



## Offgridplanner.org – an open-source planning tool for hybrid mini-grids

*Developed in the framework of the  
PeopleSuN project*

*Dr. Philipp Blechinger  
Reiner Lemoine Institut*

20.06.2024



## Overview

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- Not-for-profit research institute
- 100% owned by Reiner Lemoine Stiftung (RLS), 93 % third-party funding
- Based in Berlin, established in 2010
- Managing director: Dr. Kathrin Goldammer & Dr. Christine Kühnel
- ~100 researchers + students



## Mission

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Scientific research for an energy transition  
towards **100 % Renewable Energy**



### Reiner Lemoine

Founder of the Reiner Lemoine Foundation - An idealist, entrepreneur, philanthropist

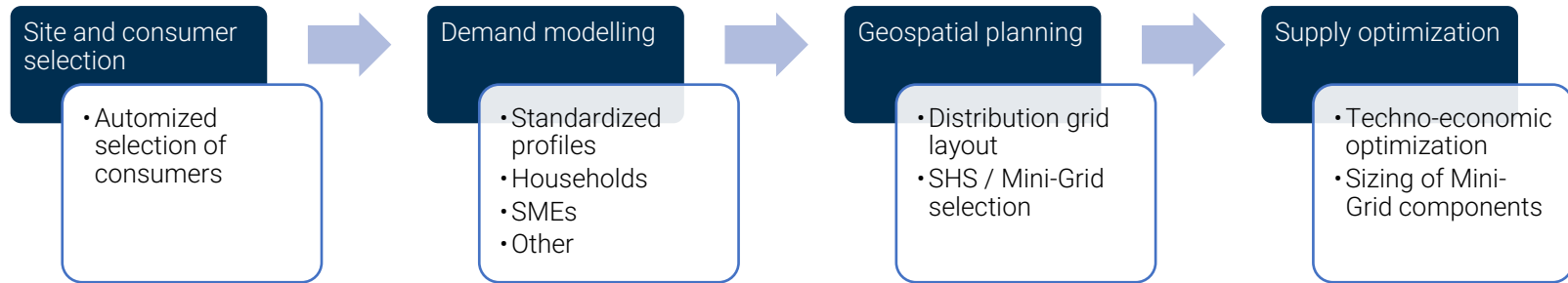
# Objective and focus of offgridplanner

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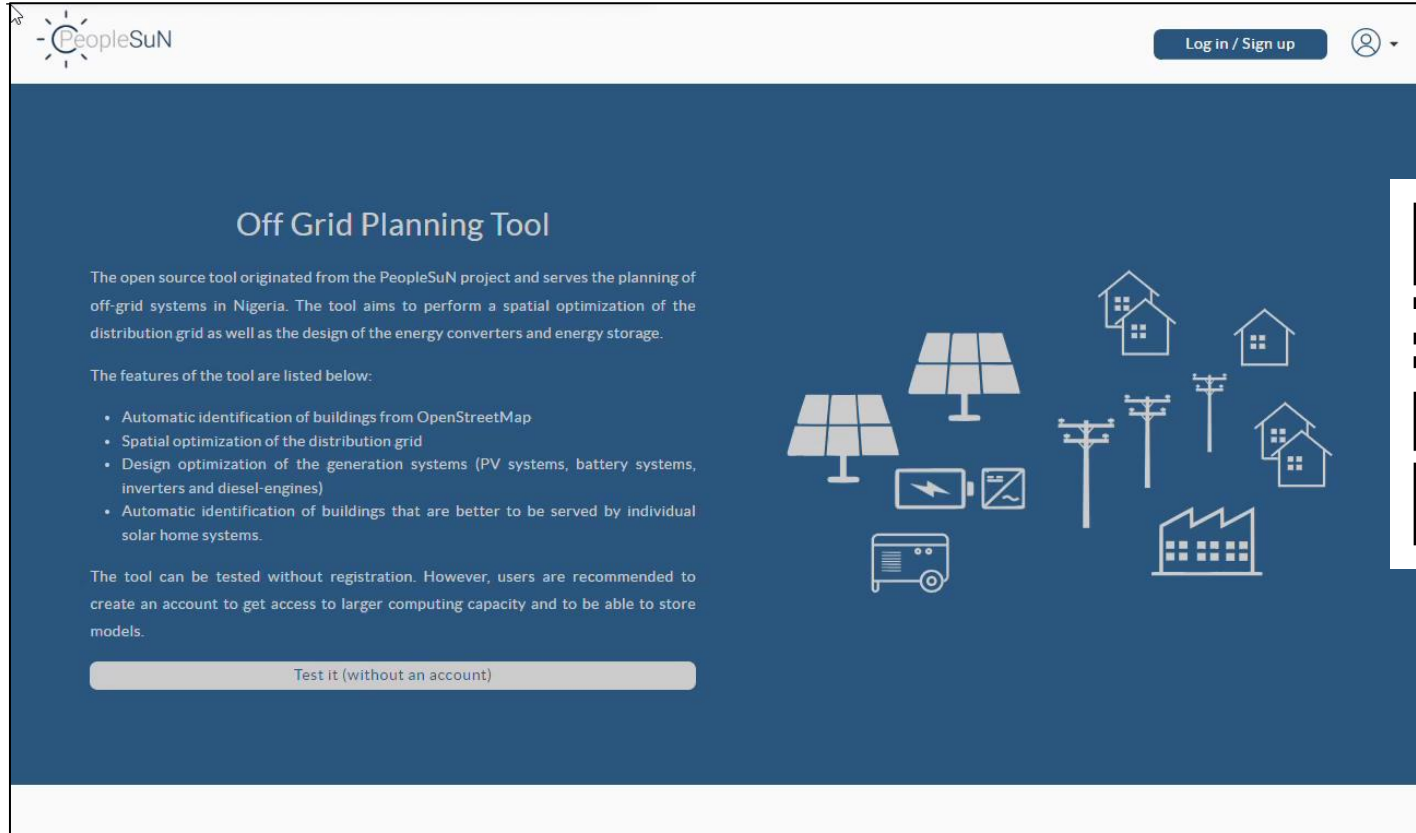


