# Nigeria Integrated Energy Plan

## Geospatial Model for Productive Use

January 2022

Powered by

SUSTAINABLE ENERGY FOR ALL

In partnership with

The Rockefeller Foundation

Global Energy Alliance for People and Planet

# 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 |

# Acronyms

| Term | Definition |
|---|---|
| IRR | Investors Rate of Return |
| kW | Kilowatt |
| kWh | Kilowatt-hour |
| LCOE | Levelized Cost of Energy |
| MG | Mini-grid |
| NEP | Nigeria Electrification Programme |
| 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 |

## Context & Objectives

Summary of Key Findings

Appendix: Methodology

# 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  - Some of its data and analysis is outdated;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

## 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…

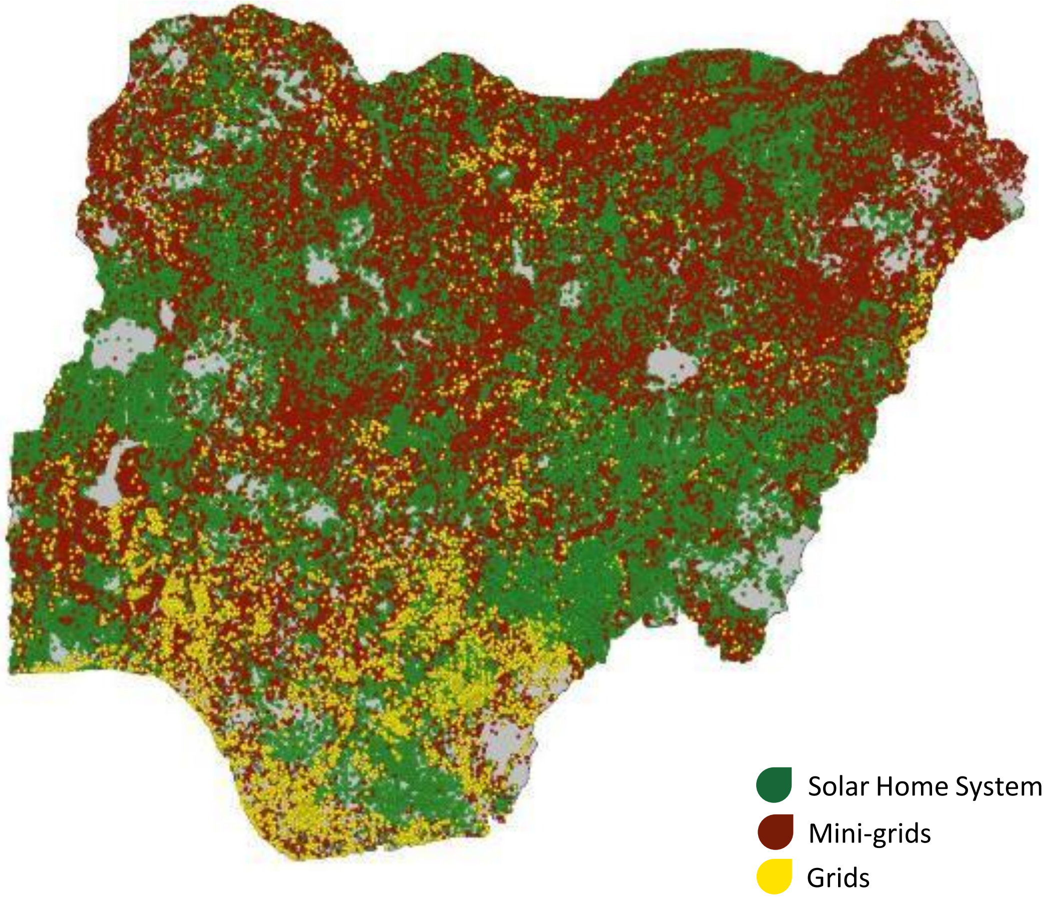
- Least-cost technology mix to electrify households (by 2030)
- Associated costs, budget implications and prioritization of sites for each technology type
- Optimised least-cost mix for settlements with no existing connection to electricity

### 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

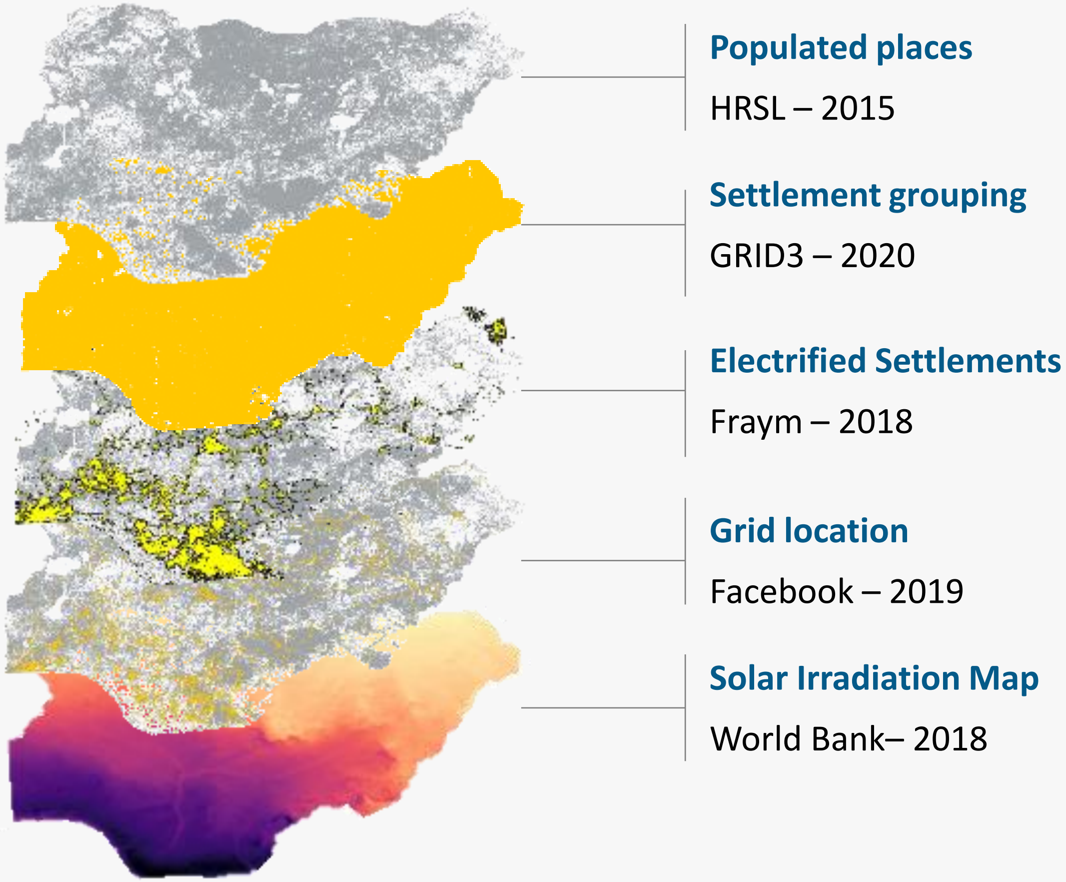
# The model determines the least-cost technology mix which can be used …

