Afghanistan Energy Study

Universal Access to Electricity

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KTH-dESA

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A research initiative supported by:

Outline

Day 1. Universal Access to electricity

1. Outline of the 2-day training session
2. Introduction to Modelling Electricity for All
3. Introduction to Energy Resources Assessment using GIS
4. Electrification analysis using GIS
5. Introduction to ONSSET
6. Introduction to Afghanistan Energy Study
7. Afghanistan Energy Study (Sharing knowledge and experiences from local experts)
8. ONSSET analysis for Afghanistan
9. Interpretation of the results
10. Open discussion on electrification planning

Day 2. Hands on experience with ONSSET

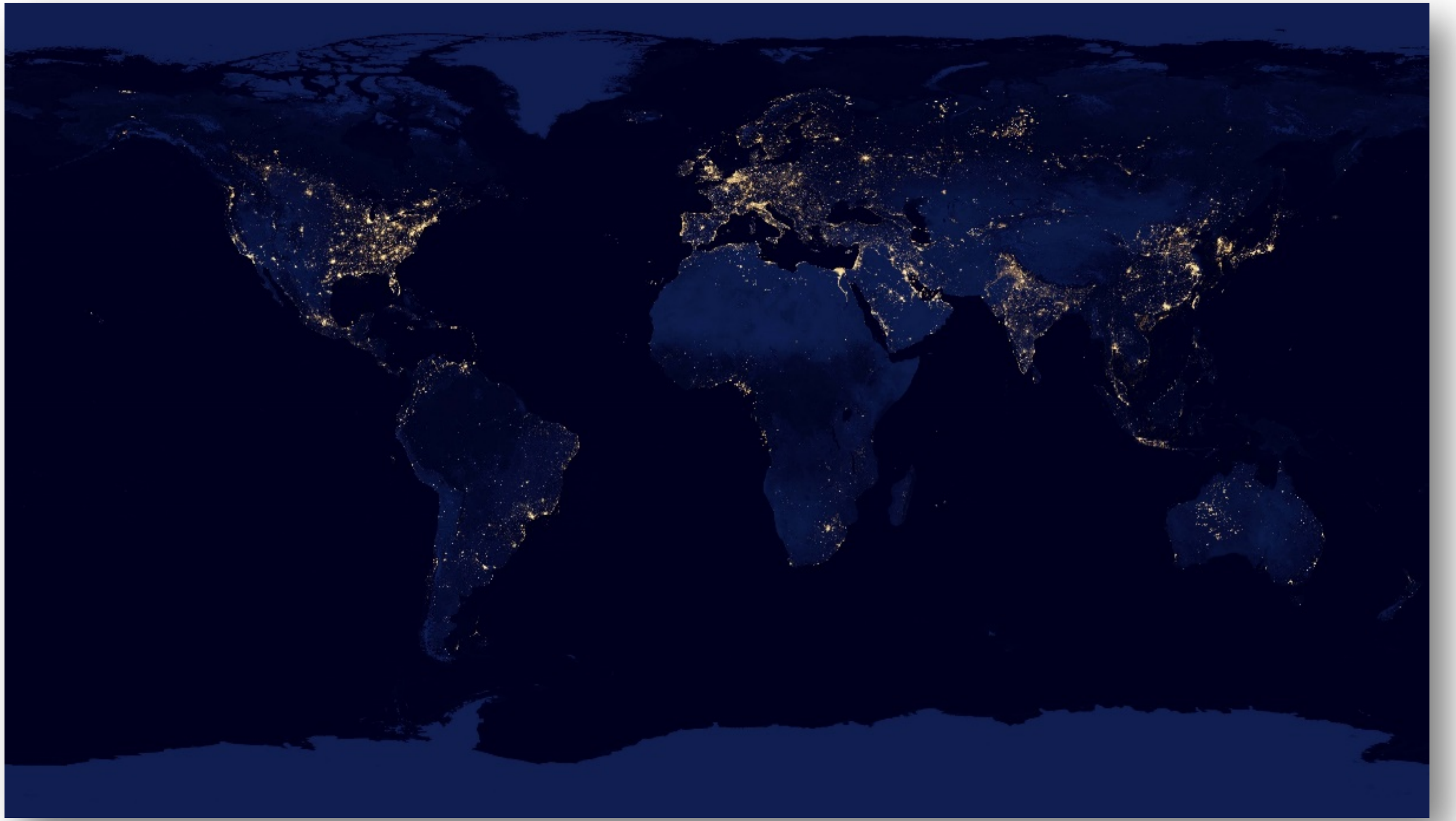
1. GIS data collection and processing
2. Hands-on experience with ONSSET (Part 1)
3. Hands-on experience with ONSSET (Part 2)
4. Stand alone version of ONSSET
5. Results visualization and interpretation and group presentations

2. Introduction to Modelling Electricity for All

Specific objective: Understand SDG7 as a relevant goal which seeks to ensure access to affordable, reliable, sustainable and modern energy for all by 2030

Energy Access Today

- About **2.7 billion** people have no access to modern energy services.
- Over **1.1 billion** people do not have access to electricity.
- The majority live mainly in rural areas of developing **Asia** and sub-Saharan **Africa**.



Nighttime light data provided by National Centers for Environmental Information

Universal Access to Electricity

Link to SDGs

Access to modern energy is beneficial for:

- Health services
- Education
- Daily activities (lighting, heating, cooking, transportation)
- Gender equality
- Indoor environment
- Business, agricultural, infrastructure and telecommunications sector

Without access to electricity | **With access to electricity**

Importance of energy planning

- Energy planning is essential for **matching demand and supply.**
- **System cost minimization** without compromising energy security, reliability of supply and environmental integrity is a primary planning objective.
- Fundamental **energy system transformation** is key to the implementation of SDG 7.

However…

- Past energy planning paradigms (models and mind-sets) are largely inadequate for access analysis and planning.
- Effective electrification planning requires **geospatial** information (e.g., settlement location, distances from the grid and road infrastructure, energy resource availability).
- In developing countries, there is a lack of reliable energy-related data.

GIS and Energy System Models

- **Conventional long-term energy models** such as OSeMOSYS, TIMES, MESSAGE etc fail to take into account the spatio-temporal fluctuations of energy resources and demand side.
  - To illustrate, the wind speed varies in time and space and so does the potential wind energy yield. The same applies to other energy sources with stochastic nature.
  - Also, the power infrastructure differs from one area to another and so does the demand.
  - Without GIS models, these details which are essential in energy planning cannot be captured.

Why **G**eographic **I**nformation **S**ystems?

The use of GIS serves multiple purposes:

Location based assessments: GIS tools enable assessments to analyse energy related geospatial information.

Remote sensing: The use of GIS tools facilitates the integration of remote sensing techniques to derive resource availability & energy potentials in cases where such data are not (publically) available.

Illustration of results: GIS is used to illustrate results in interactive maps, providing an effective science – policy interface.

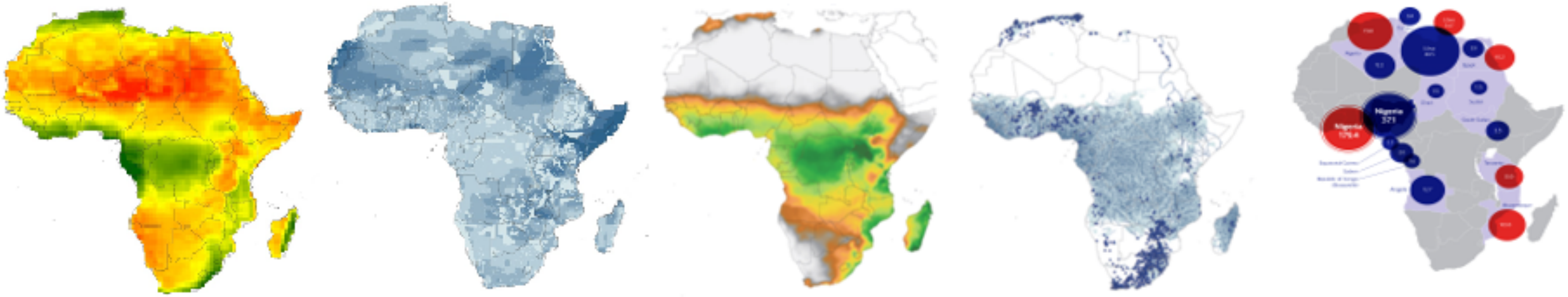
3. Introduction to Energy Resources Assessment using GIS

Specific objective: Understand the Geographic Information Systems as a tool to assess energy resources

Geospatial Resources Assessment

The quandary…

Solar Energy | Wind Power | Bio - Energy | Hydro Power | Oil - Gas Reserves

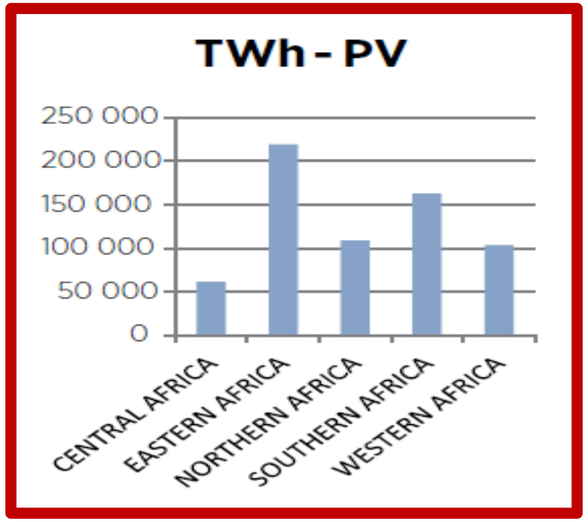


- What is the energy resource situation at each location?
- Which technologies are best suited to tap into these resources?
- What are the costs of electricity generation by technology and resource input?

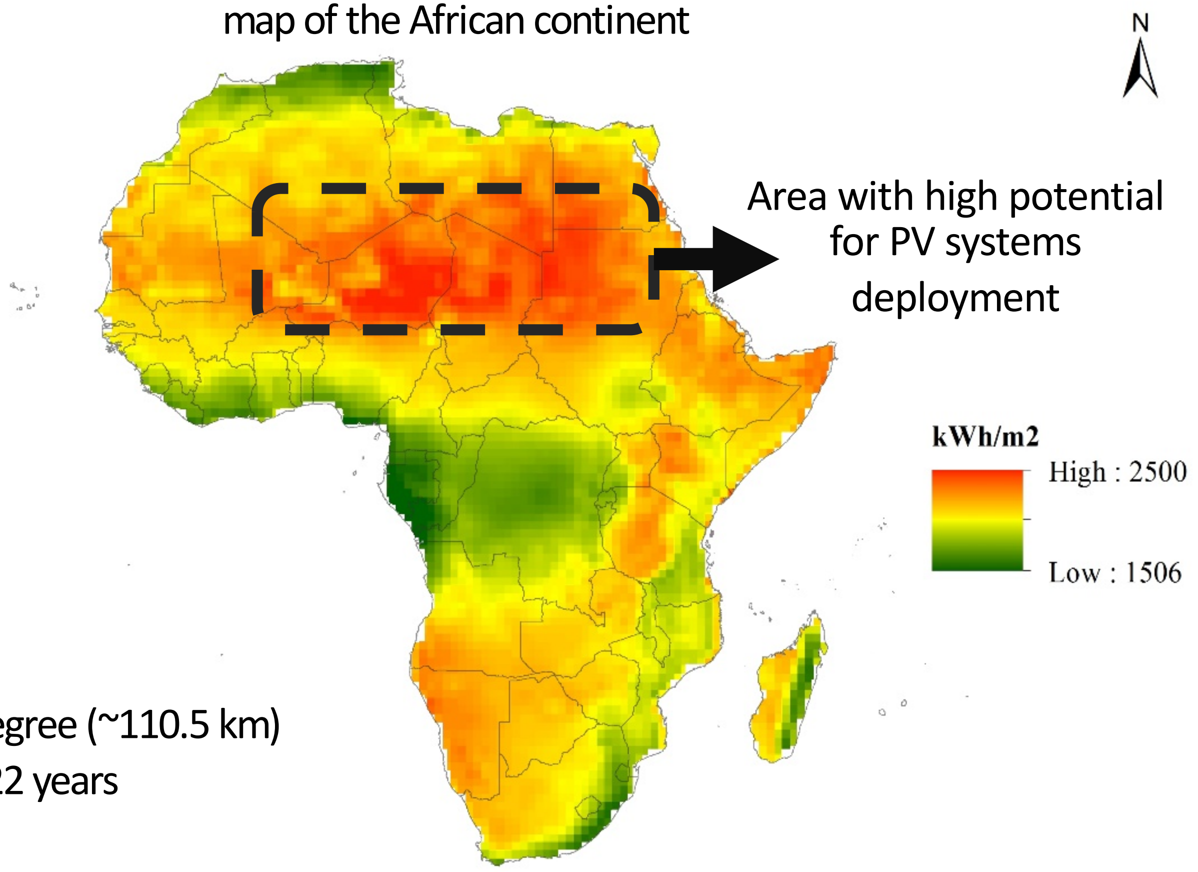
Spatial solar availability

Table 1. Summary of CSP and PV potentials in different African regions

	CSP	PV
	TWh	TWh
CENTRAL AFRICA	29 909	61 643
EASTERN AFRICA	175 777	219 481
NORTHERN AFRICA	93 544	109 033
SOUTHERN AFRICA	149 610	162 817
WESTERN AFRICA	22 747	103 754
TOTAL	471 587	656 728



Global Horizontal Irradiation (GHI) map of the African continent



Source: Langley Atmospheric Science Research Center

Layer's spefifications

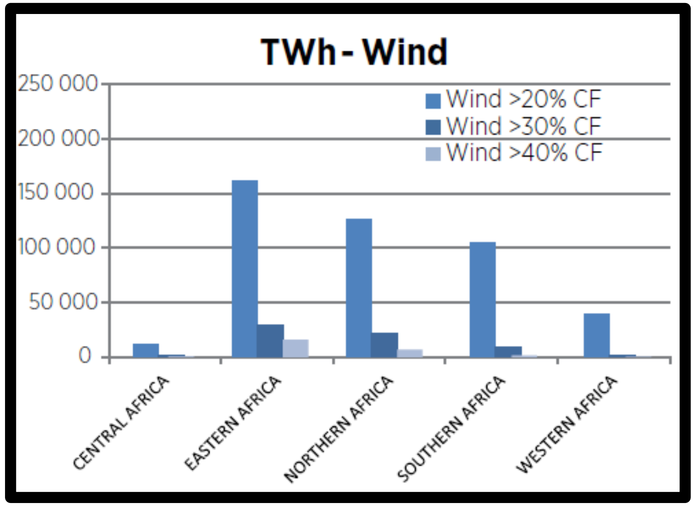
Spatial Resolution: 1 degree (~110.5 km)

Historical time series: 22 years

Spatial Wind availability

Table 2. Summary of Wind Power potential in different African regions

	All areas with wind turbine CF greater than 20 %
POWER POOL	TWh
CENTRAL AFRICA	239
EASTERN AFRICA	6694
NORTHERN AFRICA	11963
SOUTHERN AFRICA	6971
WESTERN AFRICA	5152
TOTAL	31 019