- ▶ Purpose:
  - ▶ Online tool for pre-feasibility studies of off-grid energy supply systems and their distribution grids in Nigeria
- ▶ How is this *different* to other existing tools?
  - ▶ More detailed demand estimations using large survey data
  - ▶ Includes distribution grid layout estimation and solar home systems
  - ▶ Many advanced customization options available
  - ▶ Entirely open-source code and platform which can be used or developed further for free by others supporting transparency and flexibility

# Offgridplanner – Stepwise approach for project development



# Off-Grid Planning Tool: *offgridplanner.org*

A screenshot of the website for the Off Grid Planning Tool. The page has a dark blue background. At the top left is the PeopleSuN logo, and at the top right is a "Log in / Sign up" button and a user profile icon. The main heading is "Off Grid Planning Tool". Below it is a paragraph describing the tool's purpose in Nigeria. A list of features follows, including automatic identification of buildings and spatial optimization. A "Test it (without an account)" button is at the bottom. On the right side of the page, there are icons for solar panels, a battery, a power line, and houses.

PeopleSuN

Log in / Sign up

## Off Grid Planning Tool

The open source tool originated from the PeopleSuN project and serves the planning of off-grid systems in Nigeria. The tool aims to perform a spatial optimization of the distribution grid as well as the design of the energy converters and energy storage.

The features of the tool are listed below:

- Automatic identification of buildings from OpenStreetMap
- Spatial optimization of the distribution grid
- Design optimization of the generation systems (PV systems, battery systems, inverters and diesel-engines)
- Automatic identification of buildings that are better to be served by individual solar home systems.

The tool can be tested without registration. However, users are recommended to create an account to get access to larger computing capacity and to be able to store models.

Test it (without an account)



# Basic Project Setup



- 1 Project Setup
- 2 Consumer Selection
- 3 Demand Estimation
- 4 Grid Design
- 5 Energy System Design
- 6 Simulation Results

## Project name

Copy of Exmample Project

## Project description - optional

Simulation and optimization of power supply and grid layout for an off-grid system in a rural settlement.

## Interest rate ?

12.3

%

## Project lifetime ?

25

Year

## Number of days ?

365

Day

# Customer Selection and Customization with Map Tool



Set Consumer Properties

mami

The map tool interface displays a map of a region with various consumer selection tools. The map shows a network of roads and rivers, with several locations labeled: Ahuji, Bagi, Gwachi, Mami, Batake, Sunawa, and Juyura. A legend in the bottom right corner identifies the following symbols:

- Load Center (black square)
- Household (blue dot)
- Enterprise (yellow dot)
- Public Service (purple dot)
- Pole (black circle)
- Solar Home System (orange star)
- Distribution (red line)
- Connection (green line)

Remove Consumers

Leaflet | © OpenStreetMap contributors



# Consumer Specification

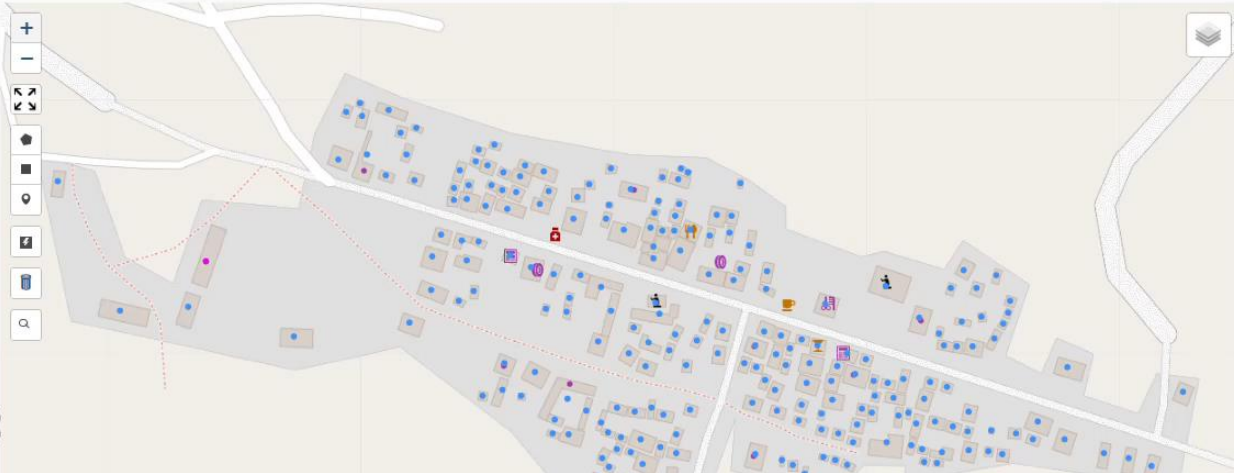
Set Consumer Properties ⤴

Show advanced Options

Number of selected Consumers: 230

Consumer Type	Consumer Category	Latitude	Longitude	Grid-/SHS-Options	Delete Consumer
Public Service	School	8,490522 Degree	6,323163 Degree	Optimize	Delete

mami





# Demand Estimation Model: Survey Data



Quantitative household and enterprise energy surveys of consumers who currently have electricity (>5,000 total) to understand:

- ▶ Average appliance ownership likelihood
- ▶ Average daily total appliance usage duration
- ▶ Appliance power and time of use assumptions

*Additionally for enterprises and public services:*

- ▶ daily opening and closing times
- ▶ Additional “high power energy intensive appliances” - *modelled separately*