## 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

Context & Objectives

**Summary of Key Findings**

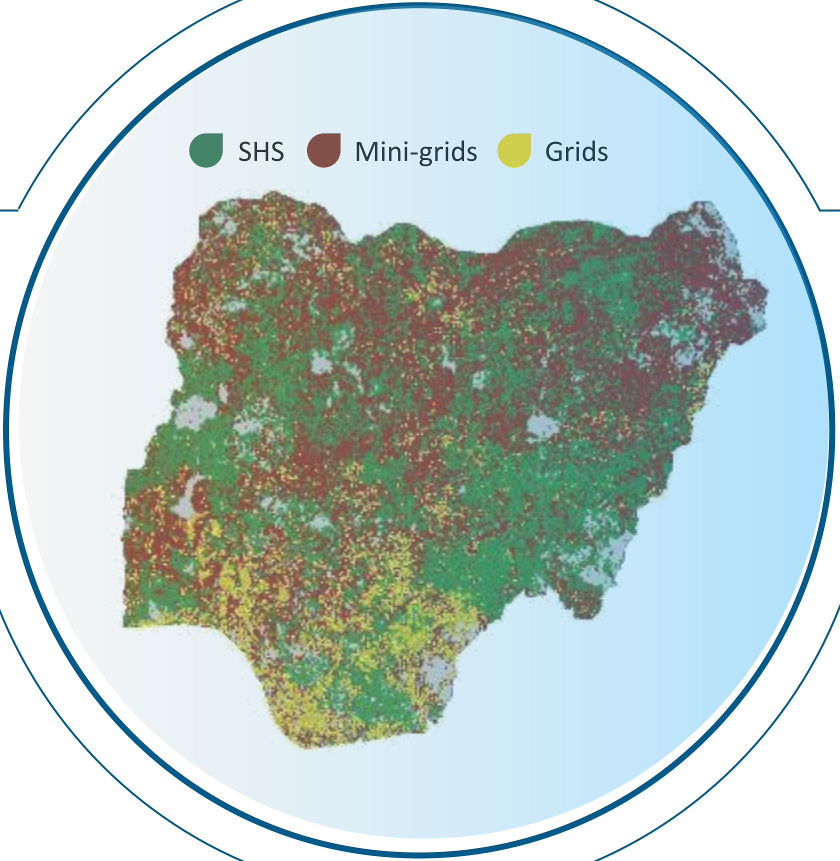
Appendix: Methodology

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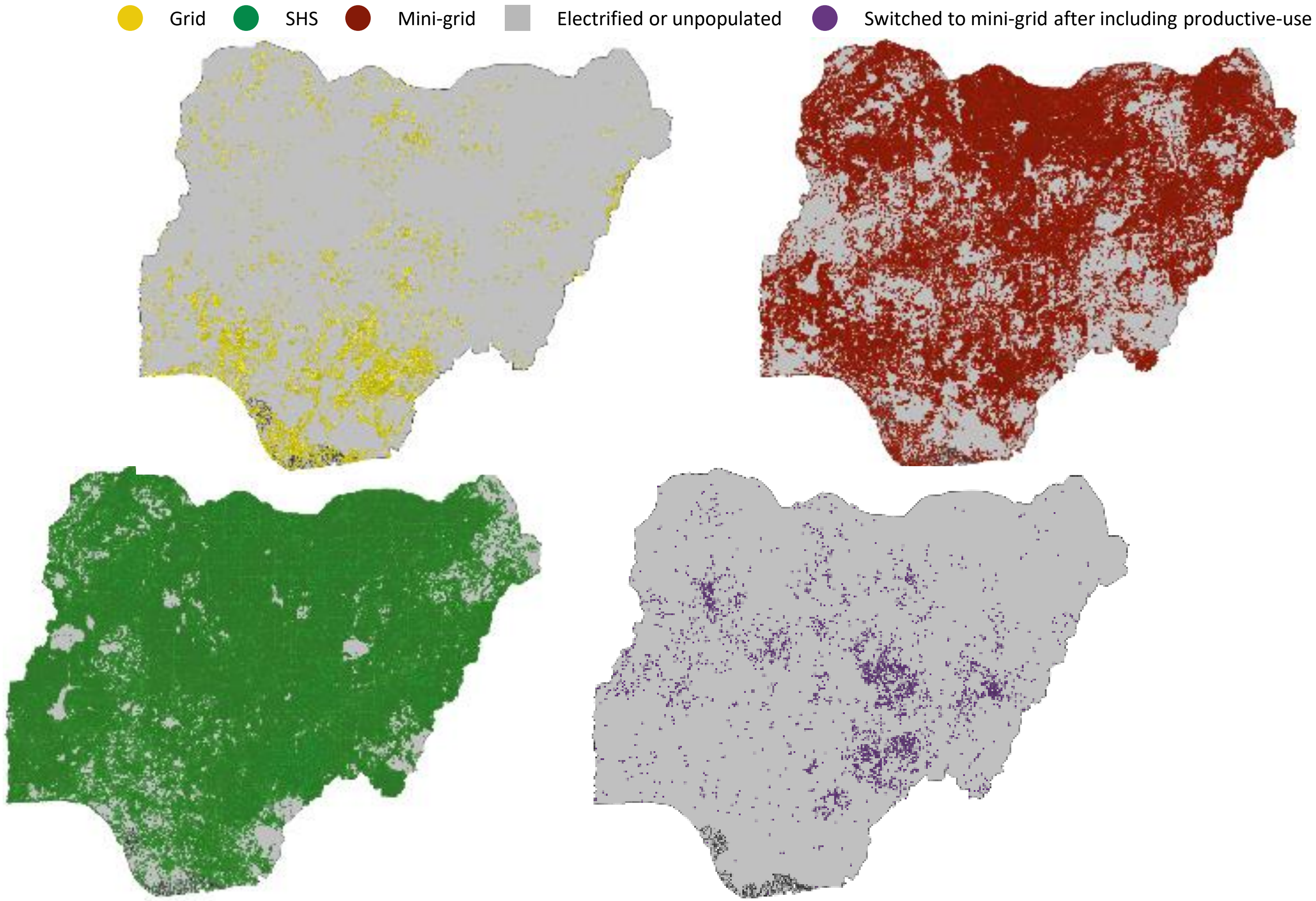
# When productive-use demand is considered, the number of mini-grid connections increases by ~200k in 2030