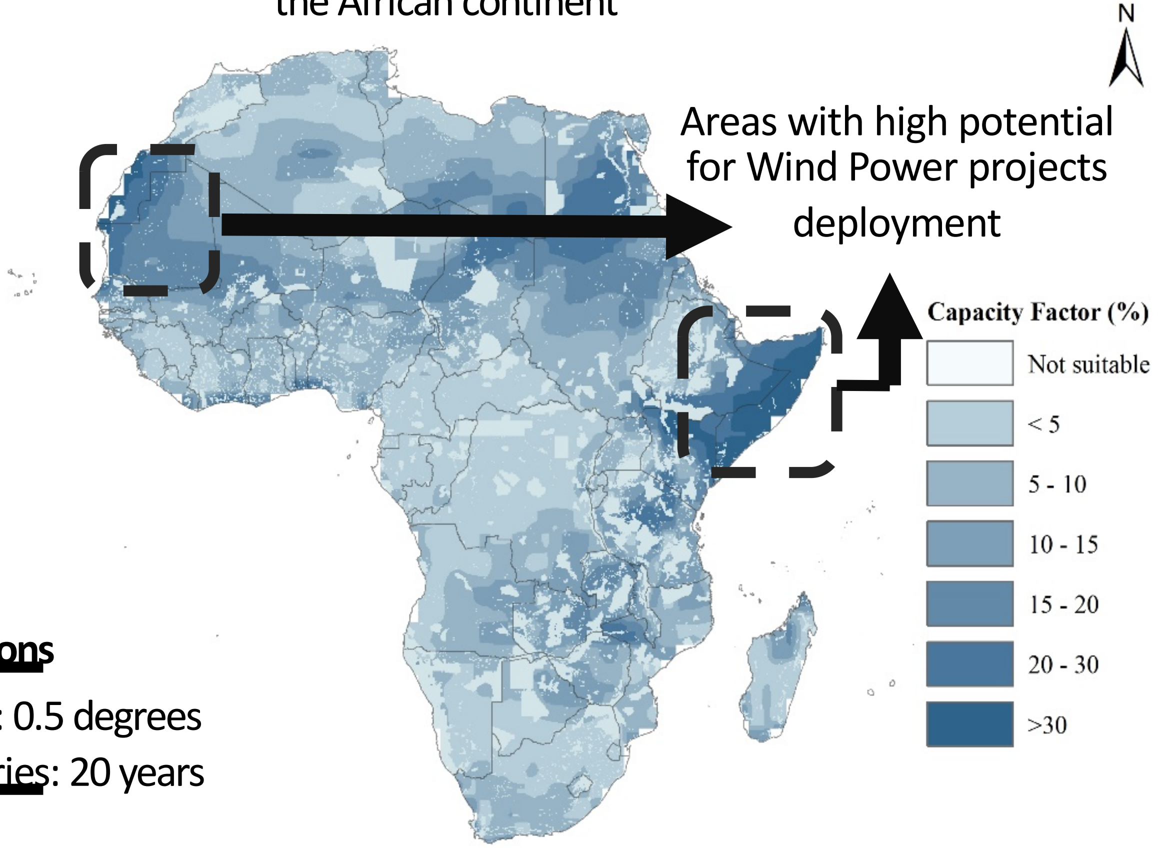


Layer's spefifications

Spatial resolution: 0.5 degrees

Historical time series: 20 years

Wind Power Capacity factor map of the African continent



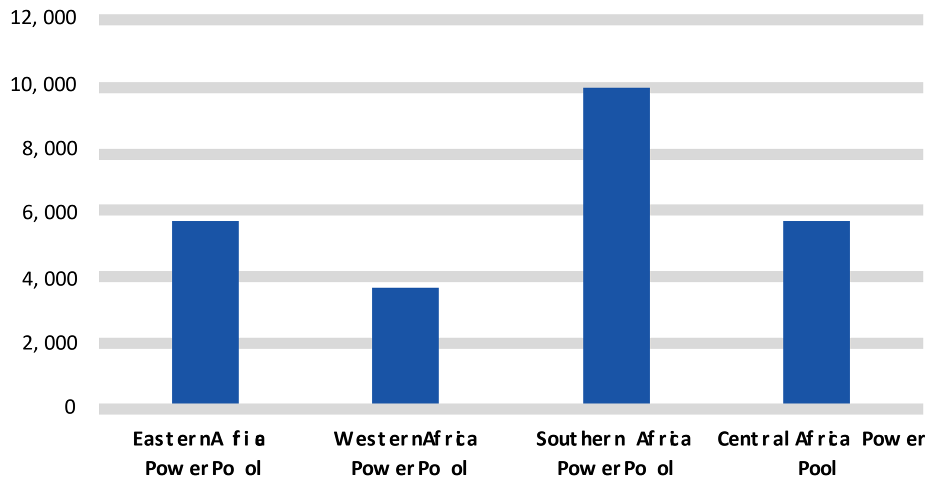
Source: NASA - GES DISC

Spatial mini/small hydropower availability

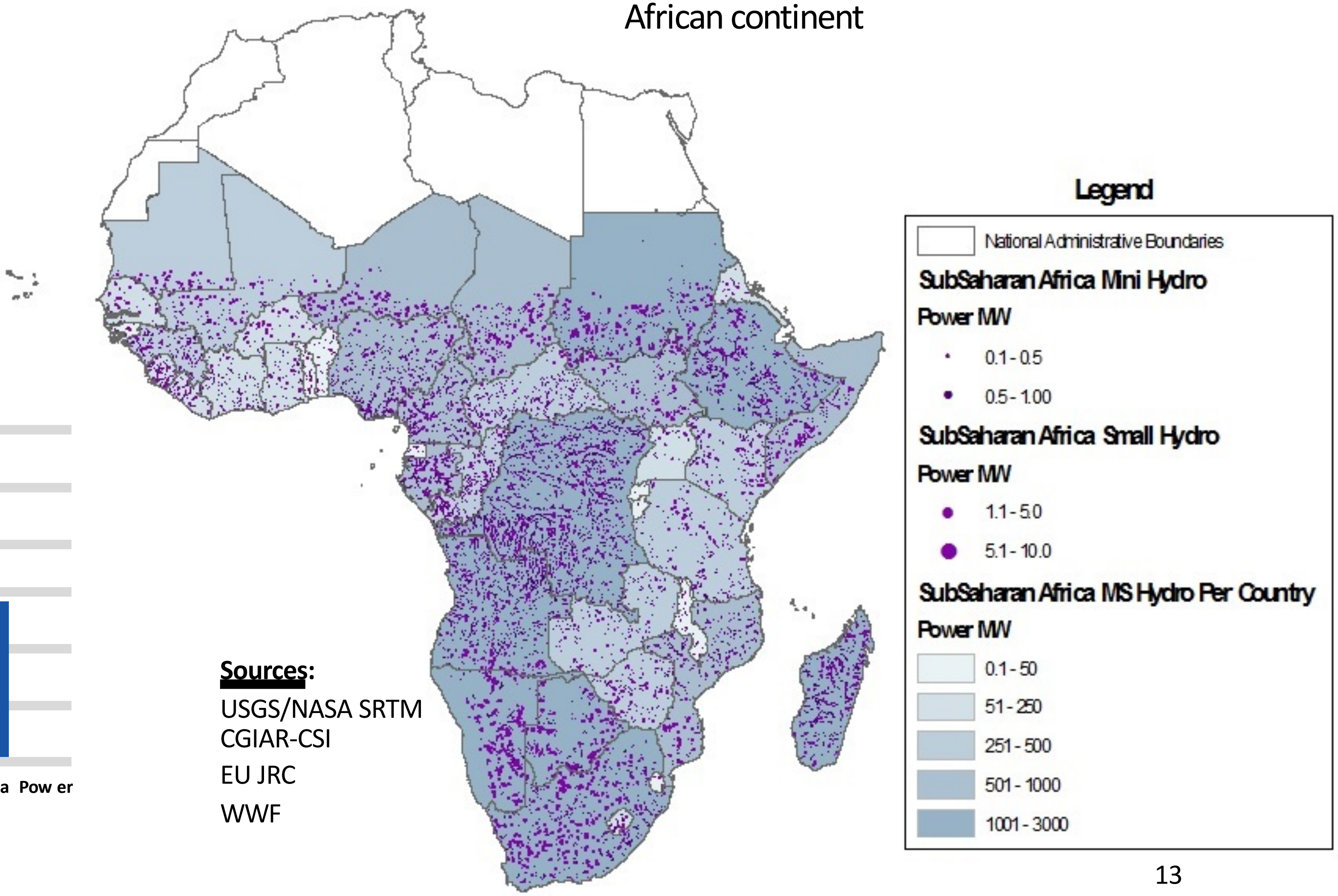
Table 3. Summary of mini/small hydropower potential in different African regions.

	MW
CENTRAL AFRICA	5,721
EASTERN AFRICA	5,699
SOUTHERN AFRICA	9,917
WESTERN AFRICA	3,884
TOTAL	25,221

Total Hydropower Potential for capacities < 10 MW



Hydropower potential map of the African continent



Sources:
USGS/NASA SRTM
CGIAR-CSI
EU JRC
WWF

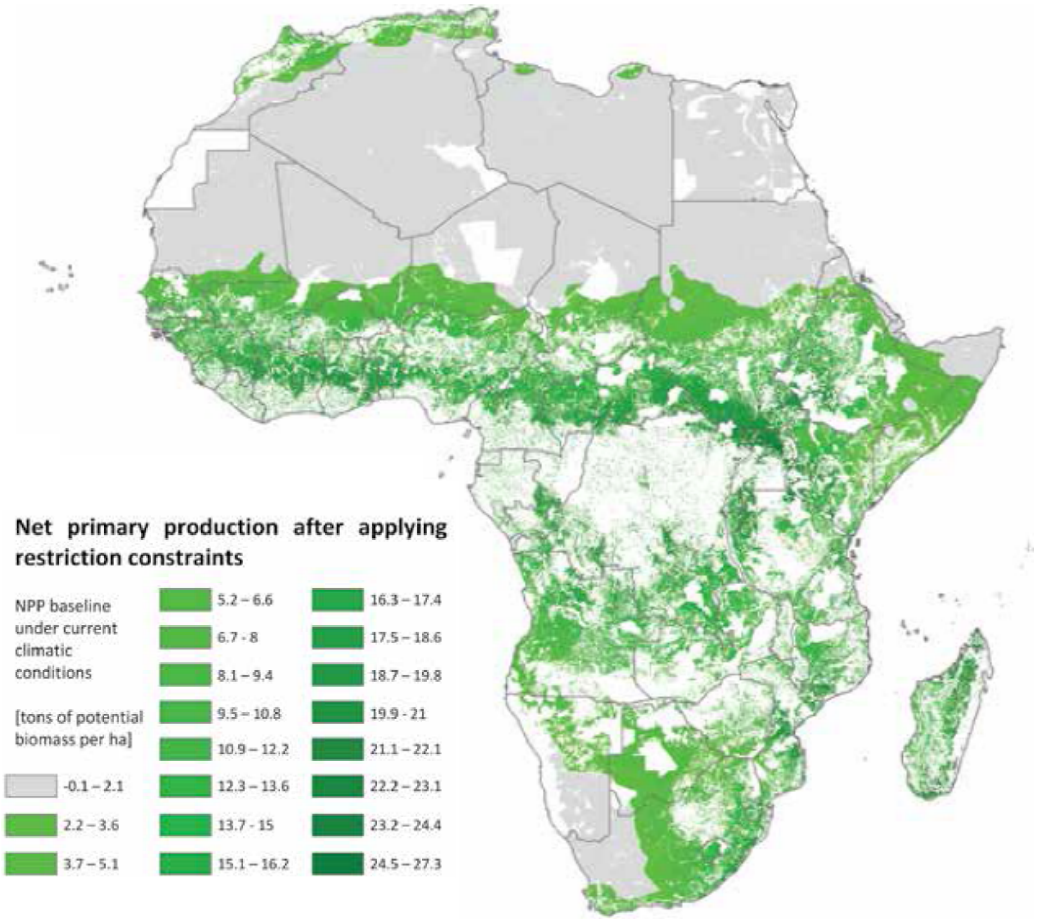
Spatial Bio-Energy availability

Table 4. Summary of sugarcane based bioethanol production in different African regions.

Region	Million litres			
	Rain-fed		Irrigated	
	>2 ton/ha	>4 ton/ha	>2 ton/ha	>4 ton/ha
Central Africa	41 901	1 172	91 734	18 472
Eastern Africa	21 715	5 200	157 932	83 272
Northern Africa	-	-	4 252	238
Southern Africa	21 325	9,085	172 344	100 226
Western Africa	10 652	218	58 617	7 616
TOTAL	95 593	15 675	484 879	209 825

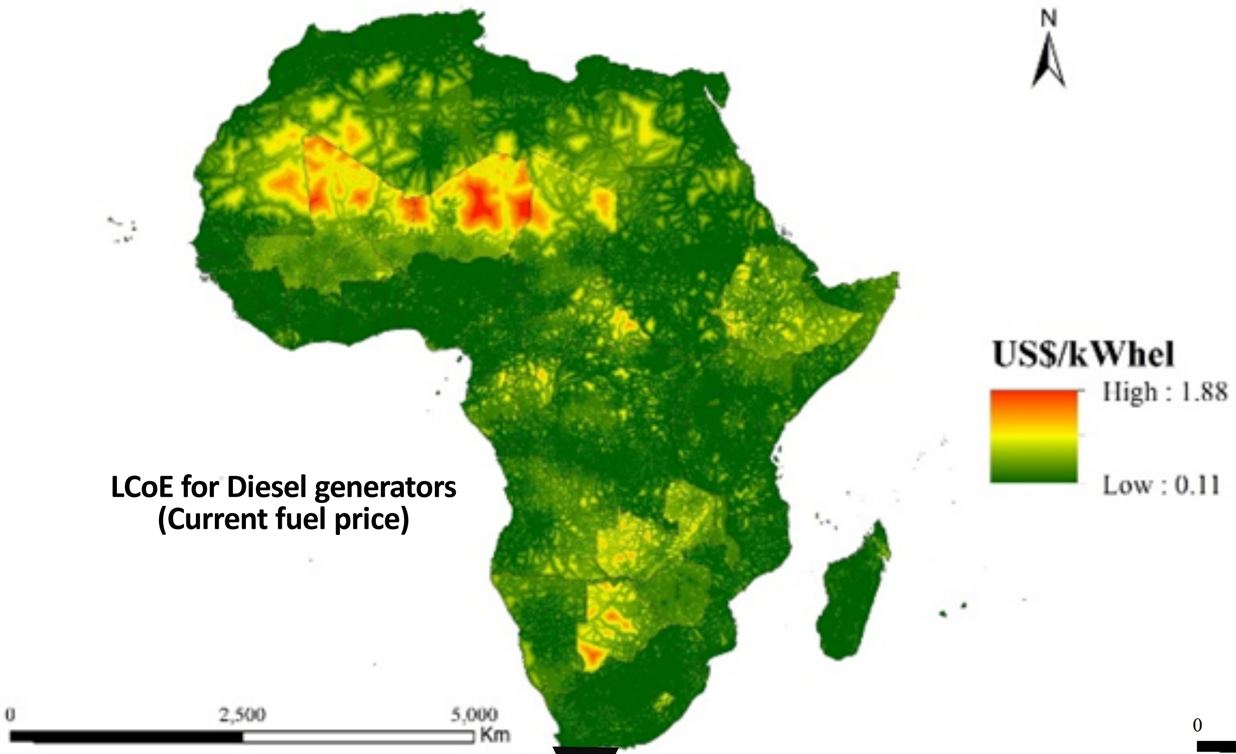
Table 5. Summary of land areas for Jatropha and soybean crops with yields over 2 tons/ha.

Region	Thousand ha	
	Jatropha	Soybean
	>2 tons/ha	>2 tons/ha
Central Africa	59	430
Eastern Africa	59	3 982
Northern Africa	-	-
Southern Africa	1 373	8 269
Western Africa	-	2 234
TOTAL	1 491	14 915

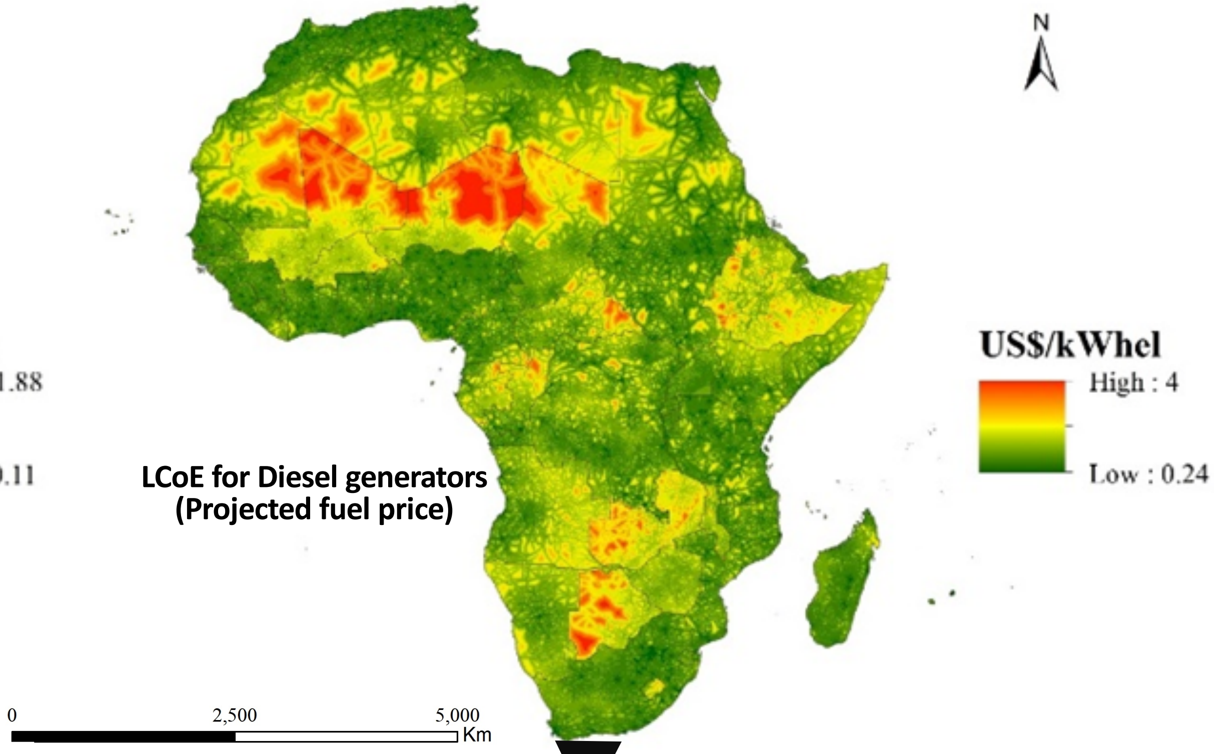


Source: IIASA - GAEZ – Global Agro-Ecological Zoning

Spatial Diesel LCoE



LCoE for Diesel generators (Current fuel price)