## scientific data

OPEN

DATA DESCRIPTOR

### Electricity supply quality and use among rural and peri-urban households and small firms in Nigeria

Setu Pelz<sup>1,2,3\*</sup>, Narges Chinichian<sup>1,3</sup>, Clara Neyrand<sup>2</sup> & Philipp Blechinger<sup>2,3</sup>

We present a household and enterprise energy survey dataset collected within the framework of the PeopleSuN project in Nigeria in 2021. Across three Nigerian geopolitical zones, a total of 3,599 households and 1,122 small and medium-sized enterprises were surveyed. The sample is designed to be representative of rural and peri-urban grid-electrified regions of each zone. Our surveys collect data on demographic and socioeconomic characteristics, energy access and supply quality, electrical appliance ownership and usage time, cooking solutions, energy related capabilities, and supply preferences. We encourage academic use of the data presented and suggest three avenues of further research: (1) modelling appliance ownership likelihoods, electricity consumption levels and energy service needs in un-electrified regions; (2) identifying supply-side and demand-side solutions to address high usage of diesel generators; (3) exploring broader issues of multi-dimensional energy access, access to decent living standards and climate vulnerability.

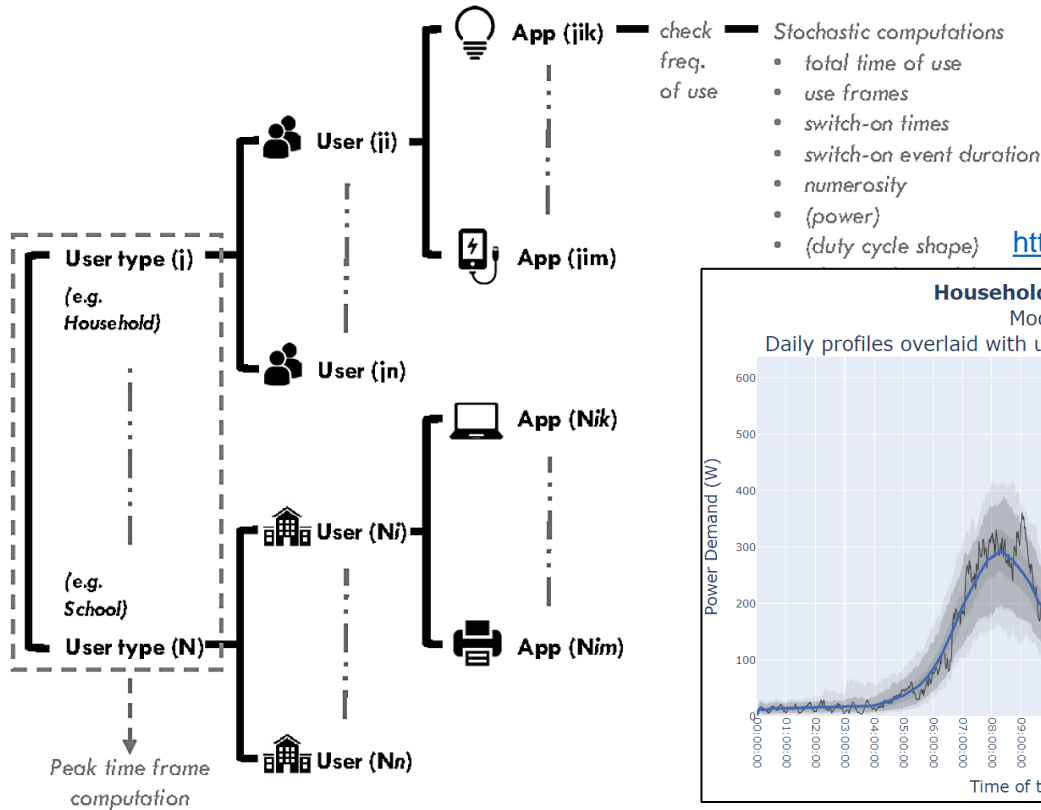
#### Background & Summary

Rural and peri-urban populations in Nigeria continue to suffer unreliable and expensive energy supply. According to the World Bank, the electricity access rate in Nigeria stood at 55.4% in 2020 with a big gap between urban and rural areas (83.9% vs. 24.6%)<sup>1</sup>. At the same time, nearly 30 million Nigerian households depend on wood as a source of cooking fuel, the collection of which is time consuming and mainly done by women<sup>2</sup>. Where there is supply, it is typically unreliable and frequently interrupted by blackouts. The Nigeria Enterprise Survey from the World Bank showed that 27% of Nigerian firms identified reliability of electricity supply as the main obstacle to their business<sup>3</sup>. On average, 32.8 power outages were reported to occur in a typical month leading to an estimated 11% loss in sales value<sup>3</sup>. The average grid-connected household receives just 6.6 hours of supply on a typical day, linked to a per capita consumption of just 144kWh per year<sup>4</sup>. In comparison, the annual per capita consumption in Ghana and South Africa is respectively 351 kWh and 4,198 kWh. Plagued by issues of supply quality, many Nigerians have resorted to self-generation using petrol and diesel generators, spending approximately 1.56 trillion Naira (3.76 billion USD, using an average exchange rate in 2021) per year on fuel<sup>5</sup>.