## 2030 least-cost technology mix including milling productive-use



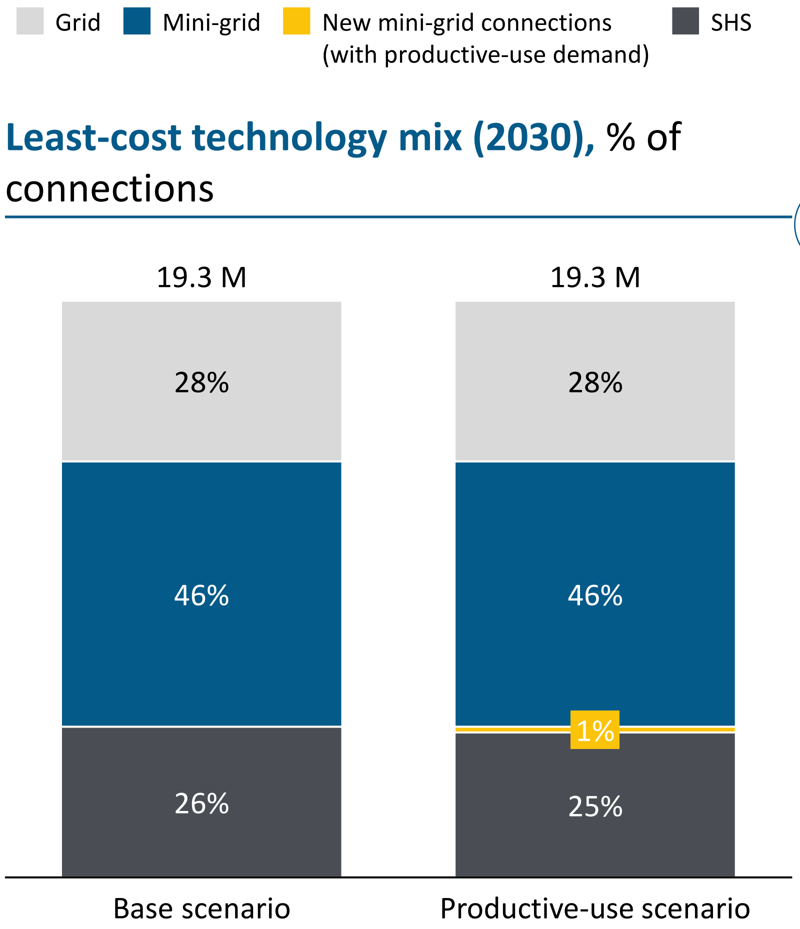

| | |
|---|---|
| **Number of settlements that can switch to mini-grid** | **3,389** |
| **Number of new mini-grid connections** | **194,870** |
| **Average reduction in least cost per connection for new mini-grids** (%)[1] | **9%** |
| **Average mini-grid cost reduction per connection for new mini-grids**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

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

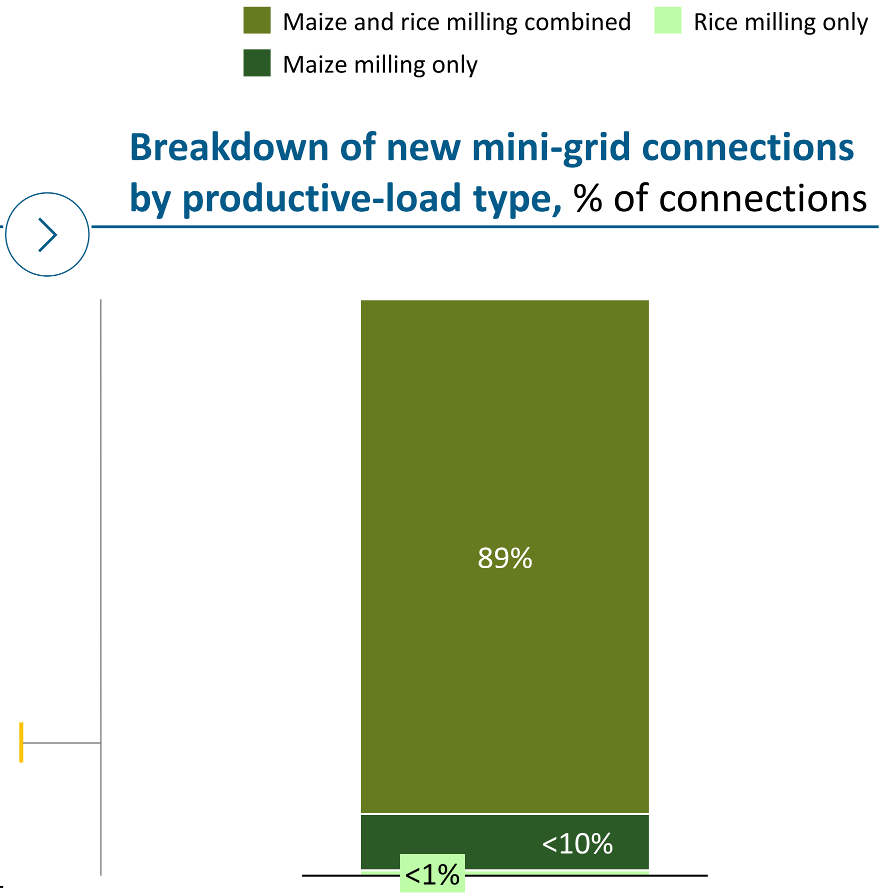
Source: Geospatial model (2021)