LCoE for Diesel generators (Projected fuel price)

~~Current diesel price*~~

Coastal countries	Land-locked countries
0.34 $/l	0.34-0.36 $/l

<

~~Projected diesel price**~~

Coastal countries	Land-locked countries
0.82 $/l	0.82-0.85 $/l

* According to the current crude oil price of 47 $/barrel

** According to the projected crude oil price of 113 $/barrel

3. Electrification analysis using GIS

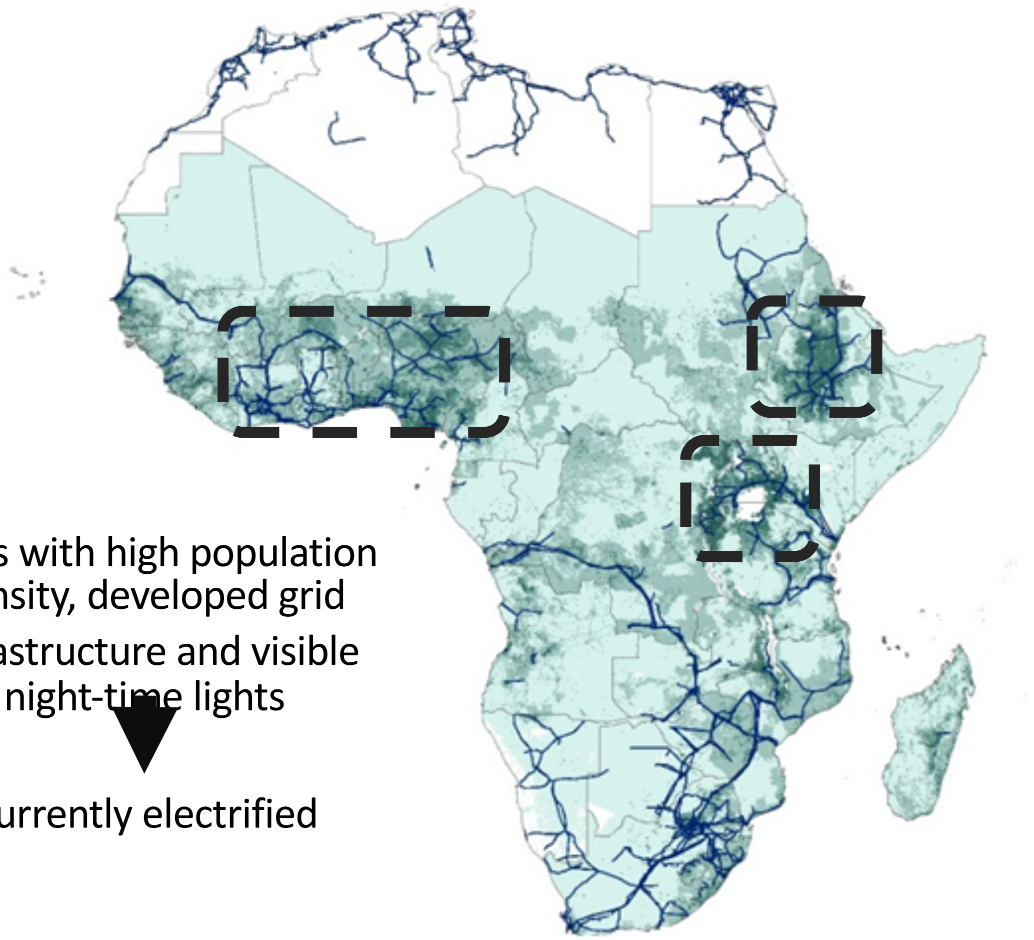
Specific objective: Summarize the steps to analyse the electrification status of countries and regions using GIS

I. Current electrification status (2015)

Geographically identify the currently un-electrified population by combining and analysing various geospatial datasets:

- Administrative boundaries
- Night-time light
- **Transmission network**
- Power plants
- Road network
- **Population distribution**

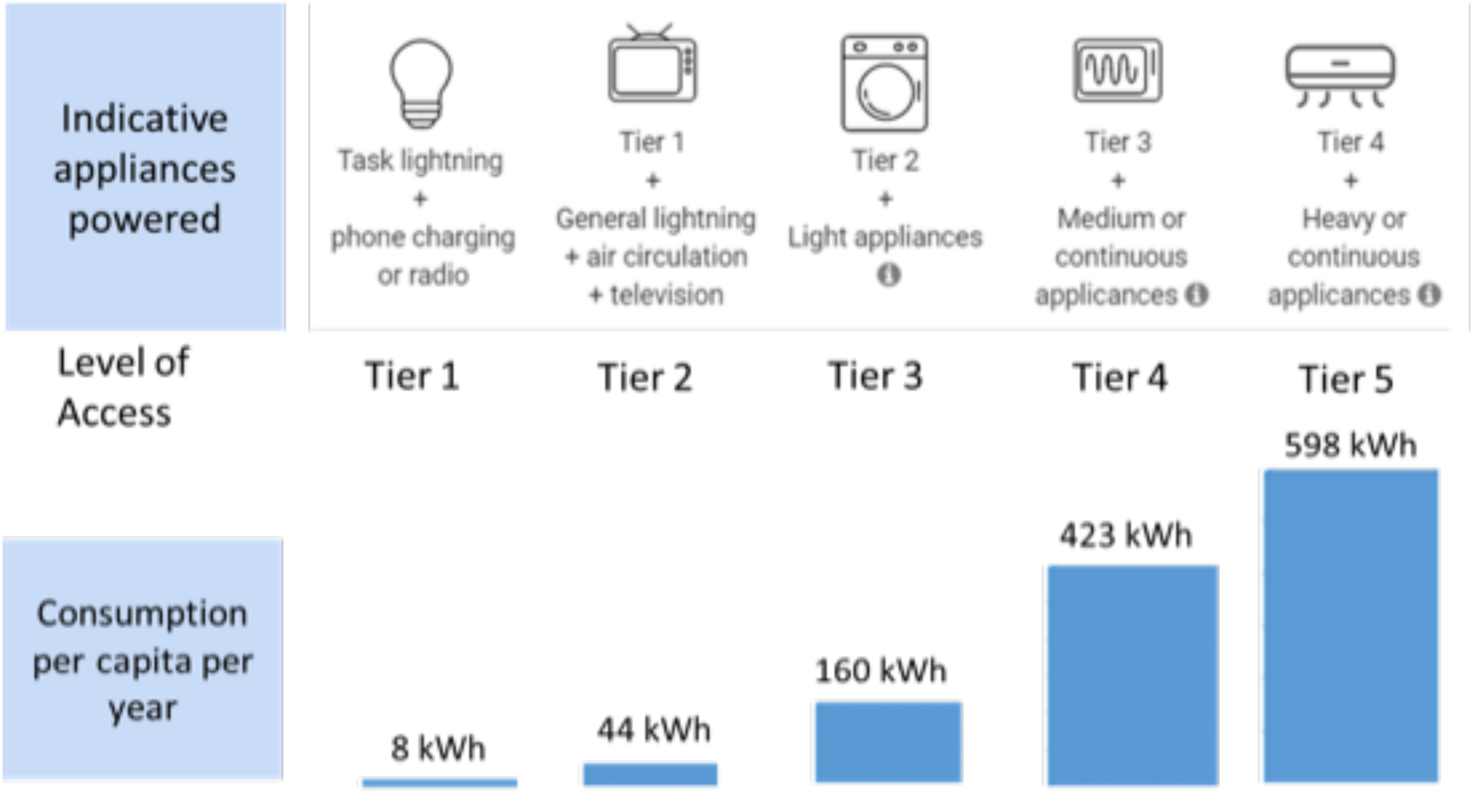
Current population and transmission network



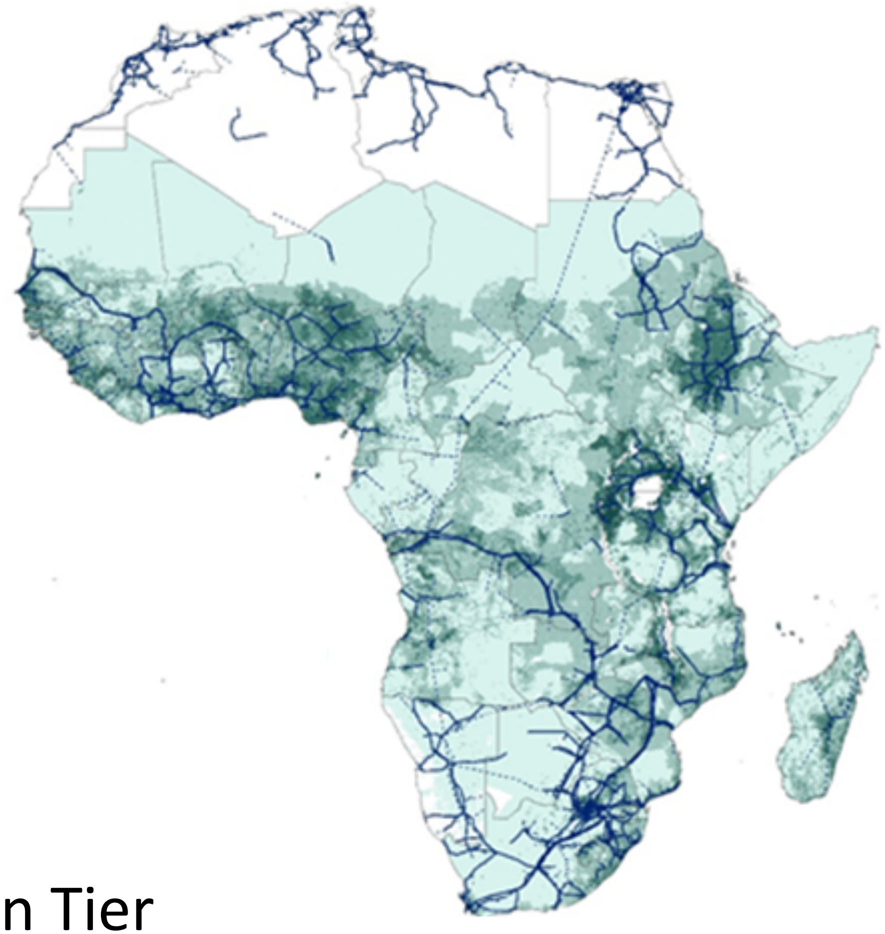
Areas with high population density, developed grid infrastructure and visible night-time lights

Currently electrified

II. Identify future electricity demand (2030)

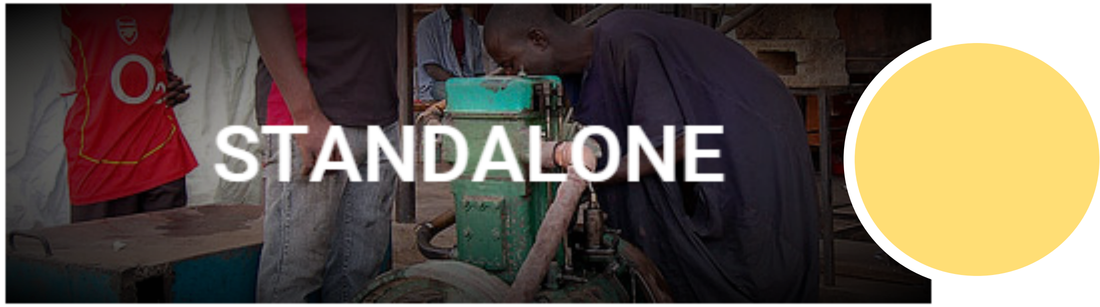


Projected population and transmission network



Electricity Demand = Population * Electrification Tier

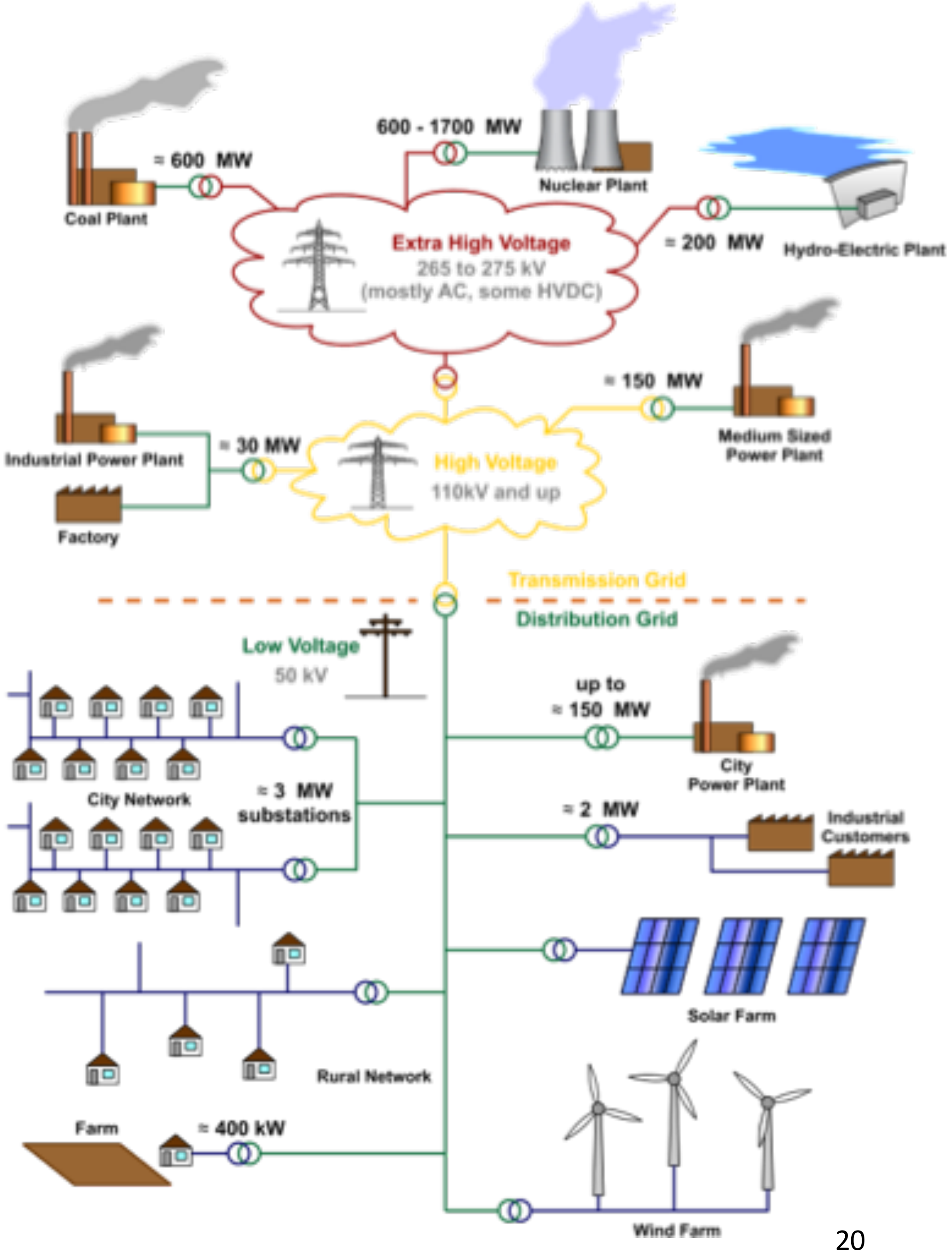
III. Electrification options



III. Electrification options (a)

Grid extension

- Centralized electricity generation
- Transmission of electricity with HV – MV lines
- Distribution of electricity with MV – LV lines



III. Electrification options (b)

Mini-grids

- Utilization of locally available energy resources backed or diesel fueled gensets
- No transmission costs – modest distribution costs
- Renewable energy sources involve battery storage
- Distribution of electricity with MV – LV lines

Example of rural electrification with small hydropower

or

or

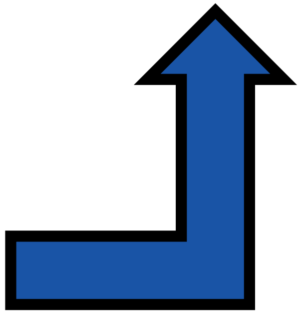
or

Photovoltaic (PV)