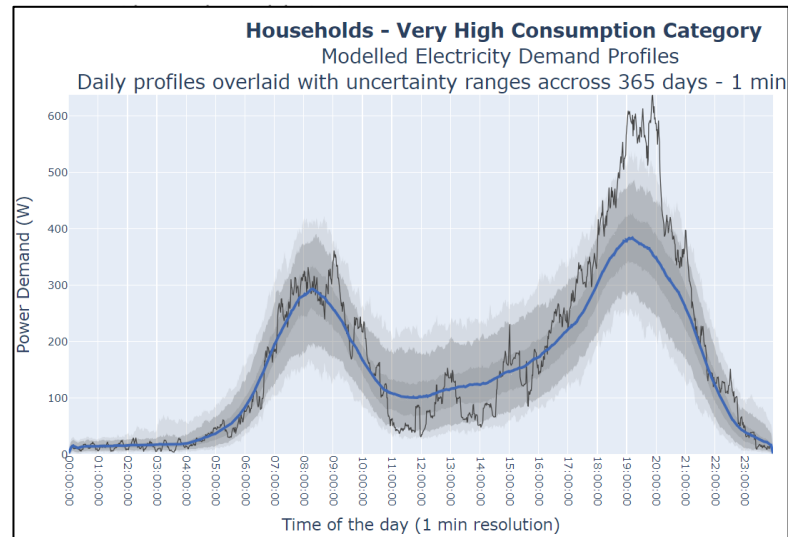
While global efforts are accelerating under the banner of achieving Sustainable Development Goal 7 (SDG7) by 2030, progress in Nigeria remains hindered by limited data availability, among other barriers. Data describing the energy access deficit in Nigeria exists (see Table 1), however, there is limited disaggregate information describing the supply quality in the existing network and the unmet demand in ‘un-electrified’ regions. In this data descriptor, we present primary survey data collected to fill this and other gaps through the ‘People Power: Optimizing off-grid electricity supply systems in Nigeria’ project (PeopleSuN)<sup>6</sup>. PeopleSuN is funded by the German Federal Ministry of Education and Research (BMBWF) within the funding initiative ‘Client II - International Partnerships for Sustainable Innovations’. Data collection followed extensive stakeholder discussions in Nigeria under the PeopleSuN project to define the data gap and the necessary survey and sampling strategy to address this. The questionnaires used draw from specific modules within established surveys capturing energy-related data, most directly from the Multi-Tier Framework for Measuring Energy Access surveys<sup>7</sup>.

<sup>1</sup>International Institute for Applied Systems Analysis, Laxenburg, Austria. <sup>2</sup>Off-Grid Systems, Reiner Lemoine Institut (RLI), Berlin, Germany. <sup>3</sup>Institute for Theoretical Physics, Technical University of Berlin, Berlin, Germany.

# Synthetic profiles for different consumers



<https://github.com/rl-institut/RAMP>



# Distribution Grid & SHS – Parameters

- 1 Project Setup   2 Consumer Selection   3 Demand Estimation   4 Grid Design   5 Energy System Design   6 Simulation Results

## Distribution Cable

Lifetime ?	25	Year
CapEx ?	10	USD/m
Max. Length ?	50	m

## Connection Cable

Lifetime ?	25	Year
CapEx ?	4	USD/m
Max. Length ?	20	m

## Solar Home System

Max. Specific Grid Cost ?	0.6	USD/kWh
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Watch video tutorial for further explanation of this parameter

## Pole

Lifetime ?	25	Year
CapEx ?	800	USD/pole
Max. Number of Connections ?	5	-

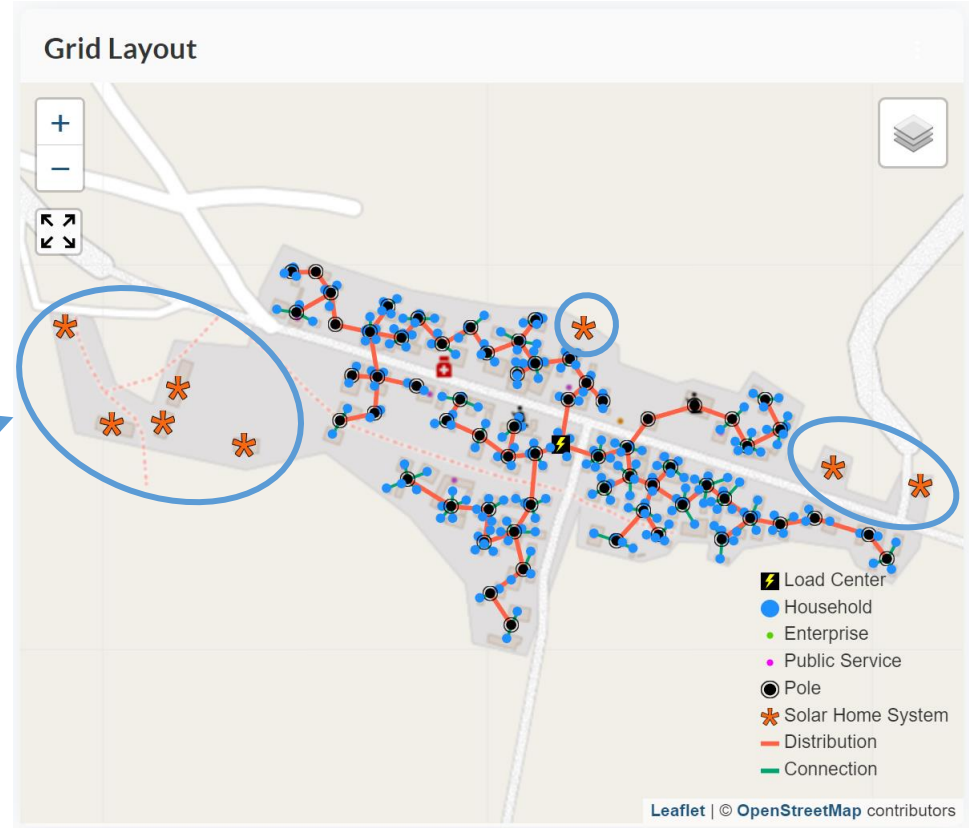
## Connection Cost

Connection Cost ?	140	USD/con
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# Solar Home Systems – Mixed with mini-grid