# +89% of the new mini-grid settlements result from a combination of maize and rice milling productive loads

**Least-cost technology mix (2030),** % of connections




**Breakdown of new mini-grid connections by productive-load type,** % of connections



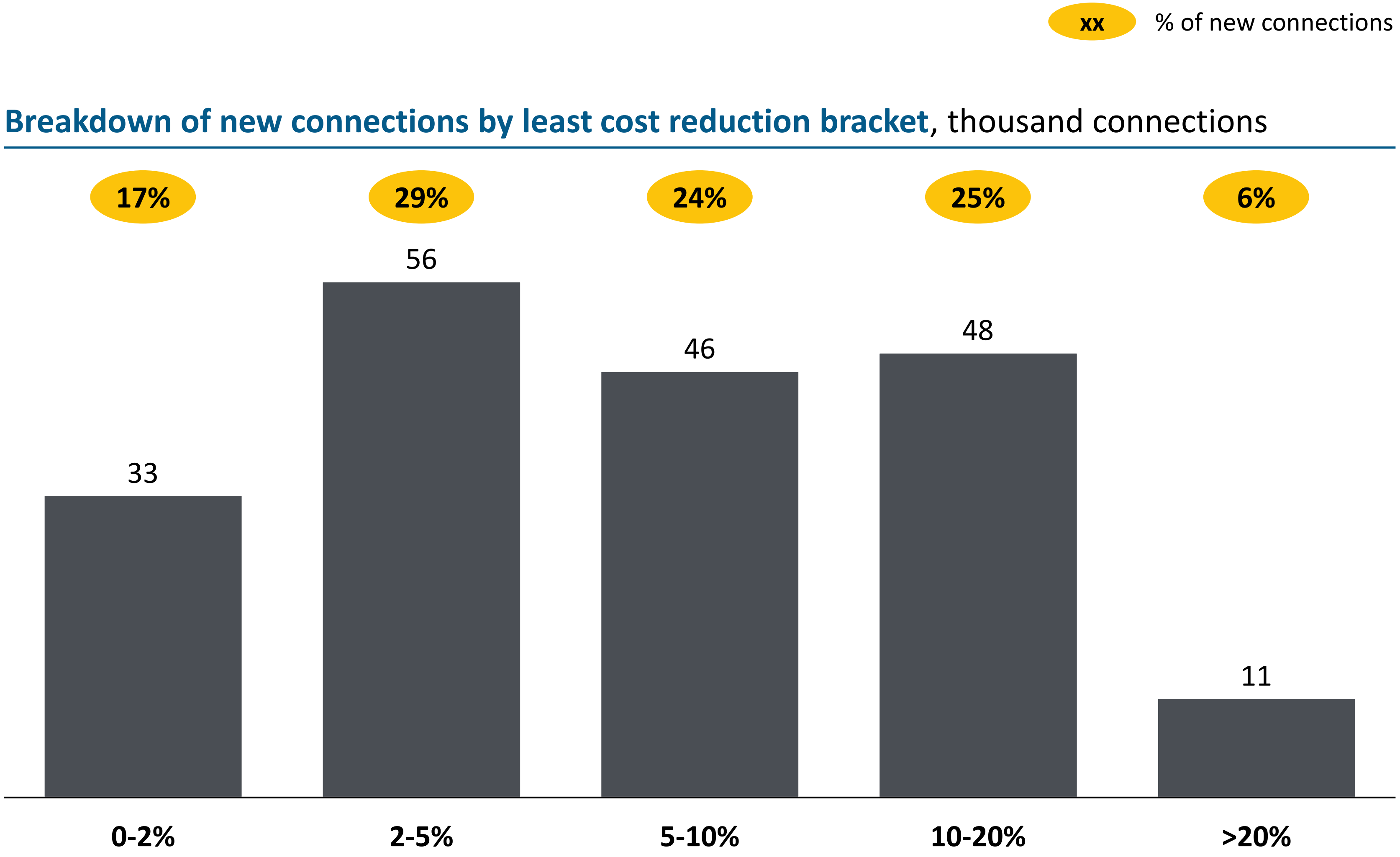

**Key insights:**

- By including productive-use, mini-grid connections would increase by ~1%
- ~89% of the new mini-grid connections will be in settlements which have both maize and rice milling activity

Source: Geospatial model (2021)

# In the new mini-grid settlements, productive-use would reduce least cost per connection by 9% on average

**Breakdown of new connections by least cost reduction bracket**, thousand connections




## Key insights:

Maize and rice milling productive-use can help reduce household least cost per connection by 9% for affected settlements

- As a result, ~200k new connections switch to mini-grid
- Less than ~10 % least cost reduction was sufficient to create ~70% of these new connections
- Meanwhile, the remaining ~30% new connections required cost reduction higher than 10% to switch to mini-grid

The cost saving on least cost technology from rice and maize milling productive-use is **~25 USD Mn**

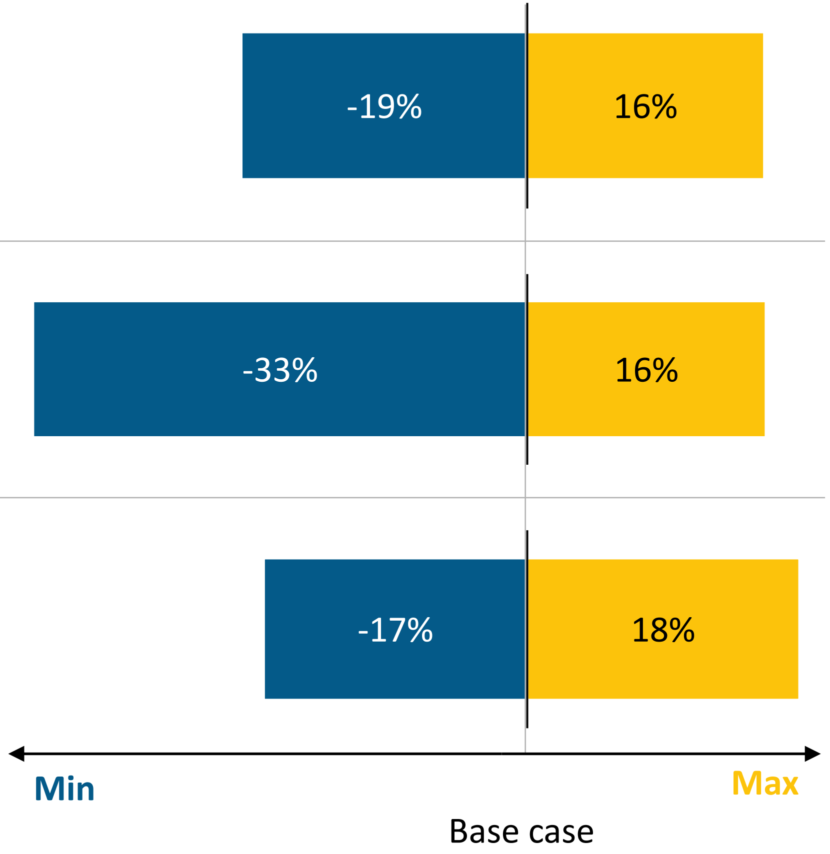
Source: Geospatial model (2021); internal analysis

# Sensitivity analysis shows that the least cost mix is most sensitive to the share of maize milled locally

Reduction | Increase

| Milling assumption | Min[1] | Base case[1] | Max[1] |
|---|---|---|---|
| **Crop milling equipment energy demand,** kWh/ton | 42.5 | 50 | 57.5 |
| **Share of domestic maize milled,** % | 40% | 65% | 80% |
| **Share of domestic rice milled,** % | 30% | 50% | 75% |

**Sensitivity of new mini-grid connections resulting from productive load,** % of new connection in base case




## Key insights:

The productive-use analysis **is most sensitive to the maize milling equipment energy usage assumption**

Considering that we have ~200k new mini-grid connections as the baseline productive-use result

- Increasing the share of domestic maize milled from 65% to 80% can help increase the new mini-grid connections by 16%
- Increasing the share of domestic rice milled can have at least a +18% impact on the new mini-grid connections

1. Minimum, base case and maximum assumptions have been identified through scientific articles and expert interviews

Source: Geospatial model (2021), International Journal of Energy Economics and Policy

# Annex

# Our approach to estimating the impact of productive-use energy requirements in the least cost mix

## I. Define productive-uses of energy

Identify productive-use cases for analysis within unelectrified settlements (i.e., agriculture, commercial and industrial energy uses) based on examples from other countries, discussions with experts and availability of data

## II. Estimate electricity demand of productive-uses

For each of the prioritized productive-use, we:

- Map areas of productive-use activity to unelectrified settlements
- Estimate productive-use activity output per settlement
- Select electric equipment to satisfy required output per settlement
- Calculate energy demand based on activity output per settlement
- Identify SHS settlements that switch to mini-grid at least-cost based on additional productive-use demand

## III. Determine impact on proposed least-cost technology mix

Aggregate additional energy requirement for productive-use and integrate in least-cost electrification model

