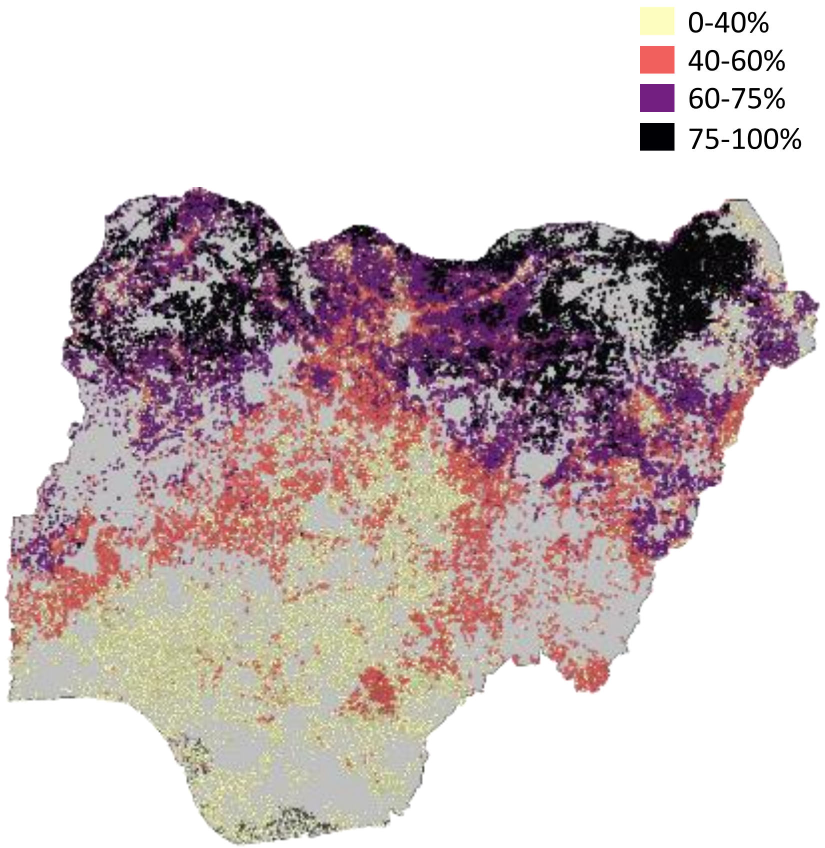
This translated to an average investment of ~USD 268 per connection[1]

1. Weighted average. Tier 2 SHS cost is USD 1202. Tier 3 SHS cost is USD 2151 (includes 3 replacements)
2. Tier 2 systems sizes are assumed at 120kW and Tier 3 systems are assumed at 200kW

Source: REA, Team Analysis

The mini-grid affordability gap is estimated at USD 681Mn which could be addressed through a subsidy of USD 145/connection

Households that cannot pay for mini-grid, %



Investment required to close affordability gap

USD 681Mn

Affordability gap per connection[1]

USD 50 - 485

Key Insights:

Settlements in the North have many households that cannot afford mini-grids

An investment of ~USD 681Mn is required to make mini-grids affordable to consumers