## Simplified optimization approach as alternative to high individual mini-grid connection costs:

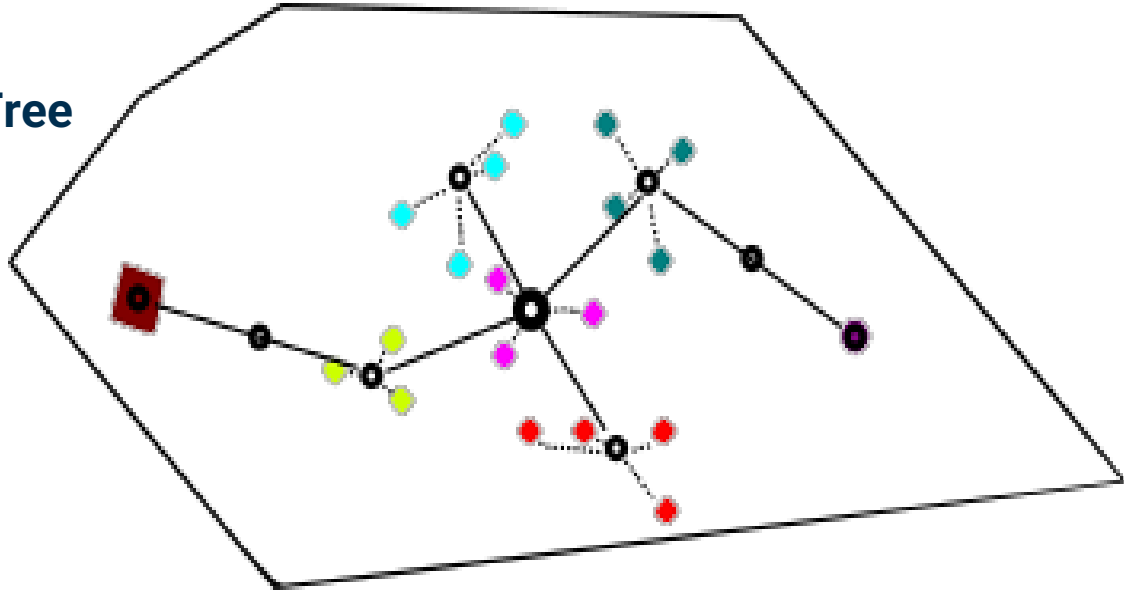
- ▶ Selecting candidates for exclusion from mini-grid connections for consumers with very high individual connection costs compared to their consumption and suggests as to supply with solar home systems (*threshold selectable by user*)
- ▶ Customers identified as candidates for connection with SHS instead of mini-grid are visualized on the results map
- ▶ Any individual customer can be “forced” to be connected to the grid (i.e. key anchor customers etc)



# Spatial Optimization of the Distribution Grid

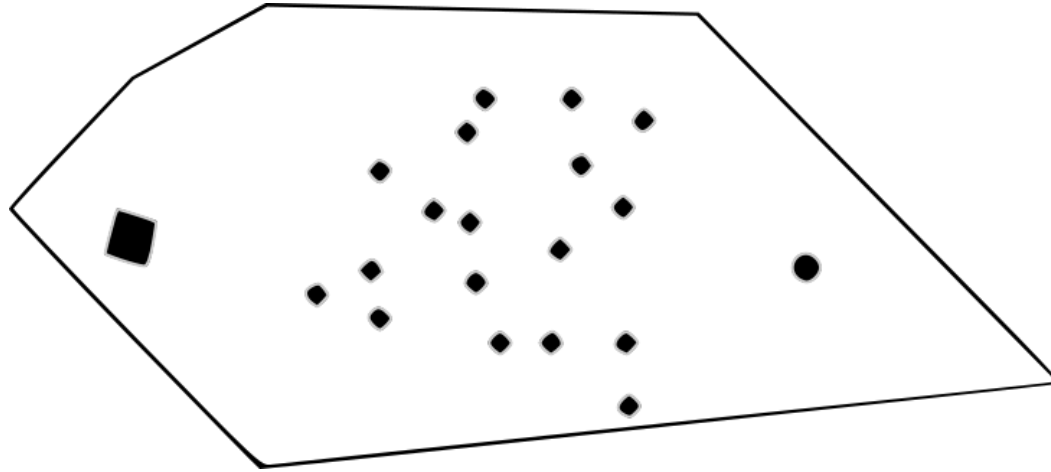
## Approximate Distribution Grid Optimization:

- ▶ **Cost minimization** algorithm
- ▶ **K-means** clustering
- ▶ Adapted **Minimum Spanning Tree**
- ▶ Cable span **length limits**
- ▶ All components **costed**



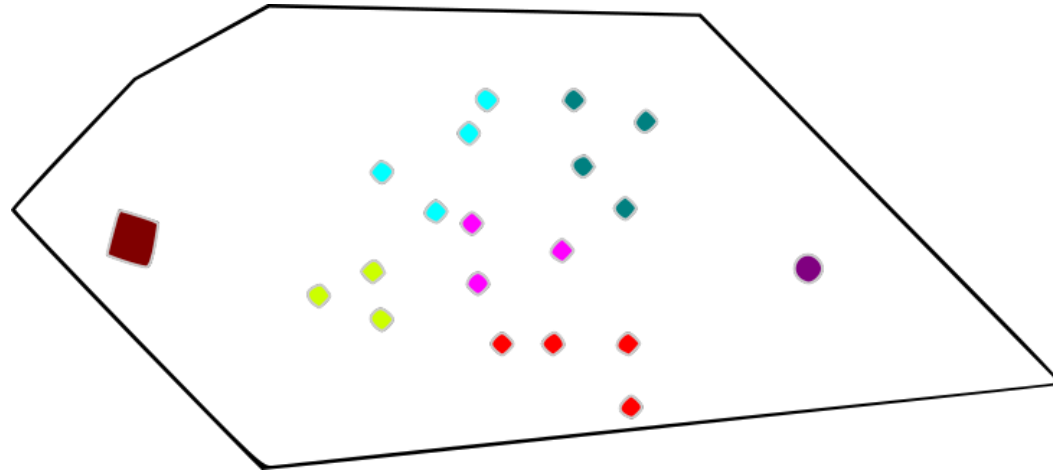
## Approximate Distribution Grid Optimization Approach:

- ▶ The starting point for the optimization are the respective geolocations of the consumers.