Estimate impact on least-cost mix and required investment

# Rice and maize milling use cases have been prioritized for analysis based on 4 criteria

**Support required:** Deployment-ready | Minimal | Moderate | Significant

**Data accessibility:** Unavailable/Difficult to find | Readily available

Deep dive follows | Use cases prioritized

| | Activity | Value Chain | Local Capacity | Offtake Market | Electric Equipment | Scalability | Data accessibility |
|---|---|---|---|---|---|---|---|
| Tier 1 | Rice Milling (use case prioritized) | Rice | Deployment-ready | Deployment-ready | Deployment-ready | Deployment-ready | Readily available |
| | Flour Milling (use case prioritized) | Maize | Deployment-ready | Deployment-ready | Deployment-ready | Deployment-ready | Readily available |
| | | Sorghum | Minimal | Minimal | Deployment-ready | Minimal | Unavailable/Difficult to find |
| | | Cowpea | Deployment-ready | Deployment-ready | Deployment-ready | Deployment-ready | Unavailable/Difficult to find |
| | | Soybean | Minimal | Minimal | Deployment-ready | Minimal | Unavailable/Difficult to find |
| | Grating | Cassava | Deployment-ready | Deployment-ready | Deployment-ready | Deployment-ready | Unavailable/Difficult to find |
| Tier 2 | Threshing | Maize | Moderate | Deployment-ready | Minimal | Deployment-ready | Unavailable/Difficult to find |
| | | Sorghum | Moderate | Minimal | Minimal | Moderate | Unavailable/Difficult to find |
| | | Cowpea | Moderate | Deployment-ready | Minimal | Minimal | Unavailable/Difficult to find |
| | | Soybean | Moderate | Minimal | Moderate | Moderate | Unavailable/Difficult to find |
| | Water Pumping | Aquaculture | Moderate | Deployment-ready | Minimal | Significant | Unavailable/Difficult to find |
| Tier 3 | Threshing | Rice | Significant | Deployment-ready | Moderate | Deployment-ready | Unavailable/Difficult to find |
| | Parboiling | Rice | Moderate | Deployment-ready | Significant | Deployment-ready | Unavailable/Difficult to find |
| | Shea Butter | Shea Nuts | Moderate | Significant | Moderate | Significant | Unavailable/Difficult to find |
| | Drying | Maize | Significant | Moderate | Significant | Minimal | Unavailable/Difficult to find |
| | | Sorghum | Significant | Moderate | Significant | Significant | Unavailable/Difficult to find |
| | | Cowpea | Significant | Moderate | Significant | Minimal | Unavailable/Difficult to find |
| | | Soybean | Significant | Moderate | Significant | Moderate | Unavailable/Difficult to find |
| | | Rice | Significant | Moderate | Significant | Minimal | Unavailable/Difficult to find |
| | | Cocoa | Significant | Moderate | Moderate | Significant | Unavailable/Difficult to find |
| | Cold Storage (deep dive follows) | Aquaculture | Moderate | Significant | Deployment-ready | Significant | Unavailable/Difficult to find |
| | | Milk (chilling) | Significant | Moderate | Minimal | Significant | Unavailable/Difficult to find |
| | Peeling | Cassava | Moderate | Minimal | Significant | Moderate | Unavailable/Difficult to find |
| | Chipping | Cassava | Minimal | Significant | Minimal | Significant | Unavailable/Difficult to find |
| | Fish Smoking | Aquaculture | Moderate | Minimal | Significant | Minimal | Unavailable/Difficult to find |
| | Kernel Production | Cashew | Significant | Significant | Moderate | Moderate | Unavailable/Difficult to find |

Source: Power Africa – Agricultural productive-use Simulation in Nigeria (2020), Rocky Mountain Institute, Employment in the Nigerian Agricultural Labor Market by Odozi (2018)

**Rice and maize milling have been prioritized for the productive-use analysis after investigating several dimensions:**

**Electrification need:** Agricultural productive-uses are a priority for electrification due to their high contribution to employment in rural settlements (~70% of employment in rural communities)

**Electrification potential:** We prioritized rice and maize milling based on Power Africa and RMI's assessment of the electrification potential of different use-cases which considers four criteria:

1. **Local capacity**: Local processors already possess the requisite knowledge and skill to operate associated equipment
2. **Offtake market**: There is a strong local market to sell the output of the process
3. **Electric equipment**: The required appliance is currently available in the Nigerian market
4. **Scalability:** Electrification of the activity will benefit many communities over a broad geographical range

**Data accessibility:** Data is available and accessible to the working team for analysis

# The viability of powering irrigation through shared mini-grid with residential is limited by proximity of irrigated land to settlement centers

Survey to farmers on average time taken from community center to their farms

Farms beyond maximum radius of mini-grids

**To farmers:** How many minutes would it take you to walk from your farm to the community center? (n-78)

| Response | Frequency | Estimated distance |
|---|---|---|
| 1-15 minutes | 8% | 1 mile |
| 15-30 minutes | 41% | 2 miles |
| 30-45 minutes | 28% | 3 miles |
| >45 minutes | 23% | >3 miles |

~92% outside mini-grid radius

## Key insights:

For a single mini-grid to support both residential and irrigation load, the **irrigated field/farm must be within ~1 mile of the closest settlement center** where we assume the **mini-grid will be placed**

Based on a survey conducted by Power Africa and Rocky Mountain institute, **~92% of farmlands are located more than a mile from community centers**, which is beyond the radius of a mini-grid

In this case, the distribution costs of a **joint mini-grid solution would be too great and would limit economic viability**

**These irrigation loads would be better served by stand-alone power systems (e.g., stand-alone solar pump)** which is out of the scope of this analysis

Source: Power Africa – Agricultural productive-use Simulation in Nigeria (2020)

# Cold-chain applications for the agriculture value chain are limited in rural agricultural communities

**Support required:** Deployment-ready · Minimal · Moderate · Significant

**Data accessibility:** Unavailable/Difficult to find · Readily available

## Cold Storage for Farmed Fish

| | | |
|---|---|---|
| **Local Know-How** | Moderate | Farmers and traders responded interest in cold storage, but none had experience in integrating the cold chain into their fish selling practices. |
| **Offtake Market** | Significant | Customers have a strong preference for local fish species such as catfish, which are consumed fresh and do not require cold storage. Integration of the cold chain into local fish marketing requires careful navigation of customer tastes. |
| **Electric Equipment** | Deployment-ready | Electric refrigerators, freezer, and ice makers are commonly available in Nigeria. |
| **Scalability** | Significant | Aquaculture is already one of the least prevalent value chains studied, and consumers' preferences around fish freshness will likely vary across geographies and cultures. |
| **Data Accessibility** | Unavailable/Difficult to find | Limited data available and accessible to working team on farmed fish |

## Milk Chilling

| | | |
|---|---|---|
| **Local Capacity** | Significant | Low milk yields limit the volume that can be off-taken, and most local value chain actors are not accustomed to milk transport and chilling operations. Significant capacity building required to ensure hygienic practices from milking to storage. |
| **Offtake Market** | Moderate | Milk off-taker in Nigeria have strong demand for fresh domestic milk but struggle to source from disparate dairy herds. |
| **Electric Equipment** | Minimal | Milk chillers are internationally available, standardized pieces of equipment that are best operated on stable electricity connections that mini-grids offer. |
| **Scalability** | Significant | Success requires a rare combination of a willing off-taker, dairy capacity building programs and a mini-grid site within a strategic catchment area for a milk collection center. |
| **Data Accessibility** | Unavailable/Difficult to find | Limited data available and accessible to working team on milk value chain |

Source: Power Africa – Agricultural productive-use Simulation in Nigeria (2020)

## Key insights:

### Cold storage for aquaculture

- Cold storage for aquaculture has limited viability due to consumer preferences for fresh fish
  - For example, catfish are among the most popular fish in Nigeria (~70% of farmed fish production). However, catfish is preferred fresh instead of refrigerated
- Beyond pumping, there is very little mechanization or cold storage involved in small-scale aquaculture