This translated to an average investment of ~USD 145 per connection in 2030

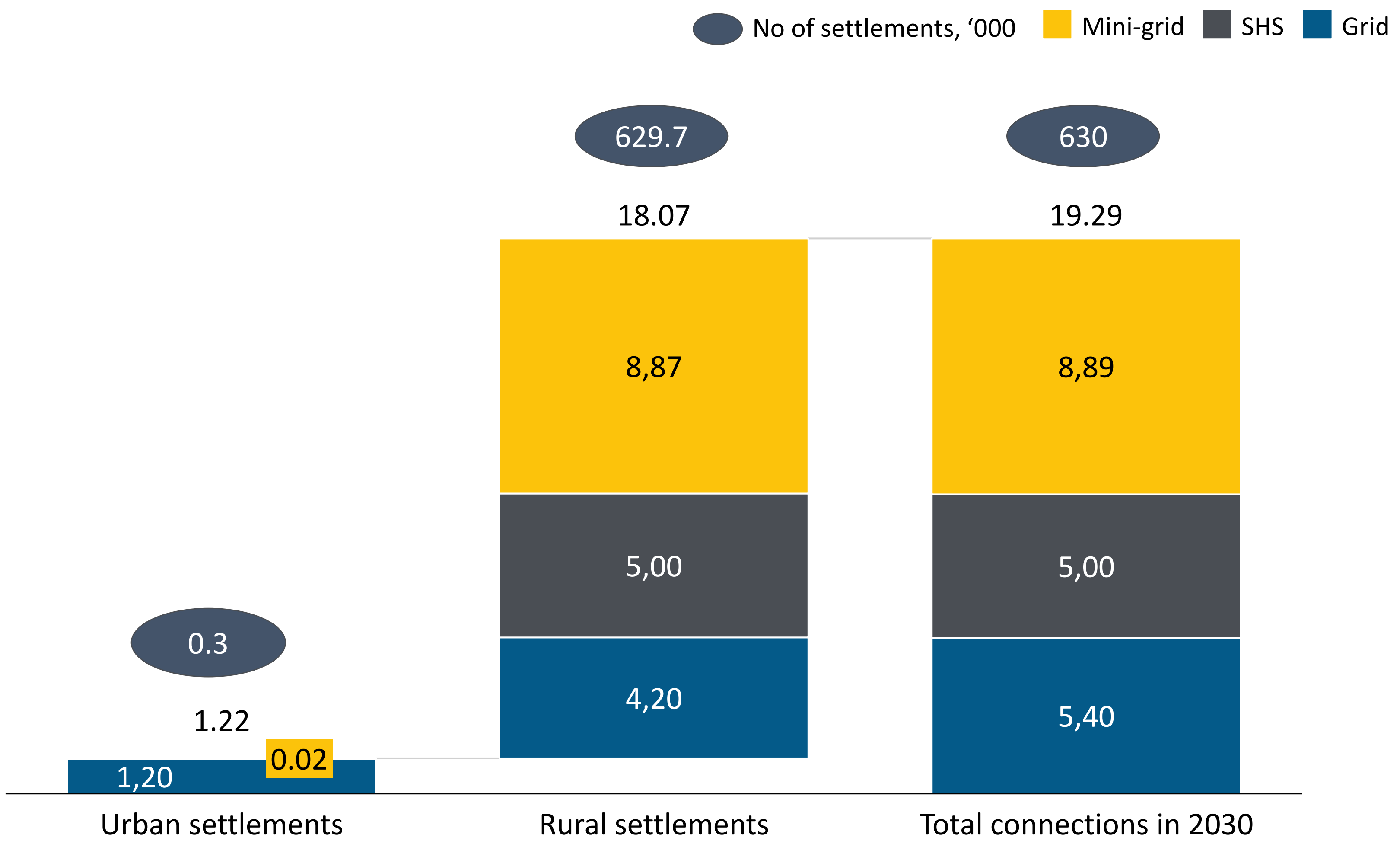
The NEP Government grant is currently USD 350/connection

1. Calculated as the affordability gap on the lifetime cost per connection

Source: REA, Team Analysis

Mini-grids are the most prevalent technology, driven by lower capital costs in the North due to high solar irradiation

Number of connections in 2030, Mn connections



Insights:

- The majority of new connections by 2030 are mini-grids. This is driven by lower mini-grid costs in the North as a result of the high irradiation
- 506k Stand-alone settlements[1] are isolated with insufficient demand to be supported by a mini-grid, and therefore opt for SHS
- Urban settlements (areas with >10,000 inhabitants) are predominantly serviced at least-cost by extending the grid, as these settlements are typically more dense and closer to the existing grid
- The biggest source of connections in rural settlements (areas with <10,000 inhabitants) is mini-grid, driven mostly by larger and more dense rural settlements

1. Standalone areas are a subset of rural areas (areas with <23 households)

Source: Geospatial model (2021)