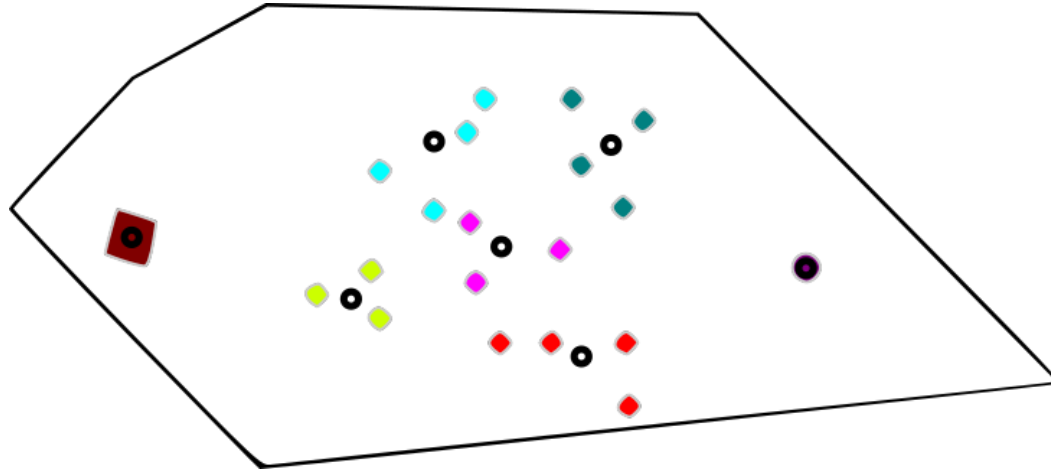
# Spatial Optimization of the Distribution Grid

- ▶ Initial clustering of consumers by constrained **K-means algorithm** (number of customers per cluster is fixed – e.g. 4 customers)



# Spatial Optimization of the Distribution Grid

- ▶ The **centroids of the clusters** are taken as the geolocations of the **poles**

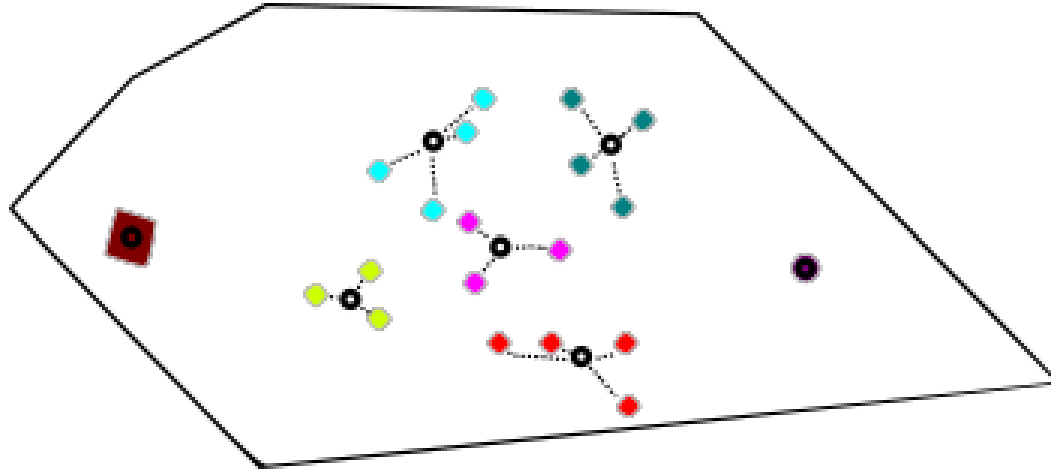




# Spatial Optimization of the Distribution Grid

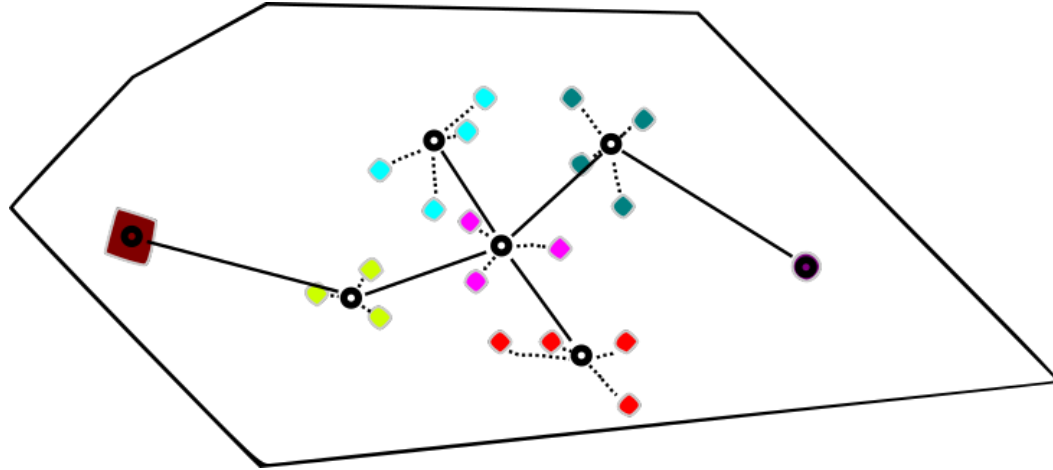
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- ▶ Each consumer is then connected to its cluster pole