Small/Mini Hydro

Wind turbine

Diesel Generator



III. Electrification options (c)

Stand alone systems

- Utilization of locally availably solar energy or diesel gensets
- Supplying lower demand levels at single households
- No transmission and distribution networks required
- PV only may involve battery storage

Photovoltaic (PV)

or

Diesel Generator

III. Electrification options

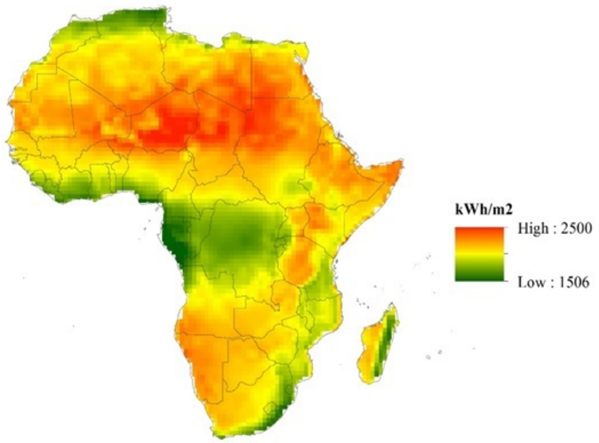
Mini grid options

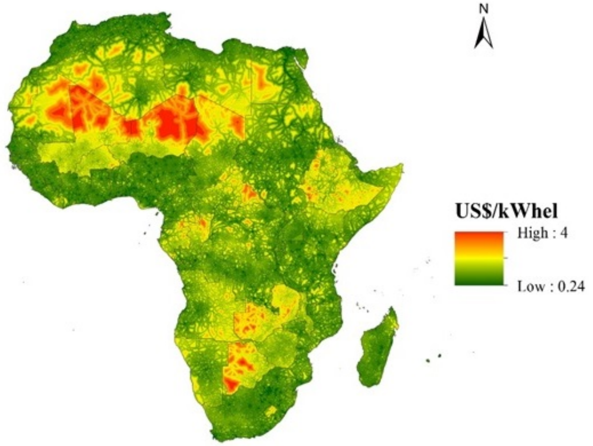
Solar

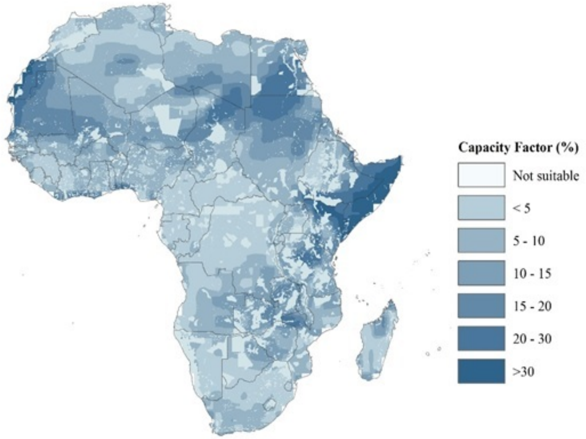
Diesel

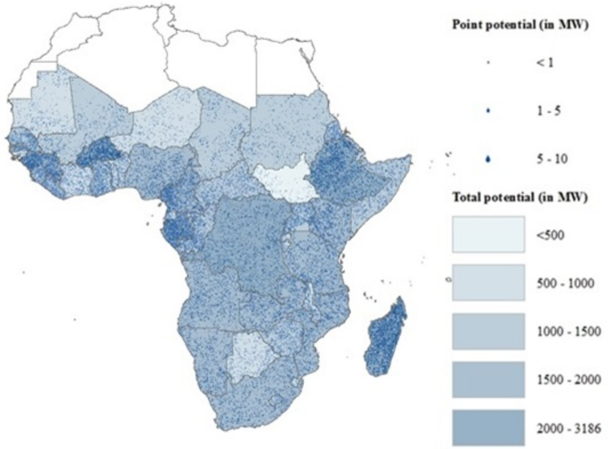
Wind

Hydro









Stand alone options

Levelized Cost of generating Electricity (LCoE)

The LCOE from a specific source represents the final cost of electricity required for the overall system to breakeven over the project lifetime.

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + O\&M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

I_t: Investment expenditure for a specific system in year *t*,

$O\&M_t$: *the o*peration and maintenance costs

F_t: the fuel expenditures,

E_t :the generated electricity,

r: the discount rate,

n: the lifetime of the system.

III. Electrification options

Goal: Access to Electricity for All by 2030

7 electrification technologies that fall within 3 main electrification options and 5 different demand levels (Tiers)

- Grid → higher electricity consumption levels and close to the planned transmission network
- Mini Grid (Wind Turbines, Solar PVs, Mini/Small Hydro, Diesel Gensets)→mini grids can provide affordable electricity to remote population with low-medium electricity consumption habits
- Stand Alone (Solar PVs, Diesel Gensets) → for remote, low populated areas with limited electricity consumption needs

Electrification Results

Tier 1 (lighting)

Electricity access kWh/capita/year

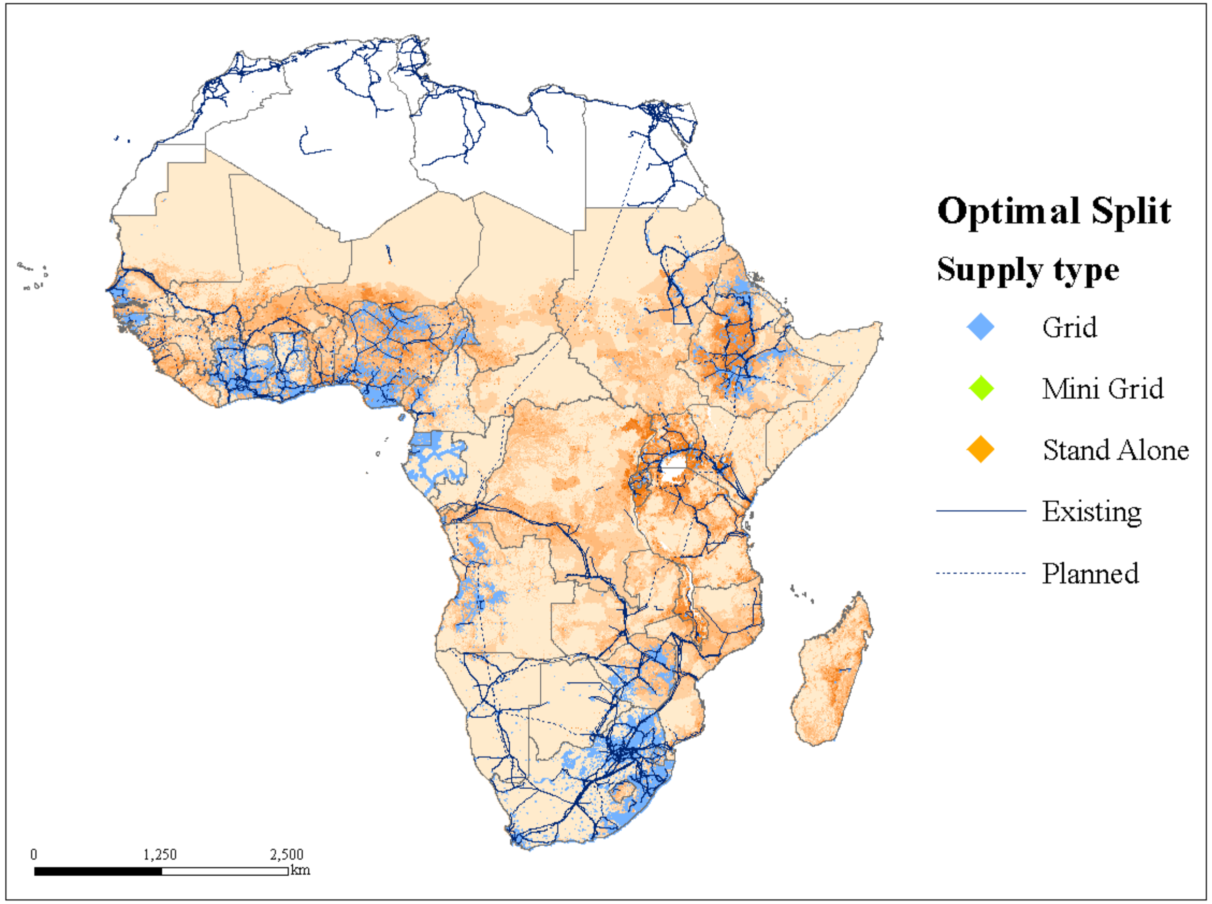
8

44

160

423

598



Technology split

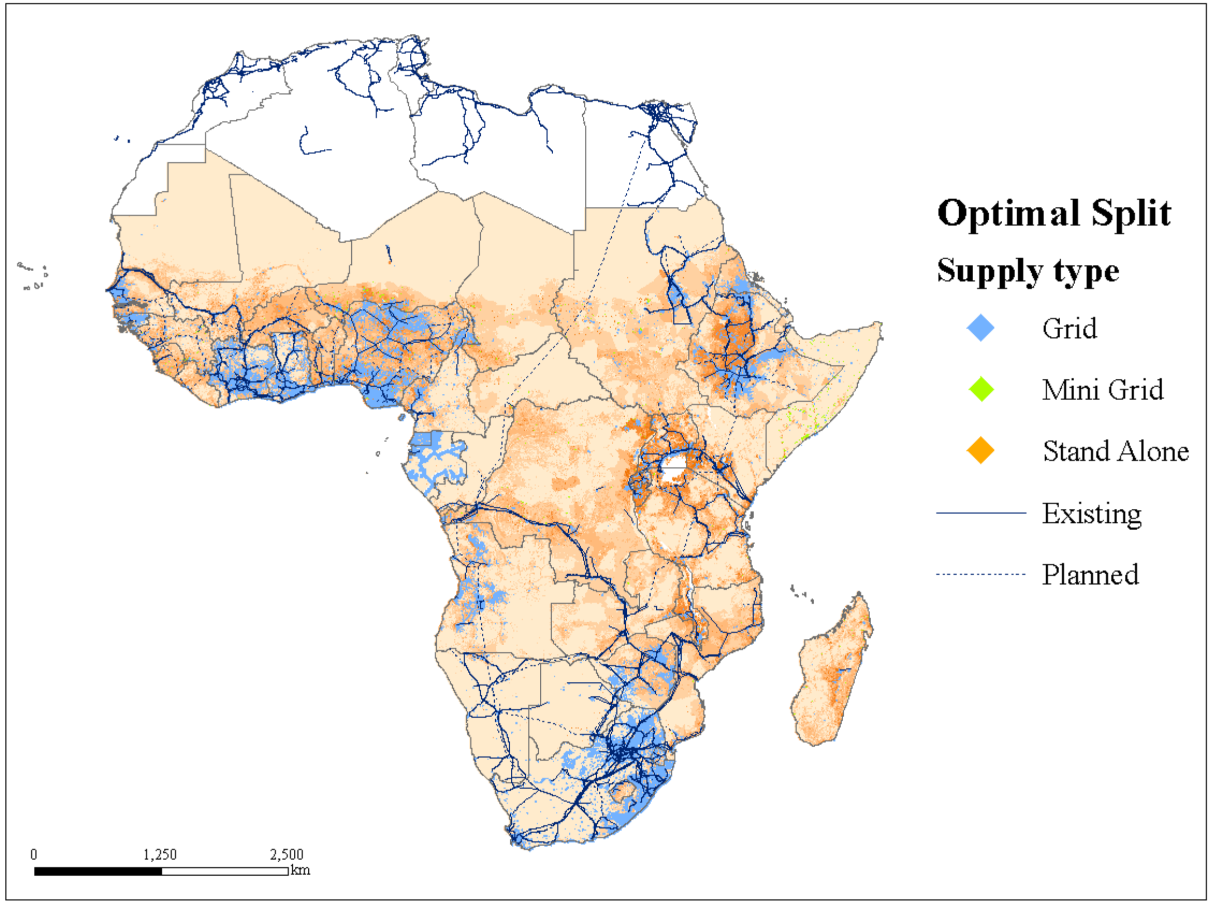
Grid extension:	**19.8%**
Mini-grid:	**0%**
PV	
Diesel	
Wind	
Hydro	
Stand-alone:	**80.2%**
PV	93.9%
Diesel	6.1%

Electrification Results

Tier 2 (lighting)

Electricity access kWh/capita/year

- 8
- **44**
- 160
- 423
- 598



Technology split

Grid extension:	**28.4%**
Mini-grid:	**0.4%**
PV	25.3%
Diesel	0.7%
Wind	27.1%
Hydro	46.8%
Stand-alone:	**71.3%**
PV	96.1%
Diesel	3.9%

Electrification Results

Tier 3 (lighting)