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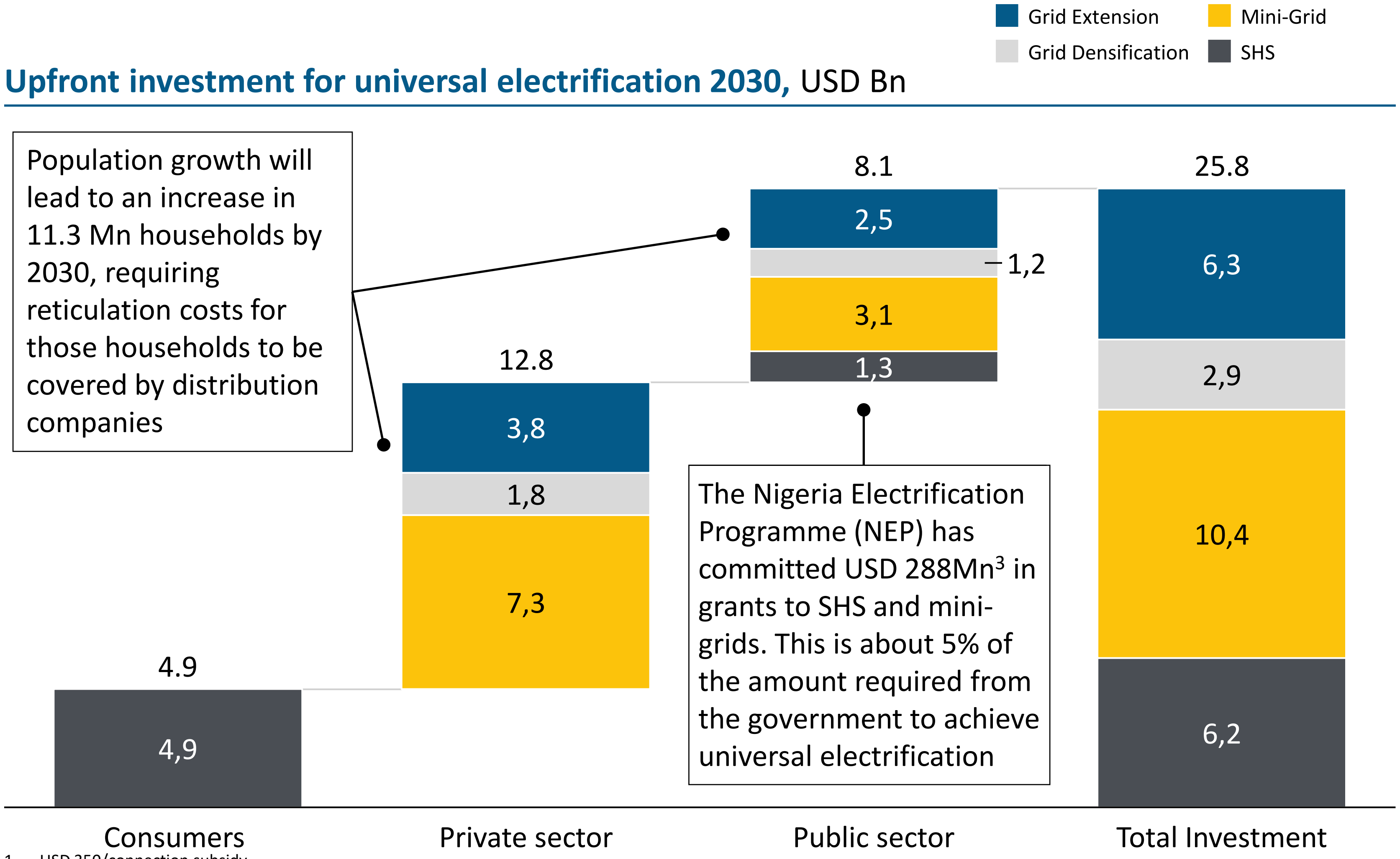
Achieving universal electrification will require an upfront investment of ~USD 25 Bn with the private sector being the key contributors

Upfront investment for universal electrification 2030, USD Bn



1. USD 350/connection subsidy
2. Mini-grids need to be cost competitive with alternative solutions (i.e., Diesel gen-sets) to avoid underutilization risk
3. Total NEP investment of USD 550Mn includes Technical Assistant costs and funds for Energizing Education. Mini-grid and SHS specific funds are USD 288Mn

Source: Geospatial model (2021), World Bank, REA

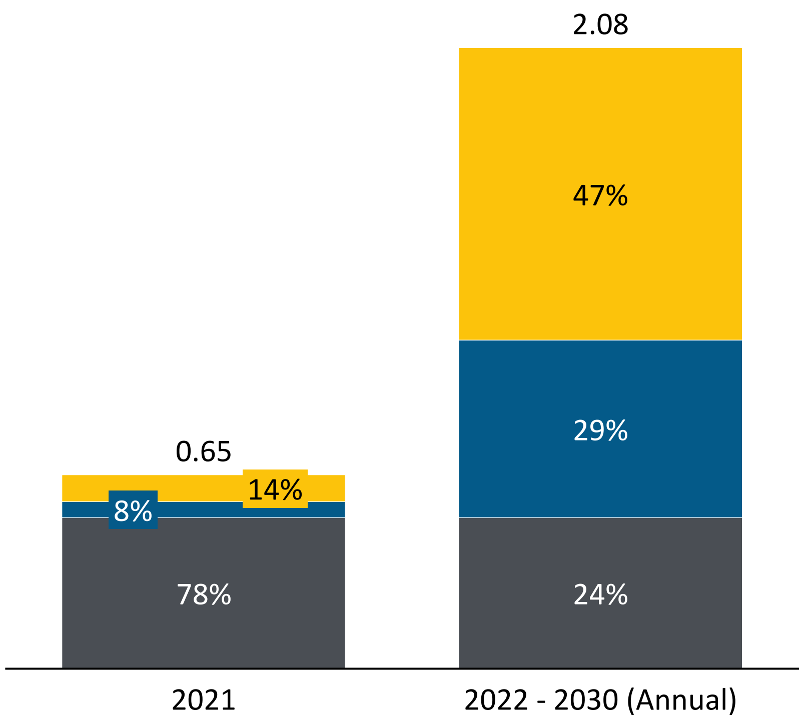
Key Insights:

- CAPEX investments for grid connections would be covered by the public (40%) and private (60%) sector in line with the ownership structure of the DISCOs
- From today to 2030, the total number of households in electrified settlements will increase by 11.3 Mn
- Majority of the investment for mini-grids would come from private sector mini-grid developers. The government could subsidise a portion[1] of the mini-grid development costs to avoid underutilisation risk[2]
- Majority of the investment for SHS would come from residents purchasing the systems. The government could subsidise a portion for households that require support

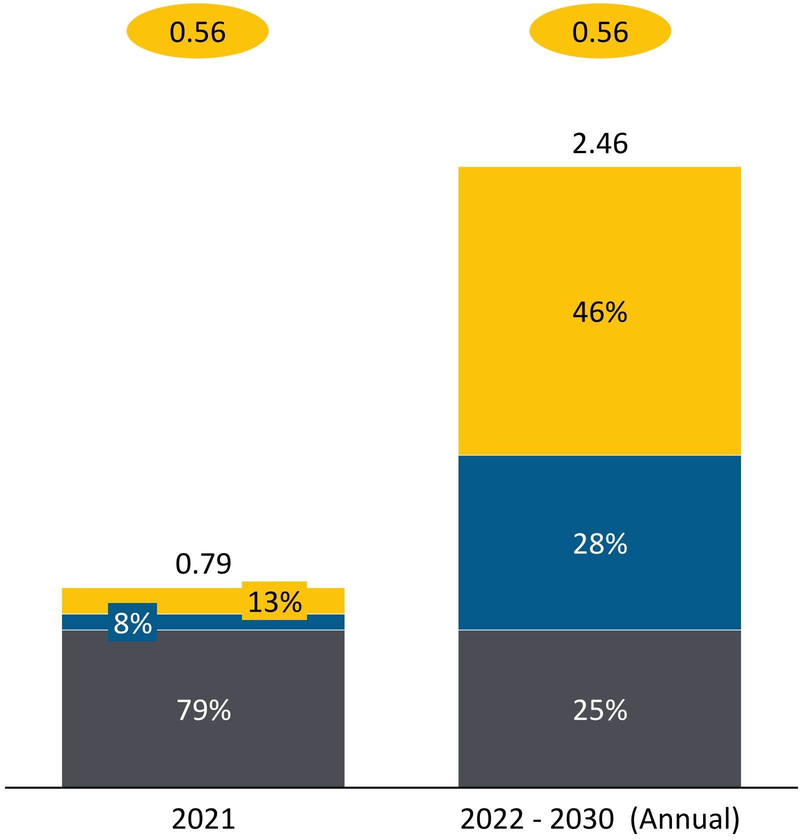
To reach universal electrification of Nigeria by 2030, annual expenses are expected to stabilize at USD 2.5 Bn/year from 2022, USD 560m/year of which would be financed by the Government

xx Government share of cost (USD Bns) MG Grid SHS

Number of residential connections, Mn households



Annual cost of electrification, USD Bns



Key Insights:

- Breakdown assumes:
  - 1% of costs for mini-grid and grid covered in 2021 then equal distribution of costs annually from 2022
  - Equal distribution of SHS costs annually from 2021
  - The government will need to finance 40% of capex (~USD 1.2Bn) for grid connections in line with the ownership structure of the Distribution Companies
  - Mini-grid developers will need to finance most of the mini-grid development costs. The government will need to subsidize the costs by ~USD 3.1Bn to make mini-grids viable
  - The government could subsidize SHS costs by ~USD 1.3Bn to make SHS affordable to consumers

Source: Team Analysis

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Appendix

Our approach to modelling the least-cost technology mix in Nigeria

Steps will be conducted iteratively (5 → 4)

1 Define unelectrified households

- a. Define and categorize settlements
- b. Identify unelectrified settlements
- c. Project future population growth

2 Calculate household electricity demand

- a. Define level of energy consumption in tiers
- b. Map settlements to consumption tiers
- c. Project future demand growth

3 Determine energy generation potential

- Define sources of energy generation mapped to consumption tiers and settlement attributes

4 Estimate least-cost technology per settlement

- a. Define bottom-up cost of each technology per connection
- b. Select least-cost technology per settlement
- c. Aggregate results to define least cost mix

5 Include non-residential energy requirements

- a. Factor in electricity requirements in public institutions
- b. Factor in productive energy use
- c. Factor in electric cooking energy requirement

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