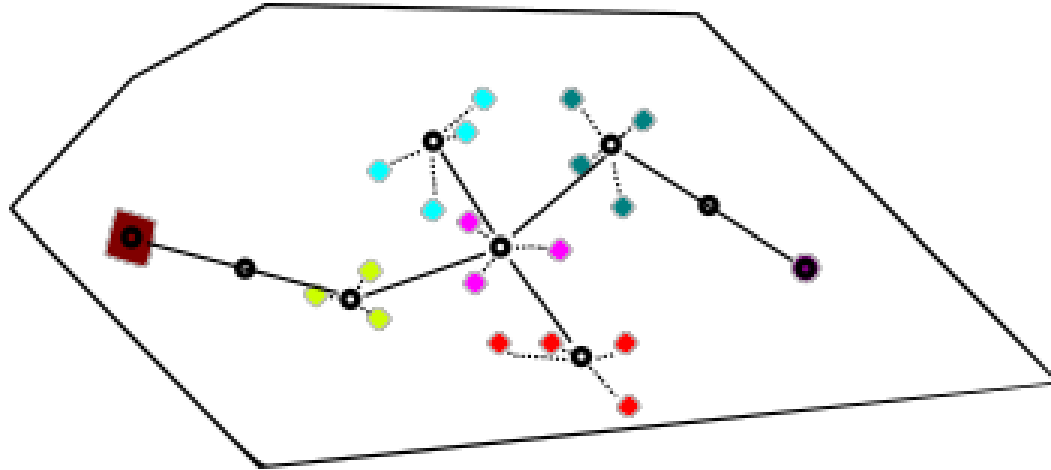
# Spatial Optimization of the Distribution Grid

- ▶ A **minimum spanning tree (MST)** is then constructed from this graph, which connects all the poles with minimum total distance (Kruskal's algorithm)



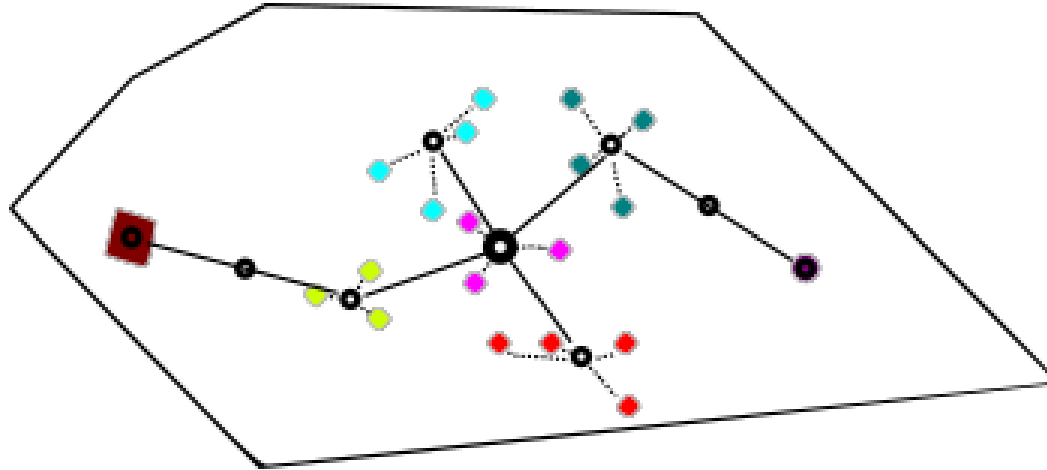
# Spatial Optimization of the Distribution Grid

- ▶ Addition of intermediate poles to prevent unacceptable cable lengths



# Spatial Optimization of the Distribution Grid

- ▶ The **pole with the smallest distance to the “load center”** is taken as the assumed **best approximate location of the power house**



# Energy Supply System



PeopleSuN cramer@tu-berlin.de

1 Project Setup 2 Consumer Selection 3 Demand Estimation 4 Grid Design 5 Energy System Design 6 Simulation Results

Diesel Genset

Design	Dispatch	Capacity	10	kW
Lifetime	8	Year		
CapEx	0	USD/kW		
OpEx	25	USD/(kW*a)		
Variable Cost	0.045	USD/kWh		
Fuel Cost	1,671	USD/L		
Fuel LHV	11.83	kWh/kg		
Minimum Efficiency	22	%		
Maximum Efficiency	30	%		
Minimum Load	20	%		
Maximum Load	100	%		

Schematic of the Selected Off-Grid System

The schematic shows a vertical black line labeled "AC Bus" on the left. A green arrow points from the AC Bus to a green rounded rectangle labeled "Demand" on the right.

Battery

Design	Dispatch	Capacity	7	kWh
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Inverter

Design	Dispatch	Capacity	9	kW
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PV

Design	Dispatch	Capacity	20	kW
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# Energy Supply System



Diesel Genset

Optimized Capacity | Fixed Capacity

Capacity 8 kW

Lifetime 8 Year

CapEx 350 USD/kW

OpEx 25 USD/(kW•a)