### Cold storage for milk

- Currently, feasibility of mini-grid powered milk chilling is limited due to low milk yields, significant sourcing difficulties for off-takers (disparate herds) and limited scalability of milk chilling productive-use
- To be considered a promising activity for electrification, significant development of local dairy values chains from farming practices, transport to offtake markets, milk chilling would be required

# Settlements with rice or maize milling activity are assessed to determine the potential to switch to mini-grids

Methodology to calculate milling electrification need per settlement

## 1 Estimate crop output milled locally in small scale mills

Maize and rice account for ~50% of grains milled in Nigeria

On average, an annual ~6 Mn tons of rice and 10 Mn tons of maize were farmed between 2010-19

~50% of domestic rice production and ~65% of maize production are ground locally by small-scale mills

## 2 Map crop output milled per settlement

Rice and maize are farmed in most states in the country

+120,000 unelectrified settlements, produce either rice and/or maize. Milling operations generally occur within settlements

In a state, the assumption is made that all farms have a similar rice or maize annual output

## 3 Select grinding equipment per crop use case

There is a large range of milling equipment at various capacities. Equipment is selected based on the capacity required to support average settlement level output

- A 7.5 kW mill with capacity to grind 150 kg of rice or maize per hour can be considered selected

## 4 Estimate impact of milling electricity demand on least cost technology[1]

The switch to mini-grid occurs in non standalone settlements with rice and/or maize milling activity:

- With a total demand[1] greater than 17,250 kWh p.a. (because mini-grid in the region have a minimum of 10kW in capacity)
- Where milling activity help reduce the residential cost per connection for mini-grid, making it the least-cost technology

1. Includes residential and productive-use demand
2. Soybean, millet, sorghum and cow peas make up remaining share of grains and cereals production

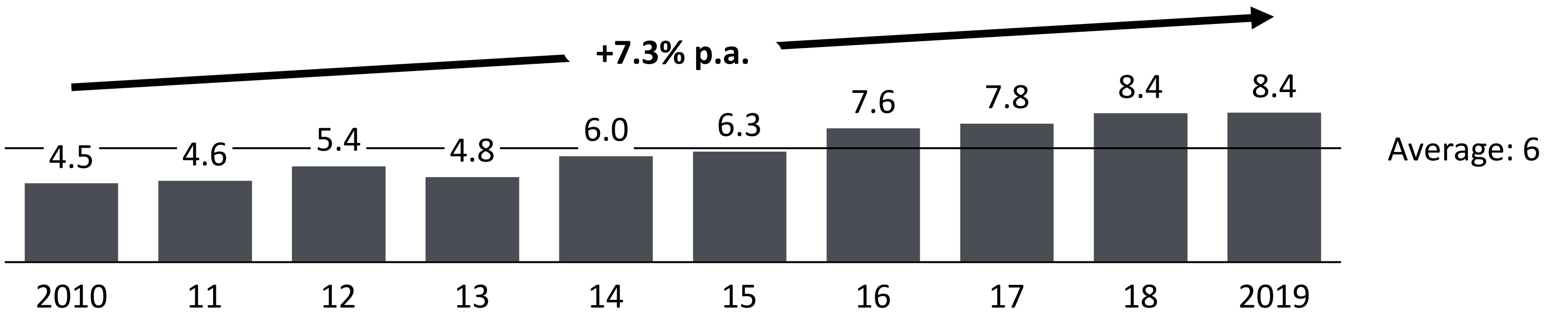
Source: FAO, Fraym (2018), Power Africa, expert interviews

# Total rice and maize output in Nigeria has averaged 6 and 10 Mn tons respectively over a 10-year period

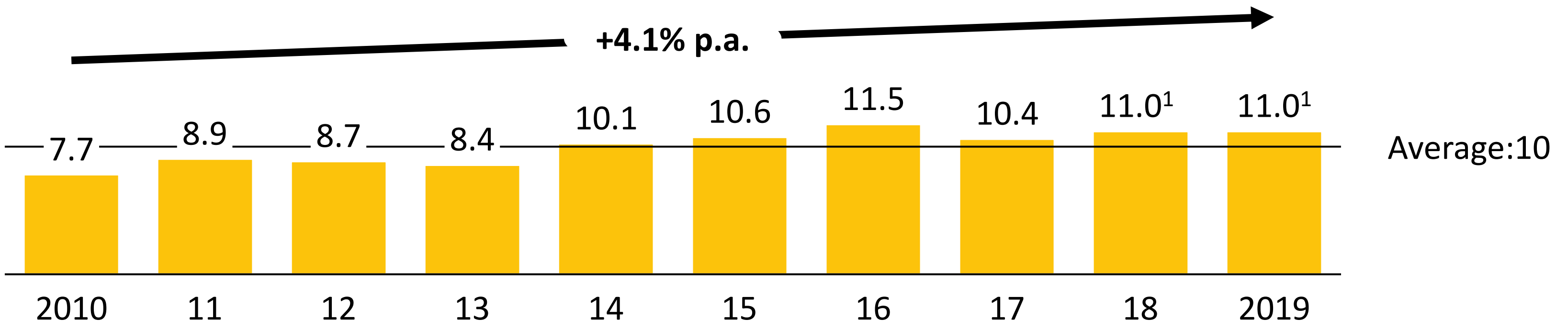


Rice Maize

## National rice output (2010 - 19), Mn tons




## National maize output (2010 - 19), Mn tons




1. Unofficial figure from FAO

Source: Food and Agriculture Organization (FAO) of the UN

## Key insights:

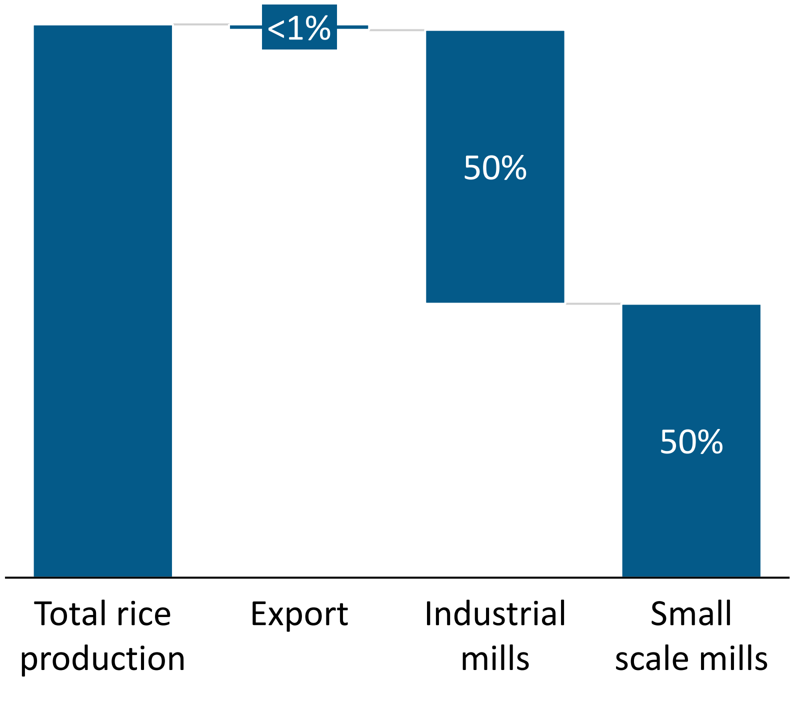
Rice production has been growing steadily at 7% p.a. in the last 10 years and has an average production of 6 Mn tons