Electricity access
kWh/capita/year

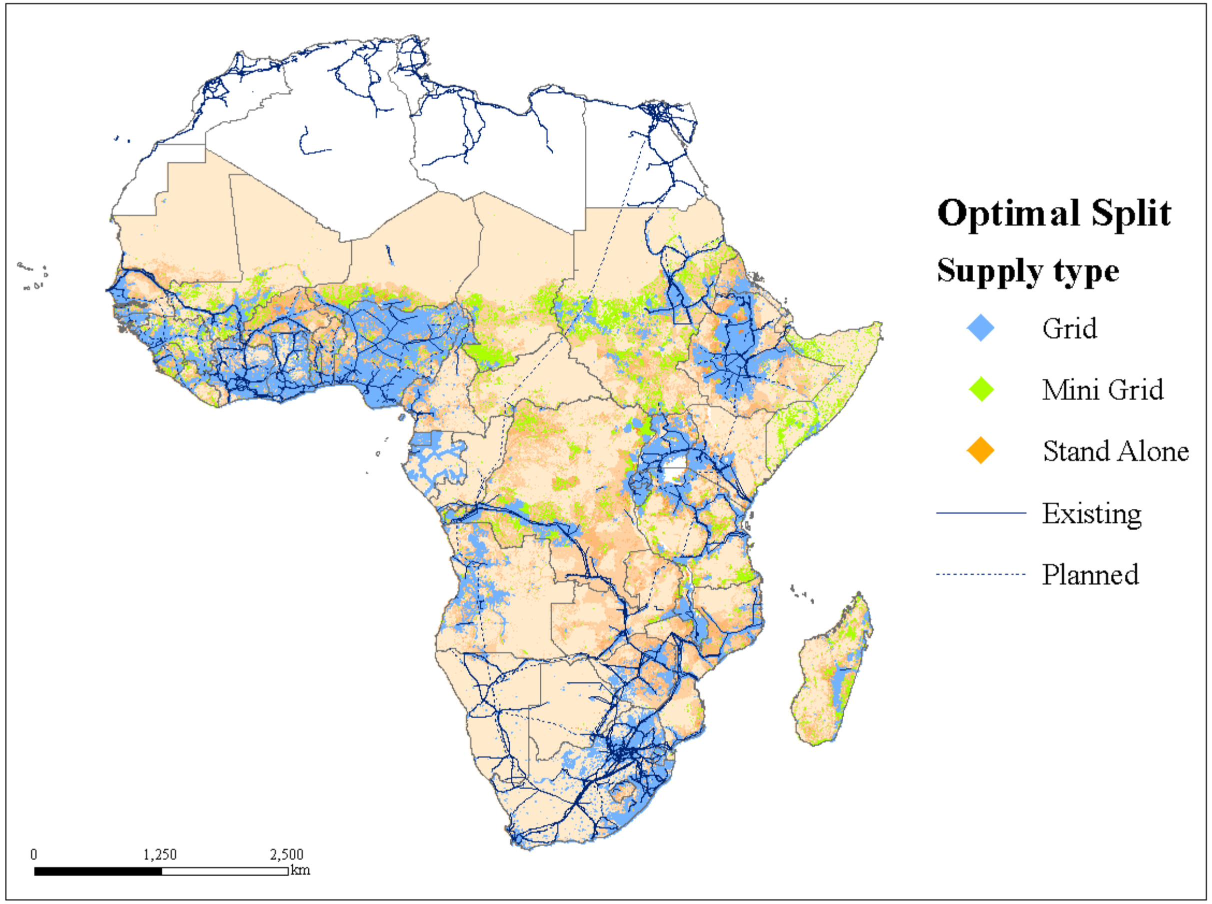
 8

 44

 **160**

 423

 598



Technology split

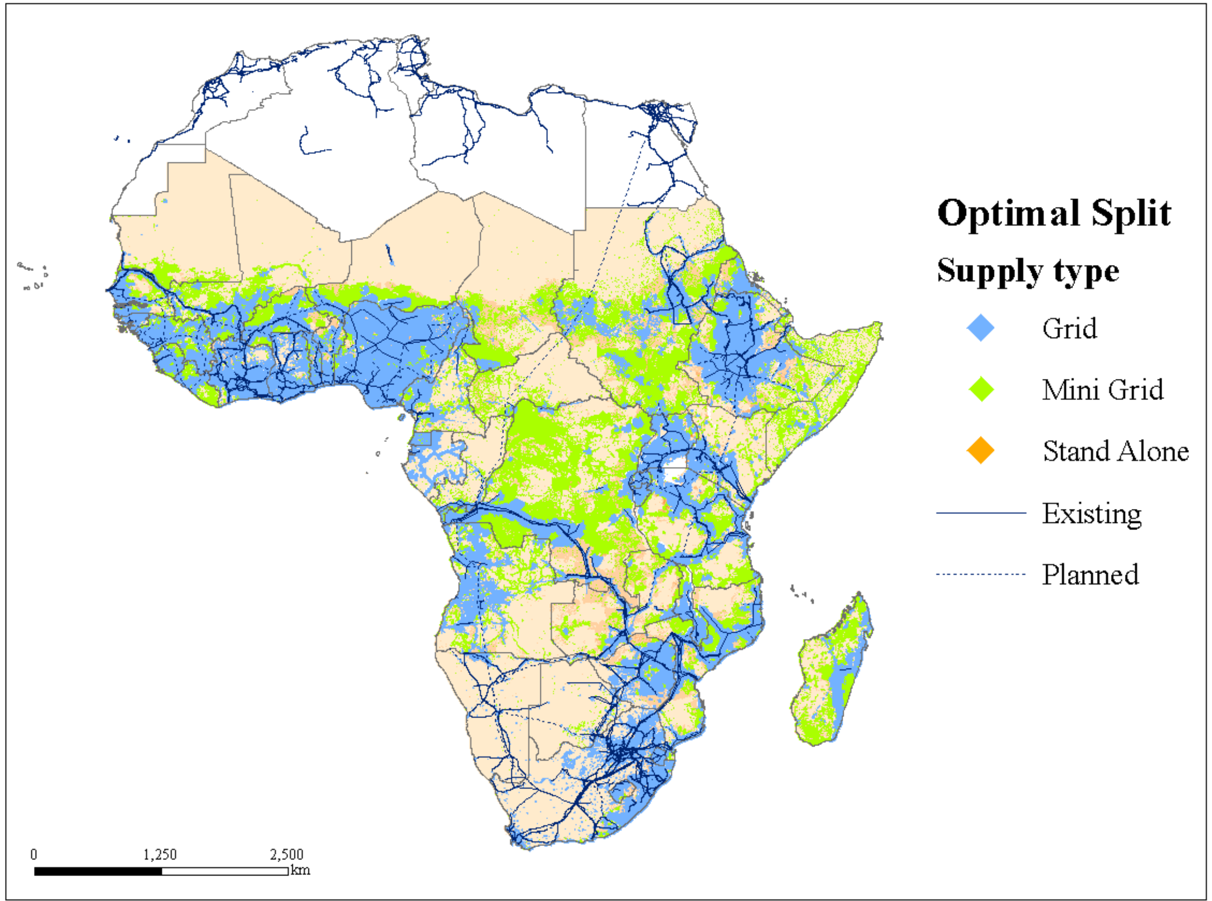
Grid extension:	**60.8%**
Mini-grid:	**4.5%**
PV	82.7%
Diesel	4.8%
Wind	5.5%
Hydro	7.0%
Stand-alone:	**34.7%**
PV	97.8%
Diesel	2.2%

Electrification Results

Tier 4 (lighting)

Electricity access kWh/capita/year

(lighting)	8
(TV)	44
(washing machine)	160
(microwave)	**423**
(air conditioner)	598



Technology split

Grid extension:	**74.9%**
Mini-grid:	**12.9%**
PV	87.7%
Diesel	6%
Wind	3.4%
Hydro	2.9%
Stand-alone:	**12.2%**
PV	98.9%
Diesel	1.1%

Electrification Results

Tier 5 (lighting)

Electricity access kWh/capita/year

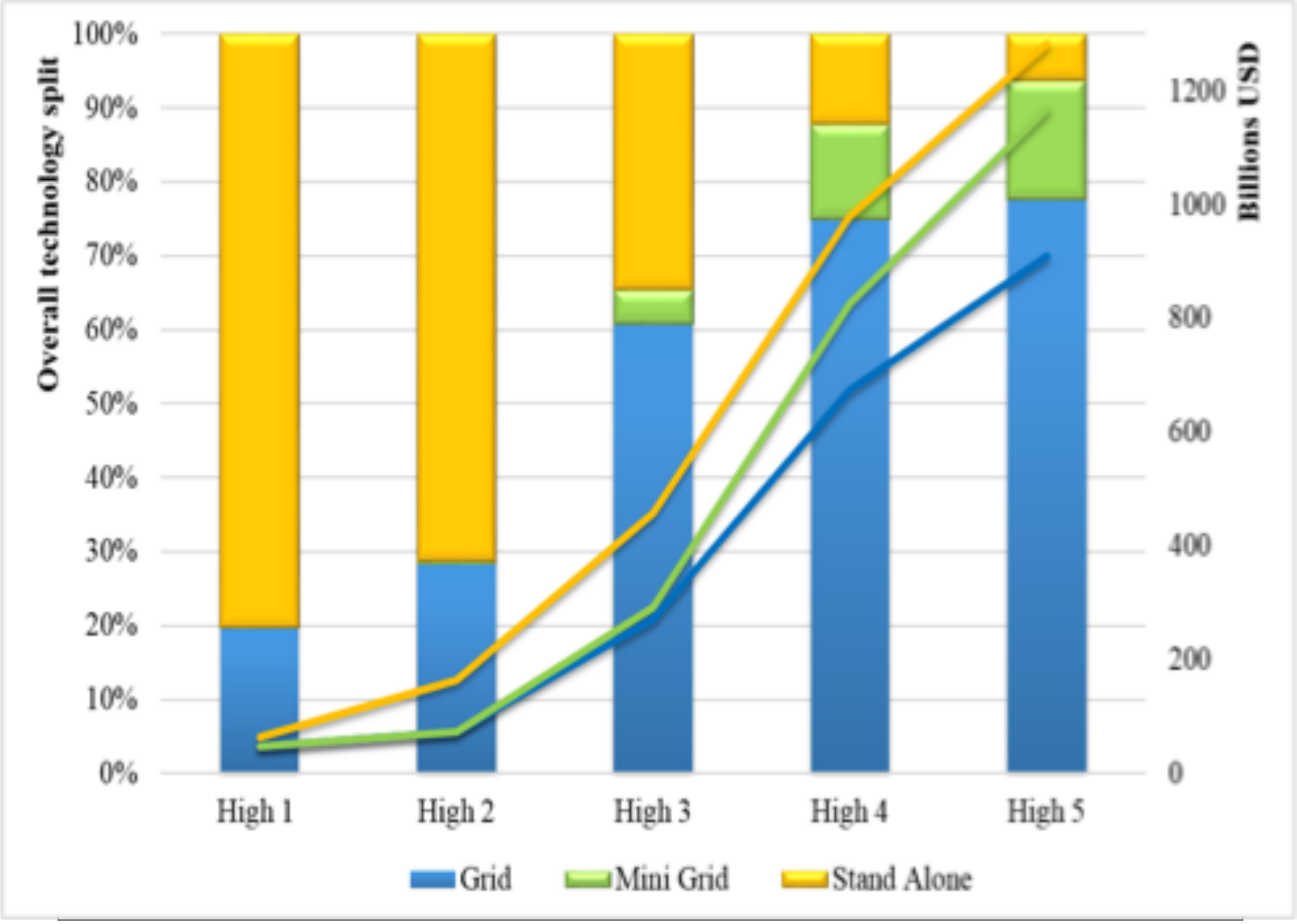
 8

 44

 160

 423

 598



Technology split

Grid extension:	**77.5%**
Mini-grid:	**16.1%**
PV	87.8%
Diesel	6.7%
Wind	3.1%
Hydro	2.3%
Stand-alone:	**6.4%**
PV	99%
Diesel	1%

Electrification Results – Interpretation

- **Grid extension** is favourable in areas with high population density and distance close (<50 km) to the grid network.
- The **diesel price** affects significantly the electrification mix. Lower prices favour diesel gensets while higher prices favour mainly PV systems.
- **Hydro** and **Wind** based mini-grid solutions appear usually in areas where these resources are available and are little affected by diesel prices.
- Increased electricity demand (Tier 1 → Tier 5) moves gradually the least cost option from **Stand-alone** → **Mini-Grid** → **Grid**.

Electrification Results – Limitations

- **Shows only end state**: the analysis ignored the dynamic expansion over time
- The country specific **grid based generation mix** has not been considered in detail in this analysis.
- **Hybrid technologies** (such as Wind + Diesel configurations etc) are not yet considered.
- **Various resolutions**: the resolution of various datasets differs (e.g. Population density data are given at 1 km whilst the wind speed at ca 50 km)
- **Residential electrification**: the analysis considers only household electrification. Other productive uses of electricity should also be taken into account.
- **Homogeneous consumption levels** across the studied area

5. ONSSET – OpeN Source Spatial Electrification Toolkit

Specific objective: Introduce an Electrification Toolkit

ONSSET – Open Source Spatial Electrification Toolkit

- An **Open Source** electrification tool that
- Bottom up optimization model
- Identifies the **least cost** technological option for un-served areas
  - Extension of the national grid network
  - Mini-grid systems (Hydro, PV, Wind turbines, Diesel gensets)
  - Stand-alone systems (PV, Diesel gensets)
- Aiming at ensuring full access to **affordable**, **reliable**, **sustainable** and **modern** electricity for all by 2030

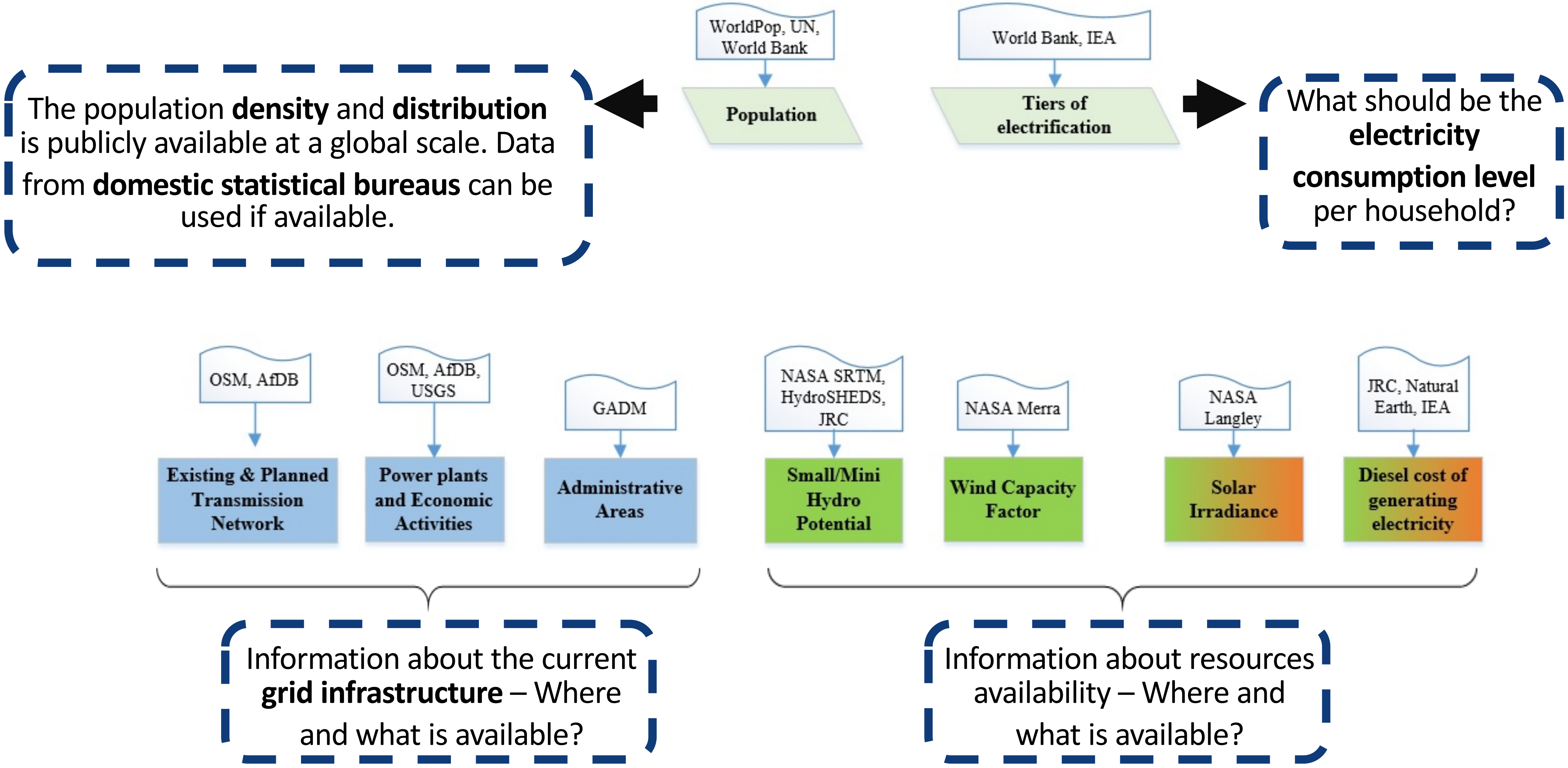
ONSSET – Open Source Spatial Electrification Toolkit

- ✓ Based on **Python** and **ArcGIS**
- ✓ Developed in **6** steps
- ✓ Country specific electrification analyses (**National** – **subnational** level)
- ✓ Better resolution (grid cell size starting from **1 km**)
- ✓ **Customize inputs** according to country specific characteristics
    - Social indicators (population growth, urbanization level, different demand patterns etc.)
    - Technical factors (T&D losses for national grid, alternative technologies available etc.)
    - Cost elements (Investment cost – O&M – Fuel etc.)
    - Energy Access targets

ONSSET in 6 Steps

Step 1. Acquire the necessary GIS data for the area of interest

A GIS environment (ArcGIS, QGIS, GRASS) is required



Step 1. Acquire the necessary GIS data for the area of interest

#	Dataset	Type
1	Population density & distribution	Raster
2	Administrative boundaries	Raster
3	Existing grid network	Line shapefile
4	Substations	Point shapefile
5	Power plants	Point shapefile
6	Mines & Queries	Point shapefile
7	Roads	Line shapefile
8	Planned grid network	Line shapefile

#	Dataset	Type
9	Nighttime lights	Raster
10	GHI	Raster
11	Wind speed	Raster
12	Hydro power potential	Point shapefile
13	Travel time	Raster
14	Elevation Map	Raster
15	Slope	Raster
16	Land Cover	Raster

GIS data requirements may vary depending on the objective of the electrification study

Step 1. Acquire the necessary GIS data for the area of interest

#	Dataset	Type	Purpose of Use in the ONSSET analysis
1	Population density & distribution	Raster	Spatial identification and quantification of the current (base year) population. This dataset sets the basis of the ONSSET analysis as it is directly connected with the electricity demand and the assignment of energy access goals.
2	Administrative boundaries	Raster	Includes information (e.g. name) of the country(s) to be modelled and delineates the boundaries of the analysis.
3	Existing grid network	Line shapefile	Used to identify and spatially calibrate the currently electrified/non-electrified population.
4	Substations	Point shapefile	Current Substation infrastructure used to identify and spatially calibrate the currently electrified/non-electrified population. It is also used in order to specify grid extension suitability.
5	Power plants	Point shapefile	Current/Future power plant infrastructure used to identify and spatially calibrate the currently electrified/non-electrified population. It is also used in order to specify grid extension suitability.
6	Mines & Queries	Point shapefile	Being very important in electrification processes, mines are usually used in order to specify grid extension suitability.
7	Roads	Line shapefile	Current Road infrastructure used to identify and spatially calibrate the currently electrified/non-electrified population. It is also used in order to specify grid extension suitability.
8	Planned grid network	Line shapefile	Represents the future plans for the extension of the national electric grid. It also includes extension to current/future substations, power plants, mines and queries.
9	Nighttime lights	Raster	Dataset used to identify and spatially calibrate the currently electrified/non-electrified population.
10	GHI	Raster	Provide information about the Global Horizontal Irradiation (kWh/m^2/year) over an area. This is later used to identify the availability/suitability of Photovoltaic systems.
11	Wind speed	Raster	Provide information about the wind velocity (m/sec) over an area. This is later used to identify the availability/suitability of wind power (using Capacity factors).
12	Hydro power potential	Point shapefile	Points showing potential mini/small hydropower potential. Dataset developed by KTH dESA including environmental, social and topological restrictions and provides power availability in each identified point. Other sources can be used but should also provide such information to reassure the proper model function.
13	Travel time	Raster	Visualizes spatially the travel time required to reach from any individual cell to the closest town with population more than 50,000 people.
14	Elevation Map	Raster	Filled DEM maps are use in a number of processes in the analysis (Energy potentials, restriction zones, grid extension suitability map etc.).
15	Slope	Raster	A sub product of DEM, used in forming restriction zones and to specify grid extension suitability.
16	Land Cover	Raster	Land cover maps are use in a number of processes in the analysis (Energy potentials, restriction zones, grid extension suitability map etc.).

Step 2. Use GIS techniques to extract useful information for the analysis

(the data are transferred to excel)

Grid cell Coordinates

Grid cell distance from the nearest town

Wind power availability in each grid cell

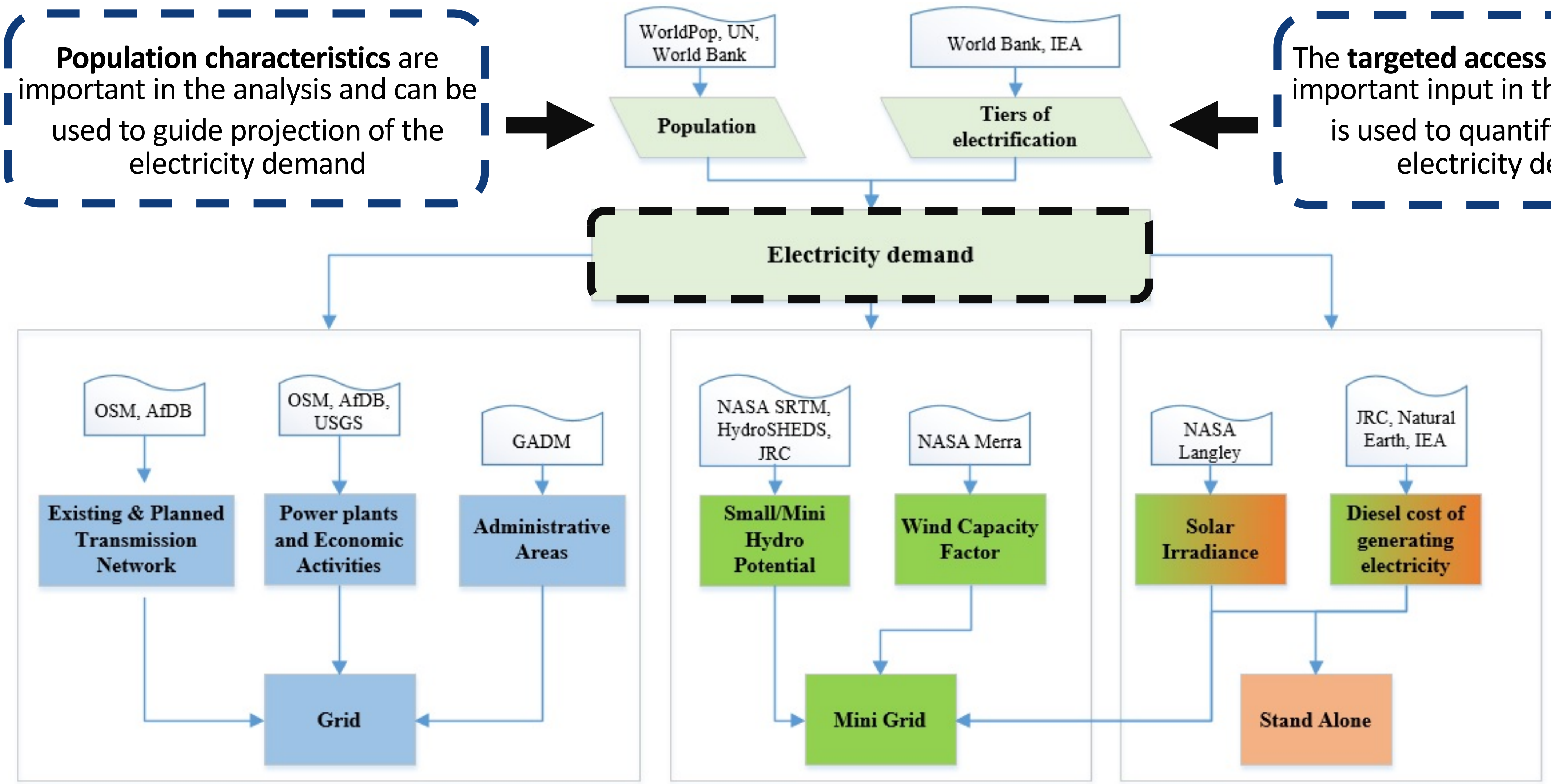
X	Y	Population (2010)	Country	Distance existing (m)	Distance planned (m)	Distance from Roads (m)	GHI (kWh/m2/year)	Travel hours (h)	Diesel current $/kWhel	Diesel future $/kWhel	Capacity Factor (%)
2370166	228283	0	Kenya	243,796	228,416	11,107	1822	1	0.12	0.26	0.0
1907255	-441856	388	Kenya	44,357	44,357	9,712	1827	3	0.14	0.29	3.2
2953836	-904402	2,136	Kenya	141,565	112,059	4,690	2006	4	0.14	0.29	10.1
3155102	-451877	2,139	Kenya	73,645	73,645	20,098	1814	15	0.23	0.51	2.2
2692191	-833762	280,088	Kenya	133	133	5,839	1912	2	0.13	0.28	0.0
1655673	-582265	543,581	Kenya	1,514	403	451	1750	0	0.11	0.24	0.0

Distance from Existing & Planned Transmission Network

LCoE of Diesel gensets under current and projected diesel price

Step 3a. Enter country-specific data (Social)

Population characteristics are important in the analysis and can be used to guide projection of the electricity demand



The **targeted access level** is also an important input in the analysis as it is used to quantify the future electricity demand

Step 3a. Enter country-specific data (Social)

Parameter	Metric	Base Year Value	Value 2030
Population, total	Million Persons	42.542 [1]	**65.412** (medium growth projection) [1]
Urban population	Percent of total population	25 % [2]	**32%** (based on >2000 people/km^2 [6]
Rural population	Percent of total population	75% [2]	**68%**
Urban growth	Percent growth per year	4.34% [3]	4% (assumed value, based on total population 2030)
Rural growth	Percent growth per year	2.14% [3]	2% (assumed value, based on total population 2030)
Electricity access	Percent of total population	**23%** [4]	**100%**[7]
Electricity access, urban	Percent of urban population	58.2% [4]	100% [7]
Electricity access, rural	Percent of rural population	6.8% [4]	100% [7]
People per household, urban	People per household	5 [5]	**4** [8]
People per household, rural	People per household	6.5 [5]	**6.5** [8]

1. UN DESA Population division, 2015
2. United Nations, Department of Economic and Social Affairs, Population Division, 2013
3. UN Statistical division, 2016
4. World Bank, 2016
5. Energy Regulatory Commission, 2011
6. Kenya National Bureau of Statistics, 2010
7. Based on SDG7
8. Energy Regulatory Commission, 2011

Step 3b. Enter country-specific data (Energy Access Target)

Scenarios	Average electricity consumption (2030)	Rural electricity consumption	Urban electricity consumption
Low electricity consumption	~1 000 kWh/household	224 kWh/household	1 800 kWh/household
Medium electricity consumption	~1 500 kWh/household	696 kWh/household	2 195 kWh/household
High electricity consumption	~2 195 kWh/household	2195 kWh/household	2 195 kWh/household

Step 3c. Enter country-specific data (Preparation - Calibration)

Grid cell Coordinates

1: Settlement electrified by grid

0: Settlement un-electrified

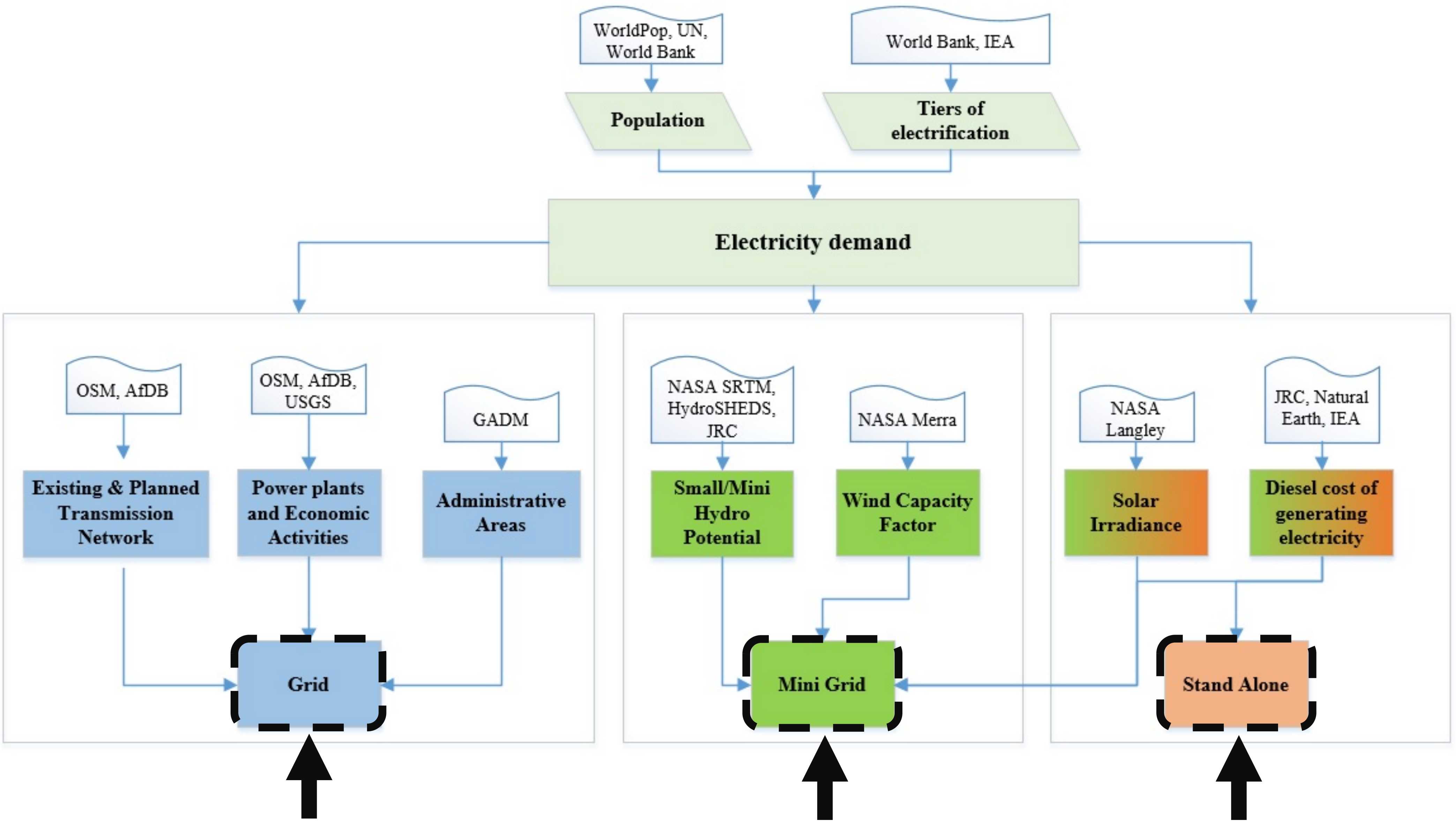
Wind power availability in each grid cell

X	Y	Population (base year)	Country	Status	Population 2030	Distance from Roads (m)	Night time lights	Electrification status	Diesel current $/kWhel	Diesel future $/kWhel	Capacity Factor (%)
2370166	228283	0	Kenya	Rural	0	11,107	1	0	0.12	0.26	0.0
1907255	-441856	388	Kenya	Rural	350	9,712	7	0	0.14	0.29	3.2
2953836	-904402	2,136	Kenya	Urban	2,500	4,690	42	1	0.14	0.29	10.1
3155102	-451877	2,139	Kenya	Rural	1,980	20,098	5	0	0.23	0.51	2.2
2692191	-833762	280,088	Kenya	Urban	295,980	5,839	64	1	0.13	0.28	0.0
1655673	-582265	543,581	Kenya	Urban	620,644	451	67	1	0.11	0.24	0.0

Change in social structures with urbanization – Decreasing population in rural areas

LCoE of Diesel gensets under current and projected diesel price

Step 3d. Enter country-specific data (Technology specifications & Costs)



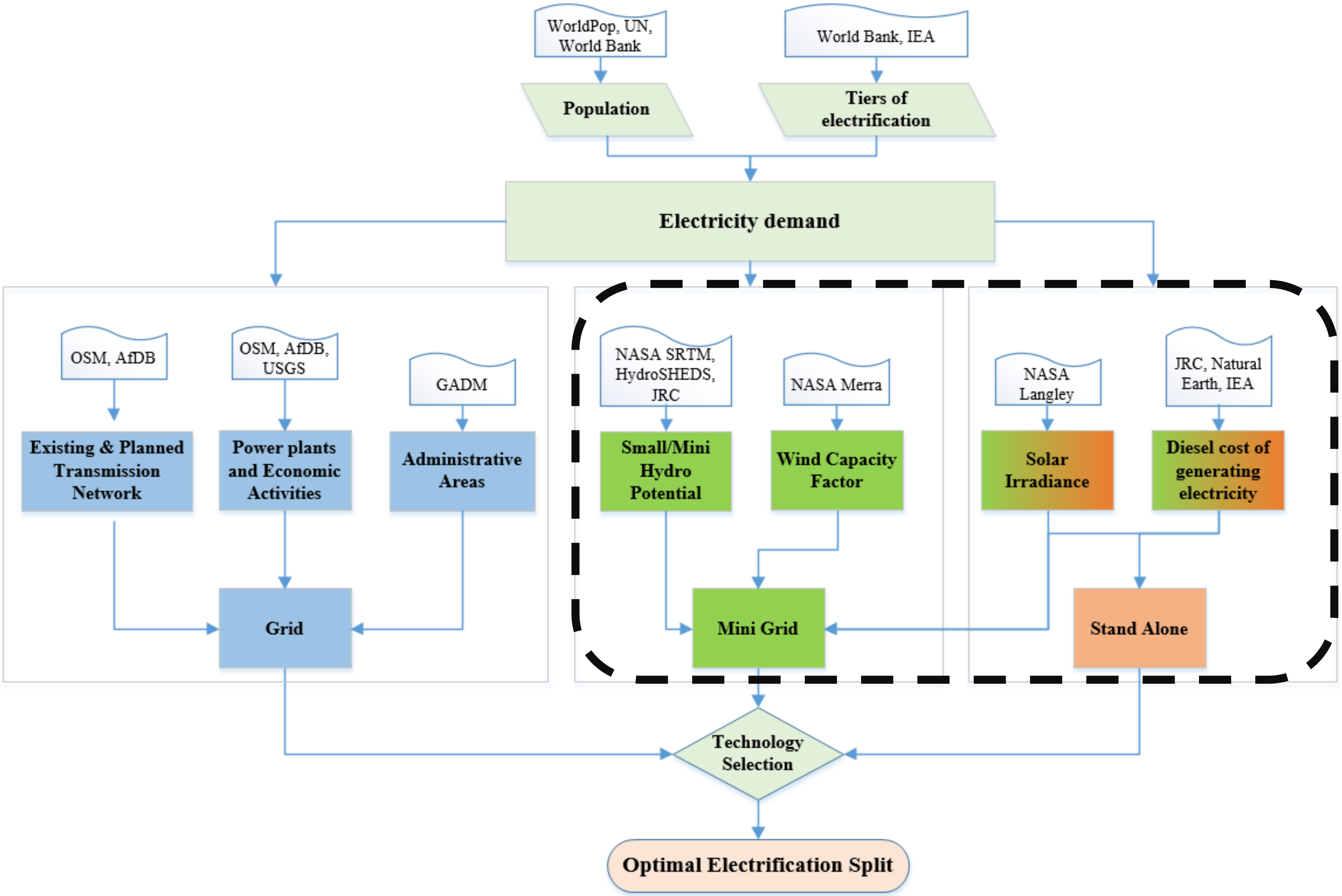
Step 3d. Enter country-specific data (Technology specifications & Costs)

Parameter	Capital cost $/kW	O&M $/kW	Fuel cost $/MWh
PV	2 566 [1]	389 (1.5% of capital cost) [1]	-
Wind	2 500 [2]	50 (assumed 2% of capital cost)	-
Diesel generator, Stand Alone	938 [3]	93 (assumed 10% of capital cost)	173 [4,5]
Diesel generator Mini grid	721 [3]	72 (assumed 10% of capital cost)	173 [4,5]
Mini Small hydro	3 190 [3]	64 (2% of capital cost)	-
Grid LCoE	**0.125 $/kWh**		