Rice production is supported by the rice import ban implemented in 2015

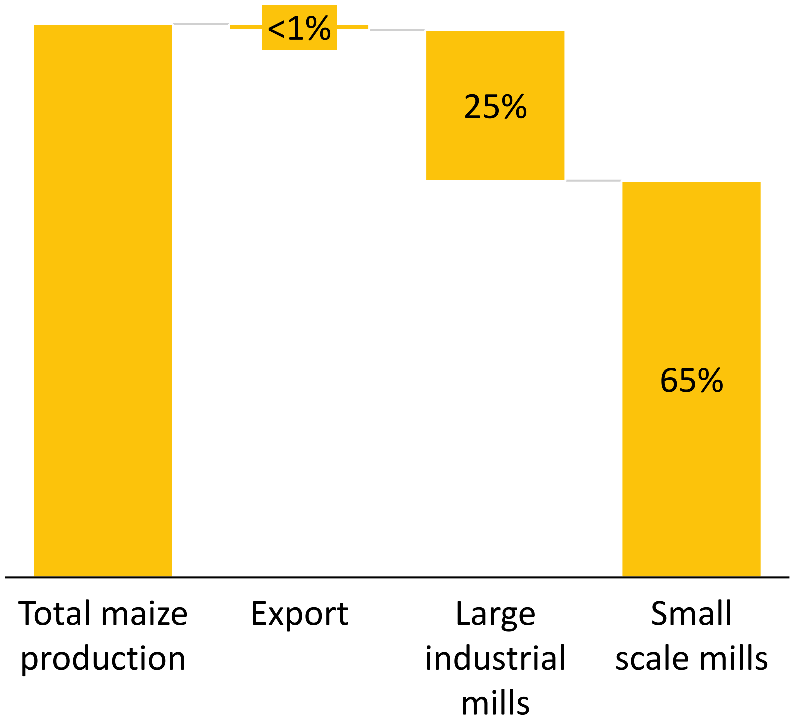
Maize production has been increasing at a 4% p.a. growth rate

# 50% and 65% of the total rice and maize produced respectively are milled locally by small scale mills

**Total rice output split by specific use,** percent




**Total maize output split by specific use,** percent




## Key insights:

~50% of domestic rice and ~65% of domestic maize produced is milled locally by small scale mills:

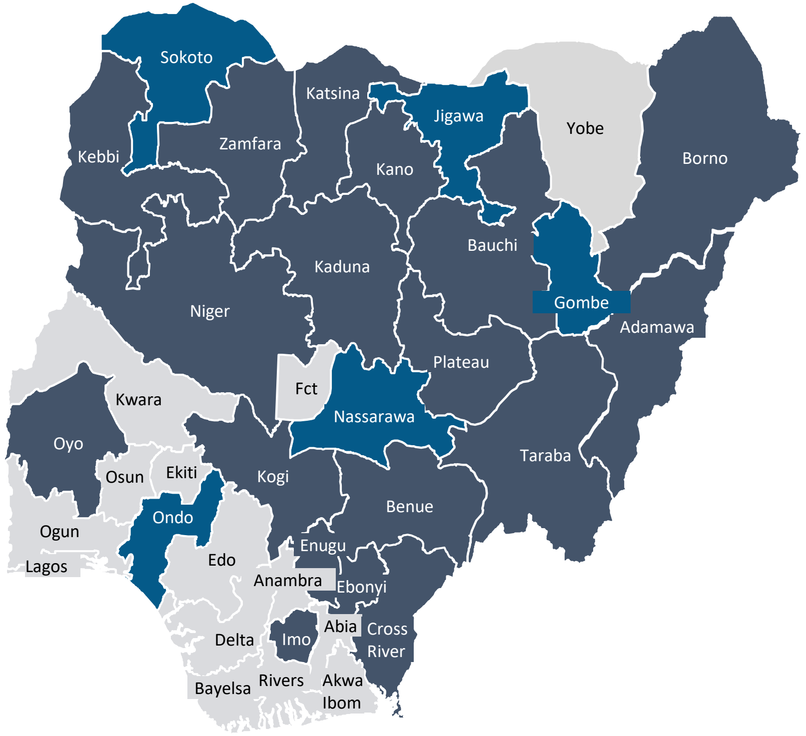
- Export of rice and maize is very limited and represents less than 1% of total production
- Large scale mills ground ~50% of domestic rice production and ~25% of domestic maize production
- It is assumed that large industrial mills and small scale mills will grind both maize for animal feed and maize for human consumption

Source: FAO, expert interviews

# Maize farms are located mainly in Nigerian northern and central states, with the highest production in states like Kano and Kaduna

## Maize farms per state as a proportion of total maize farms in Nigeria (2019), %

Less than 1.5% | 1.5% - 2.5% | Higher than 2.5%




## Maize production per state as a proportion of total maize production in Nigeria (2019)[1], %

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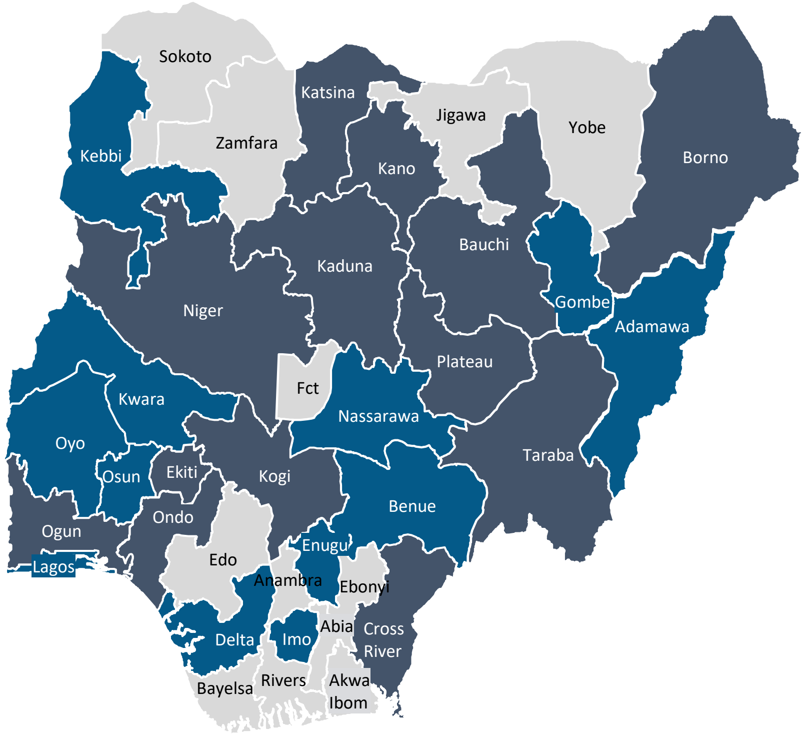



1. Rice production estimated from 2012 state production and national rice output growth between 2012-19 of 3% p.a.

Source: Fraym geospatial data, Ministry of Agriculture, NASS (2012)

## Key insights:

Fraym geospatial data-set on maize farm smallholders has been used. The data-set predicts the percentage of households who own a maize farm (<5Ha) at a 1 $km^2$ level

Using this data-set, it is assumed that:

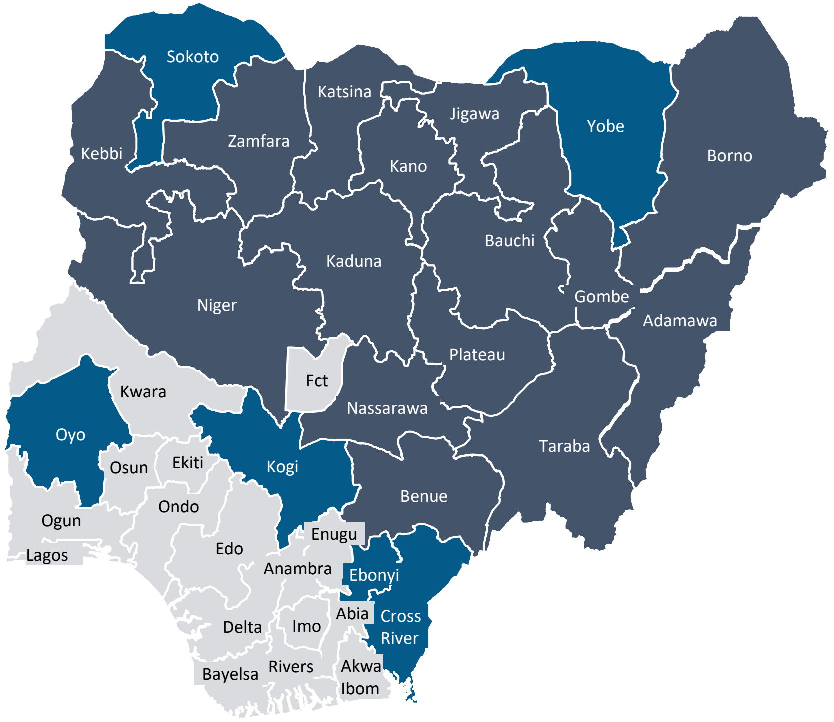
- Each households would own a single maize farm
- Settlements where at least one household owns a farm will be considered for analysis

On average, ~35% of the households in each settlement own a maize farm

# Rice farms are located mainly in Nigerian northern and central states, with the highest production in states like Kogi, Kwara, Kaduna and Kano

## Rice farms per state as a proportion of total rice farms in Nigeria (2019), %

Less than 1.5% | 1.5% - 2.5% | Higher than 2.5%

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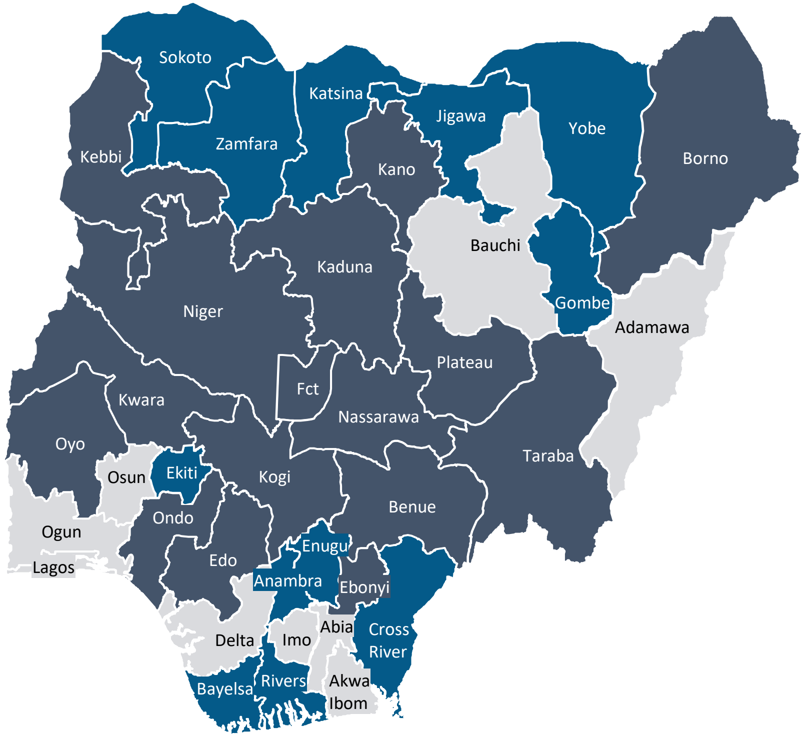
Less than 1.5% | 1.5% - 2.5% | Higher than 2.5%




## Key insights:

Fraym geospatial data-set on rice farm smallholders has been used. The data-set predicts the percentage of households who own a rice farm (<5Ha) at a 1 $km^2$ level

Using this data-set, it is assumed that:

- Each households would own a single maize farm
- Settlements where at least one household owns a farm will be considered for analysis

On average, ~16% of the households in each settlement own a rice farm

1. Rice production estimated from 2012 state production and national rice output growth between 2012-19 of 6% p.a.

Source: Fraym geospatial data, Ministry of Agriculture, NASS (2012)

# We consider a 300 ton/year rice and maize mill of 7.5 kW capacity each based on milling output per settlement



ESTIMATION

## Selected milling equipment for a settlement

| | Milling output | Mill capacity | Mill energy requirement |
|---|---|---|---|
| **Rice** | • **Average rice production[2]**: ~72 tons/year/settlement<br>• **Average output of rice milled:** ~36 tons /year/settlement | • **Capacity** : 150 kg/hour meaning the mill is able to grind more than 300 tons rice or maize per year[1] which is sufficient for +95% of the settlements with rice or maize farms in the model<br>• **Size**: 7.5 kW in size | • 50 kWh/ton |
| **Maize** | • **Average maize production[2]**: ~75 tons/year/settlement<br>• **Average output of maize milled:** 49 tons/year/settlement | | |

1. At an utilization rate of ~30% (based on seasonality of crop production) and efficiency of 80%
2. Actual production per settlement varies based on geospatial dataset however average rice production was used to select appropriate milling equipment for the analysis

Source: Energy use pattern in rice milling industries-Goyal, Agriculture researcher, desktop research

# ~3,300 settlements switch to mini-grid when productive-use demand is considered, resulting in ~200k additional mini-grid connections

| | A | B | C | D |
|---|---|---|---|---|
| **All settlements** | 123,583 settlements | 121,776 settlements | 93,536 settlements | 3,389 settlements (194,870 households) |
| | **Non-standalone settlements** | **Settlements with rice/maize farms** | **Sufficient total demand for mini-grid** | **Settlements eligible for a switch from SHS to mini-grid** |
| **Criteria** | Settlement is not stand-alone, thus has sufficient building footprint to benefit from productive-use | Settlement has rice and maize farming activity | Settlement total energy demand – residential and milling use – is sufficient to consider a 10kW mini-grid | Settlements where the reduced mini-grid cost becomes the least cost technology |
| **Rationale** | Distribution costs per household for standalone settlements is too high to make mini-grids viable for residential use | Locally grown maize and rice are among the main cereals and grains milled and consumed in Nigeria | 10kW is typically the smallest size of mini-grid found assumed in the model | Incorporating productive-use demand reduces the mini-grid cost per connection for residential households as the cost is shared with productive-load institutions (Milling operations in this case) |

Source: Geospatial model (2021)

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