Parameter	Capital cost $/km
HV lines (>33kV)	92 823 [6]
MV lines (33 kV)	43 687 [3]
LV lines (220 V)	5 000 [3]
HV/LV transformer	5 000 $ per unit [3]
Transmission loses	18%
Connection cost per HH	$125

1. Adapted from Ondraczek, 2014
2. Adapted from IRENA, 2012
3. Adapted from ESMAP - World Bank
4. Adapted from Ministry of Energy Kenya, 2010
5. Adapted from U.S. Energy Information Administration, 2016
6. Adapted from Energy Regulatory Commission, 2013

Step 4. Calculate technology costs for every settlement in the country



LCoEs achieved per technology per settlement

Settlements (people)	MG Hydro	MG PV	SA PV	MG Diesel	SA Diesel	MG Wind
11000	99.00	**0.16**	0.33	27.49	0.40	99.00
500	99.00	99.00	**0.34**	33.87	0.39	99.00
1300	99.00	99.00	0.33	12.12	**0.31**	99.00
23000	99.00	**0.22**	0.35	22.25	0.42	99.00
25000	**0.16**	21.53	0.34	22.94	0.46	99.00
680	99.00	99.00	**0.35**	27.23	0.47	99.00
15000	99.00	46.68	0.34	50.02	0.67	**0.13**

99 → Not available

Step 4. Calculate technology costs for every settlement in the country

Here is an example of how the different technologies perform under certain assumptions:

- **Energy Access Target:** 1000 kWh/hh/year
- **Distance from the National Electricity grid:** 20 km
- **Global Horizontal Irradiation:** 1500 kWh/m2/year
- **Hydro Availability:** Positive
- **Wind capacity factor:** 40%
- **Diesel price:** 0.345 USD/liter

LCoE Tables

Stand alone systems LCoEs change on later stage according to transportation costs

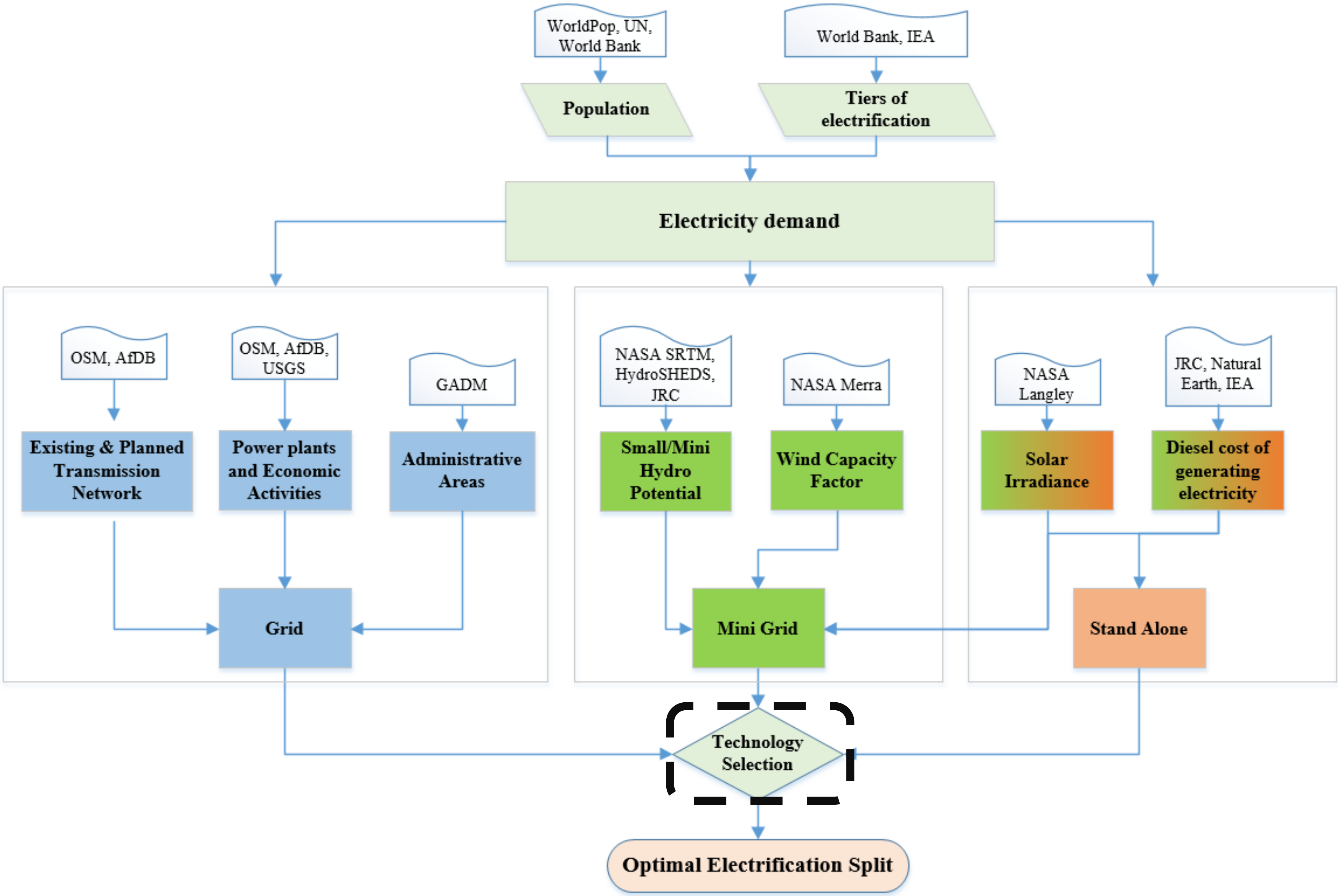
Example of LCoE variation per technology depending on number of people per settlement

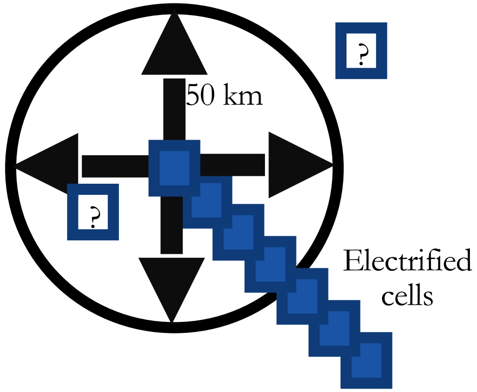
Population	Grid	Mini Grid Wind	Mini Grid Hydro	Mini Grid PV	Mini Grid Diesel	Stand alone PV	Stand alone Diesel
1,000	0.55	0.26	0.30	0.34	0.81	0.36	0.18
2,000	0.41	0.23	0.26	0.31	0.72	0.36	0.18
10,000	0.26	0.18	0.18	0.26	0.68	0.36	0.18
50,000	0.21	0.16	0.16	0.24	0.65	0.36	0.18

Grid LCoE reduces in areas with high population density and proximity to the national grid

Mini-grid LCoEs depend usually on resource availability and fuel costs

Step 5. The electrification algorithm – Grid extension or off-grid?

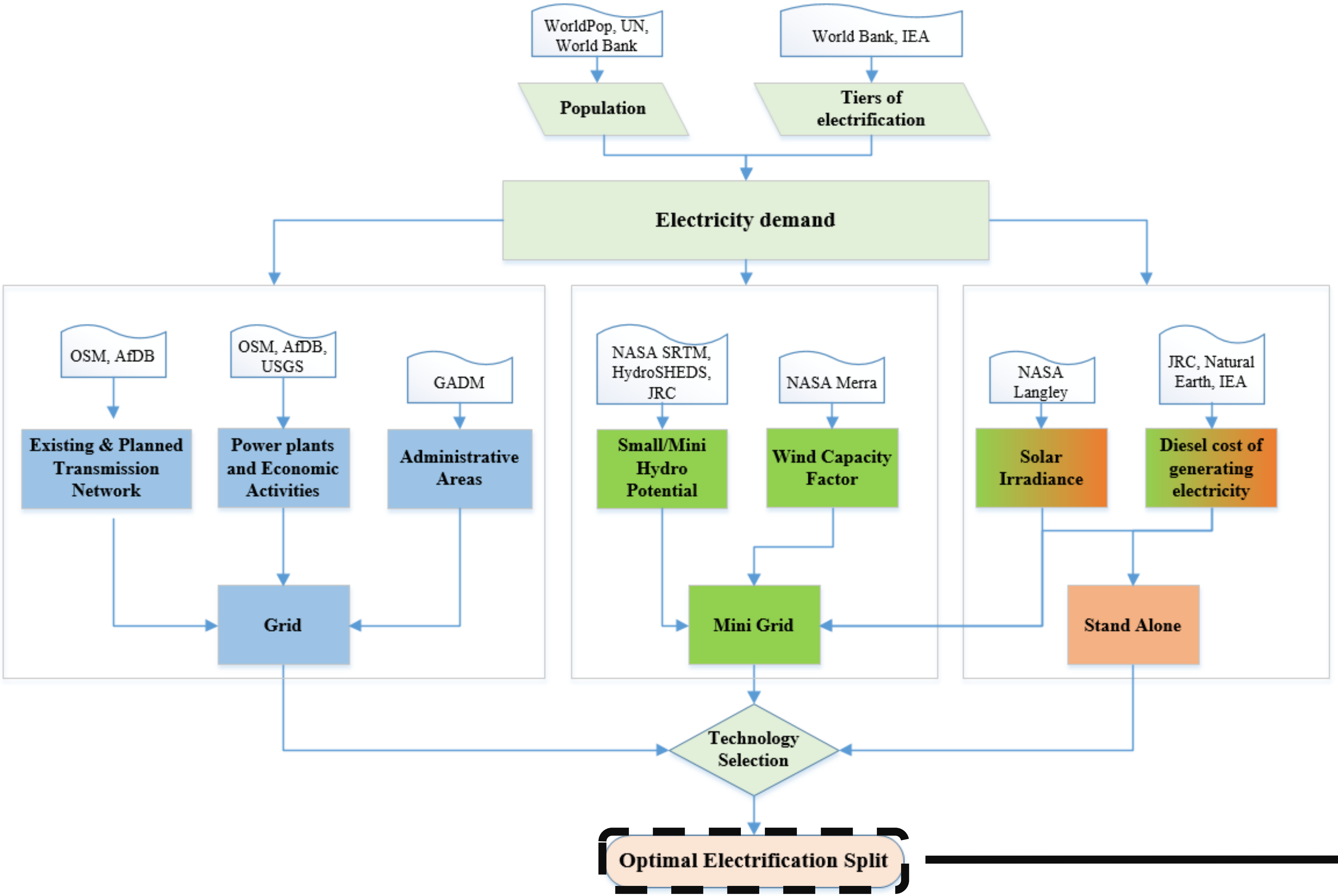




1. Is the total additional MV line less than **50 km**?

2. Is there **adequate amount of people** (thus demand) to justify an extension of the grid?

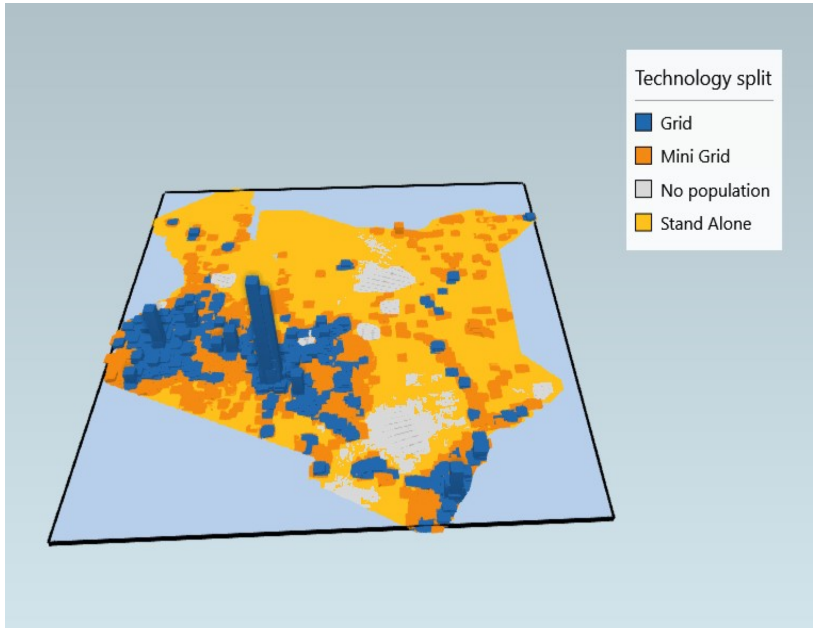
Step 6. Results, Summaries and Visualization



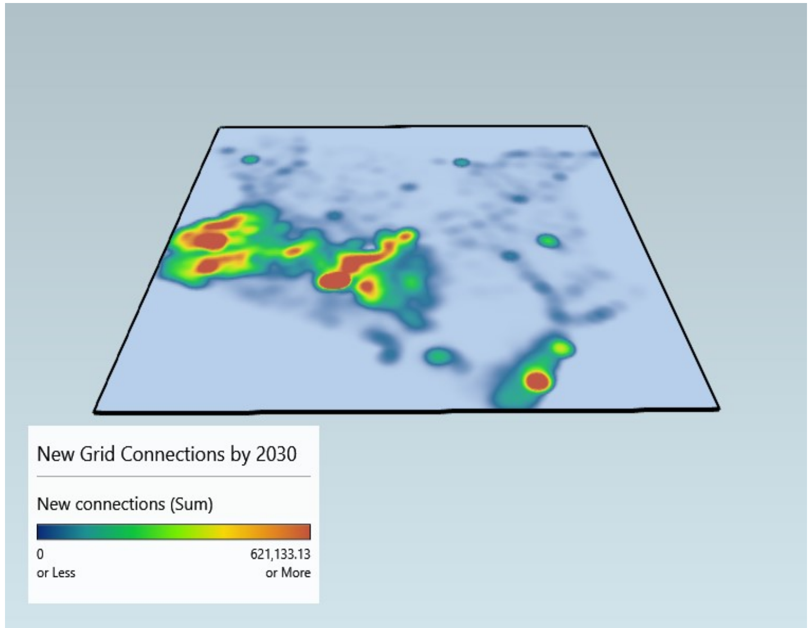
Based on the optimal split identify per technology:

- New connections by 2030
- Additional capacity needed
- Investments requirements

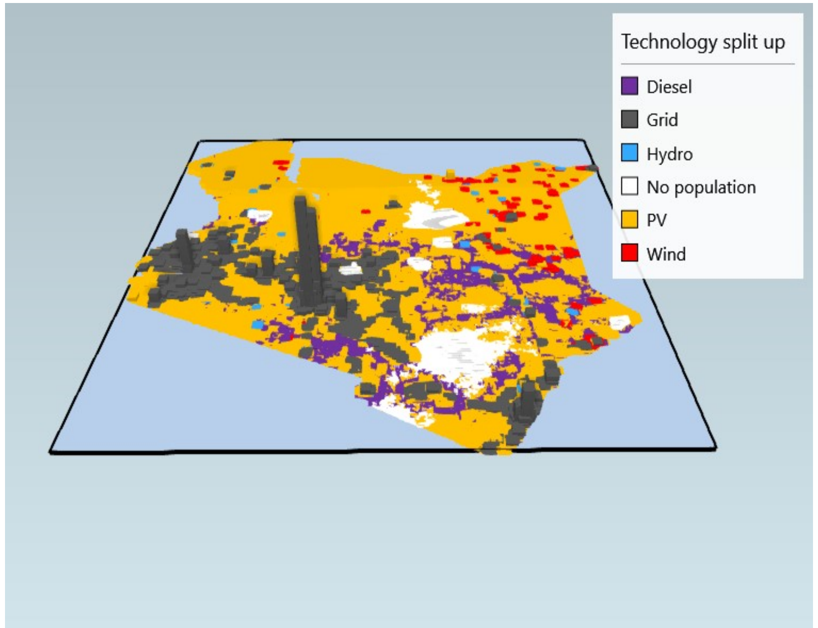
Results Visualization



Household demand Vs Technology spit under High consumption scenario

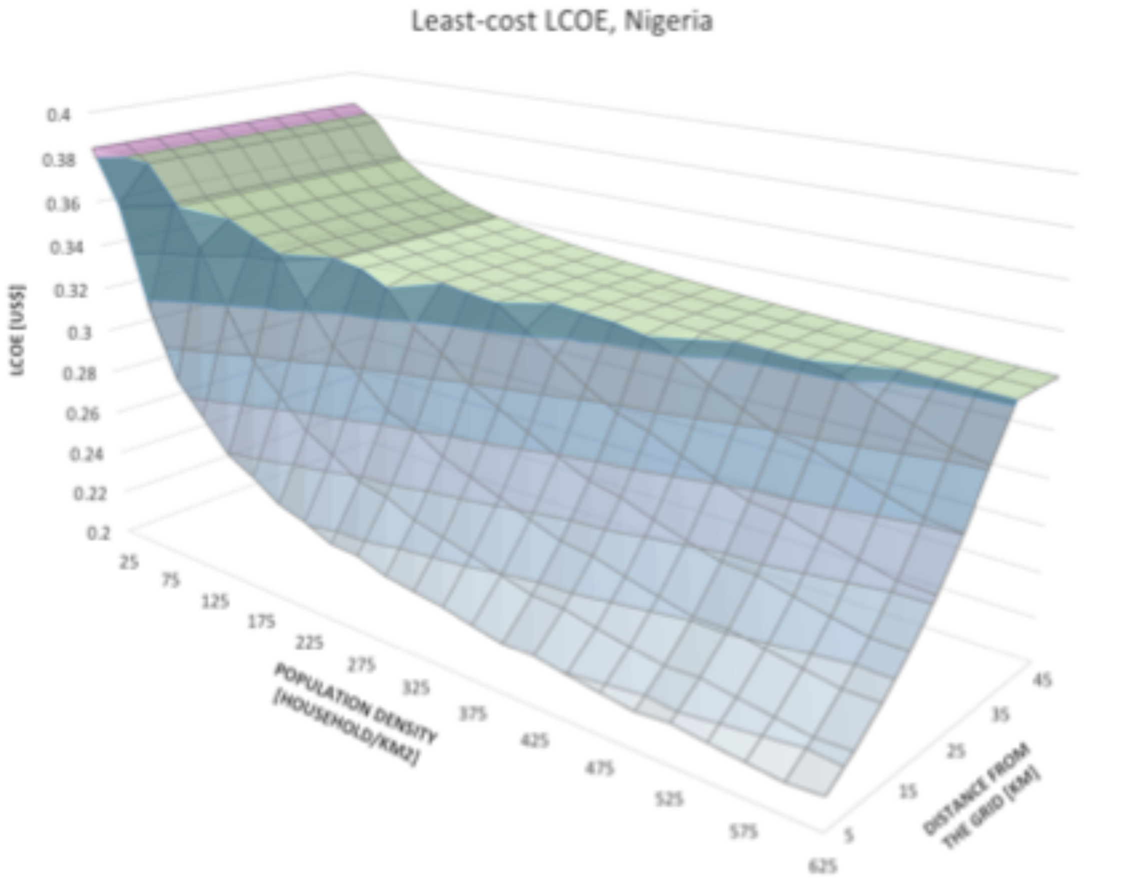


New Grid connections – High consumption scenario

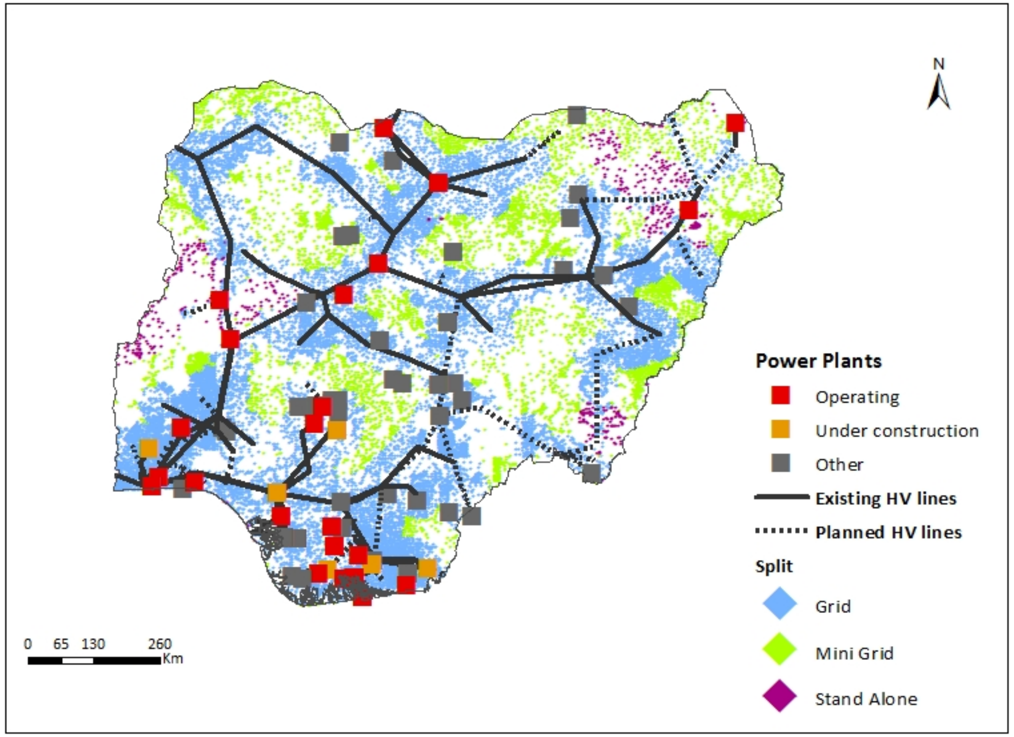


Household demand Vs Technology spit under High consumption scenario

ONSSET Results – The case study of Nigeria



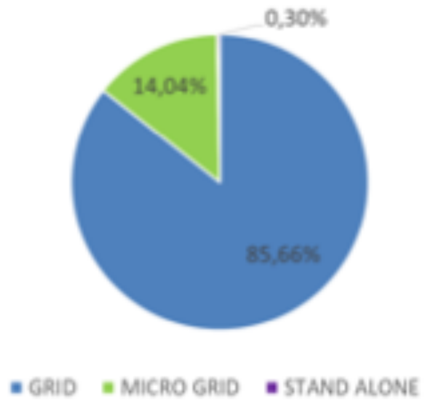
Least cost LCOEs in Nigeria as a function of the distance to the grid and population density



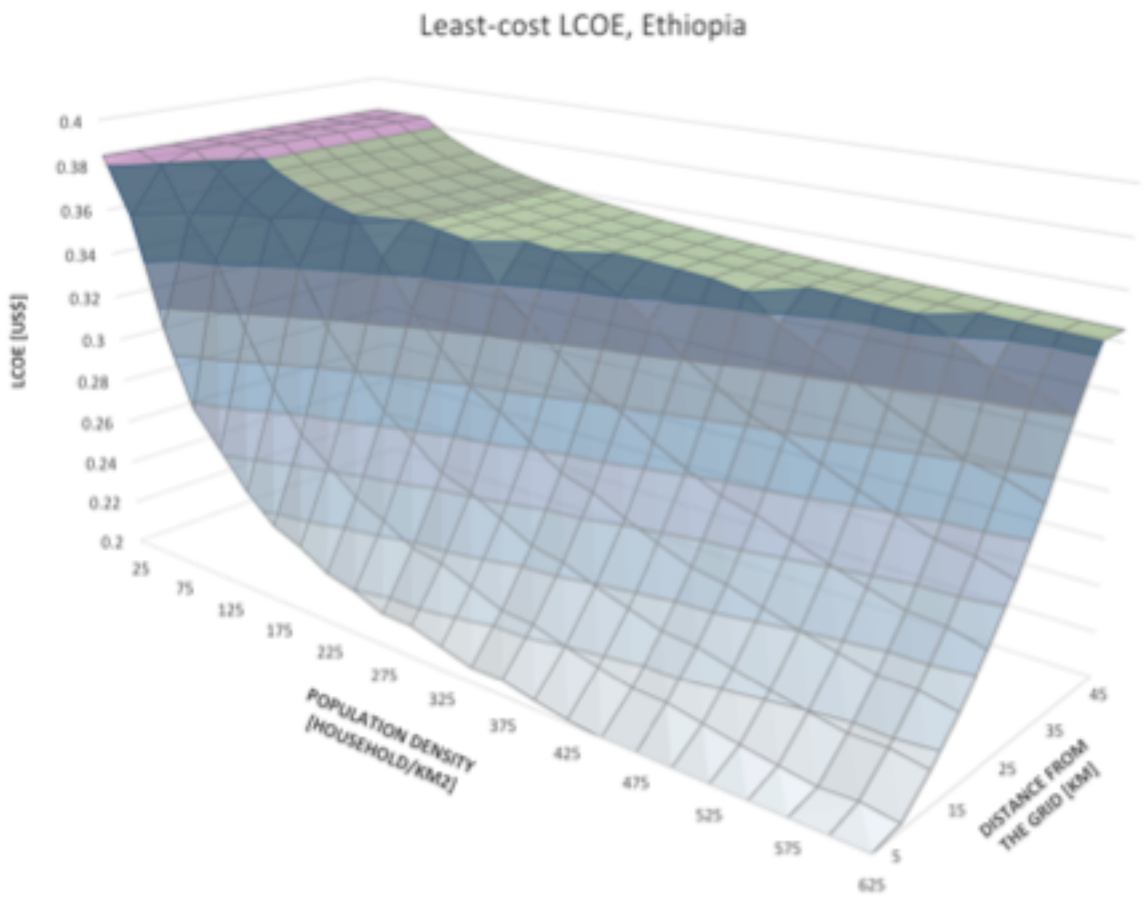
Nigeria, least cost split among Grid, Mini-grid, and Stand-alone electrification technologies

ONSSET Results – The case study of Nigeria

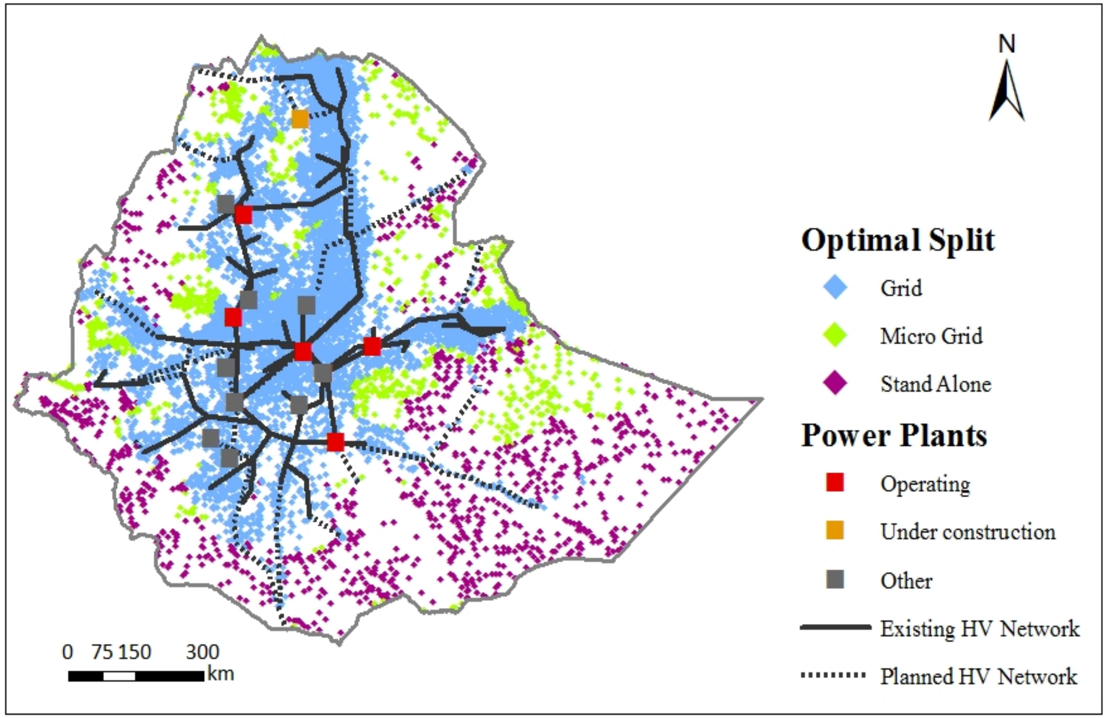
Item	Related physical unit	*Unit*
Rural demand target	170	kWh/capita/year
Urban demand target	350	kWh/capita/year
Grid connections	1,549	*Settlements*
Grid connections	33,727,783	*Households*
Grid connections	168,638,916	People
Planned grid expansion (Transmission with HV lines)	4,334	*km*
Grid extensions for those gaining access (Transmission with MV lines)	78,295	*km*
Grid extensions for those gaining access (Distribution with MV & LV lines)	1,084,544	*km*
Mini grid systems	5,475	*Settlements*
Mini grid systems	2,433,871	*Households*
Mini grid systems	12,169,354	People
Mini grid generating capacity	0.9	*GW*
Mini grid electricity generation	2.1	*TWh*
Stand alone systems	539	*Settlements*
Stand alone systems	51,636	*Households*
Stand alone systems	258,180	People
Stand alone systems generating capacity	0.015	*GW*
Stand alone systems electricity generation	0.044	*TWh*



ONSSET Results – The case study of Ethiopia



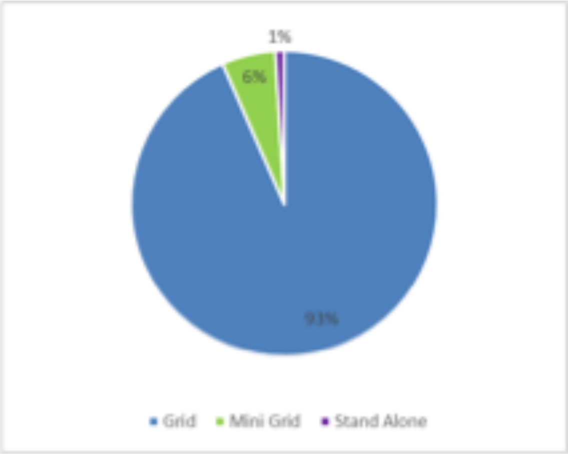
Least cost LCOEs in Ethiopia as a function of the distance to the grid and population density



Ethiopia, least cost split among Grid, Mini-grid, and Stand-alone electrification technologies

ONSSET Results – The case study of Ethiopia

Item	Related physical unit	*Unit*
Rural demand target	150	kWh/capita/year
Urban demand target	300	kWh/capita/year
Grid connections	7,844	*Settlements*
Grid connections	25,424,842	*Households*
Grid distribution	127,124,209	People
Planned grid expansion (Transmission with HV lines)	5,431	*km*
Grid extensions for those gaining access (Transmission with MV lines)	36,343	*km*
Grid extensions for those gaining access (Distribution with MV & LV lines)	513,407	*km*
Mini grid systems	915	*Settlements*
Mini grid systems	791,739	*Households*
Mini grid systems	3,958,695	People
Mini grid generating capacity	0.34	*GW*
Mini grid electricity generation	0.84	*TWh*
Stand alone systems	1060	*Settlements*
Stand alone systems	131,353	*Households*
Stand alone systems	656,767	People
Stand alone systems generating capacity	0.032	*GW*
Stand alone systems electricity generation	0.086	*TWh*

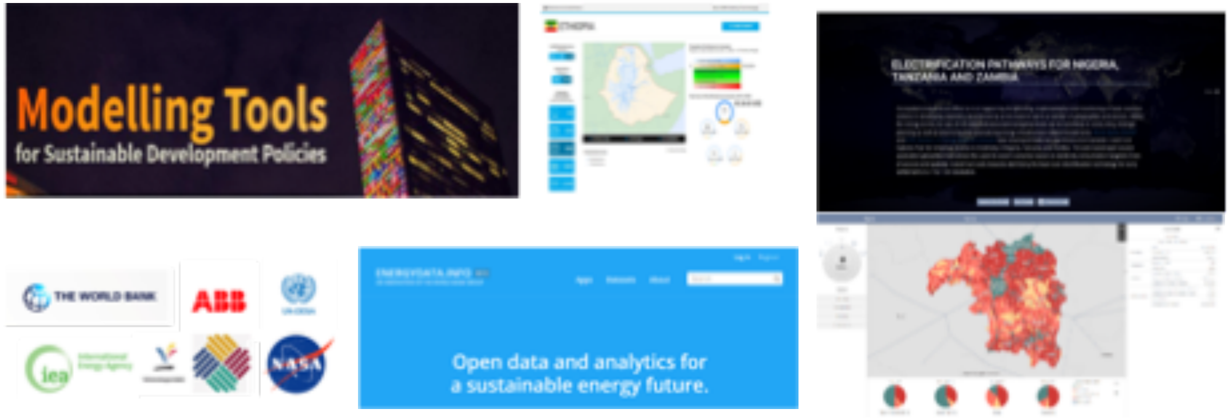


ONSSET contributions

International reports

Peer reviewed publications

Open source platforms and applications



Capacity building activities

Introduction to Modelling tools for Sustainable Development at UNDP, Addis, Ethiopia, August, 2016