Variable Cost 0 USD/kWh

Fuel Cost 1.7 USD/L

Fuel LHV 11.8 kWh/kg

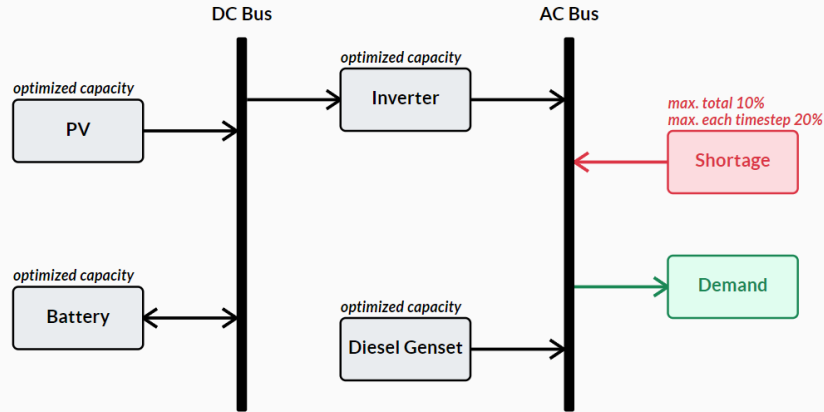
Minimum Efficiency 22 %

Maximum Efficiency 30 %

Minimum Load 20 %

Maximum Load 100 %

Schematic of the Selected Off-Grid System



Battery

Optimized Capacity | Fixed Capacity

Capacity 7 kWh

Lifetime 7 Year

CapEx 314 USD/kWh

PV

Optimized Capacity | Fixed Capacity

Capacity 20 kW

Lifetime 25 Year

CapEx 441 USD/kW



Shortage

Max. Total Shortage 10 %

Max. Shortage Each Timestep 20 %


Shortage Penalty Cost 0.8 USD/kWh

# Results – Many different metrics - Downloadable

cramer@tu-berlin.de 

1 Project Setup   2 Consumer Selection   3 Demand Estimation   4 Grid Design   5 Energy System Design   6 Simulation Results

### Grid Layout



- Load Center
  - Household
  - Enterprise
  - Public Service
- Pole
- Solar Home System
- Distribution
- Connection

Leaflet | © OpenStreetMap contributors

### Summary of Results

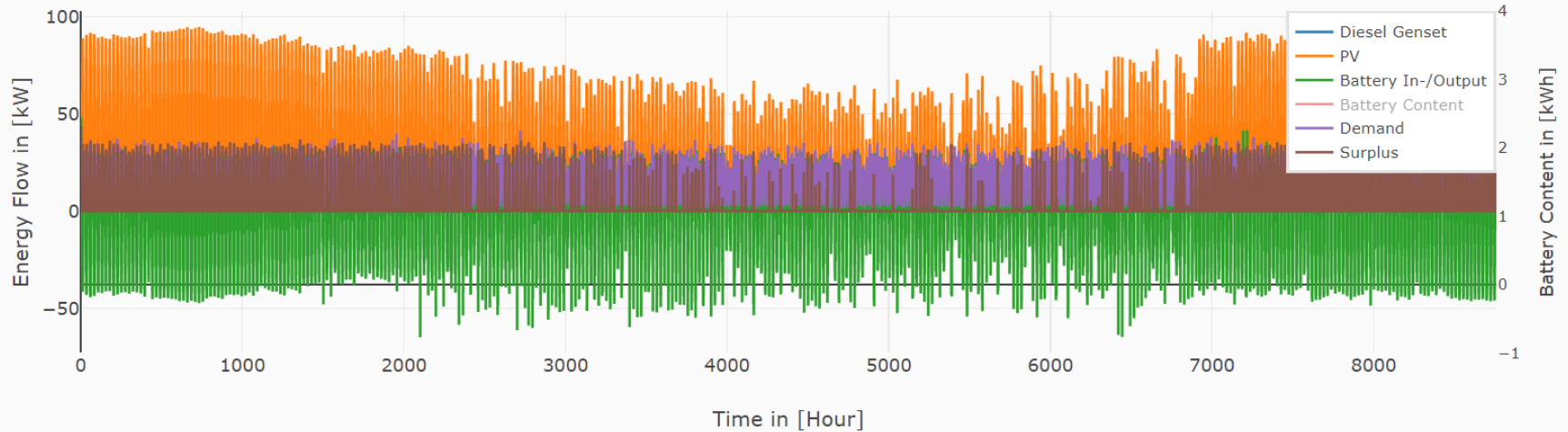
Levelized Cost of Electricity (w/o SHS)	Total upfront Investment Cost	Share of Generation-Related Costs in LCOE	Share of Grid-Related Costs in the LCOE
42 €USD/kWh	226,214 USD	61.8 %	38.2 %
Capacity PV	Capacity Battery	Capacity Diesel Generator	Renewable Energy Share
41.7 kW	5.1 kWh	20.3 kW	67.3 %
Number of grid-connected Consumers	Total annual Consumption (w/o SHS)	Annual average Demand per Consumer	Calculation Time
231	89,225 kWh/a	45.3 W	25.7 s

Download Results (xlsx-format)

Recalculate

# Results – Energy Flows of All Components

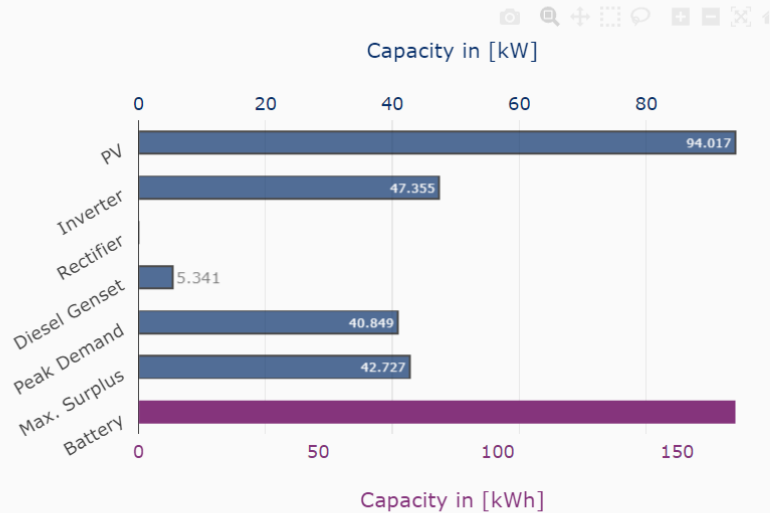
Annual Energy Flows with 1-Hour Resolution



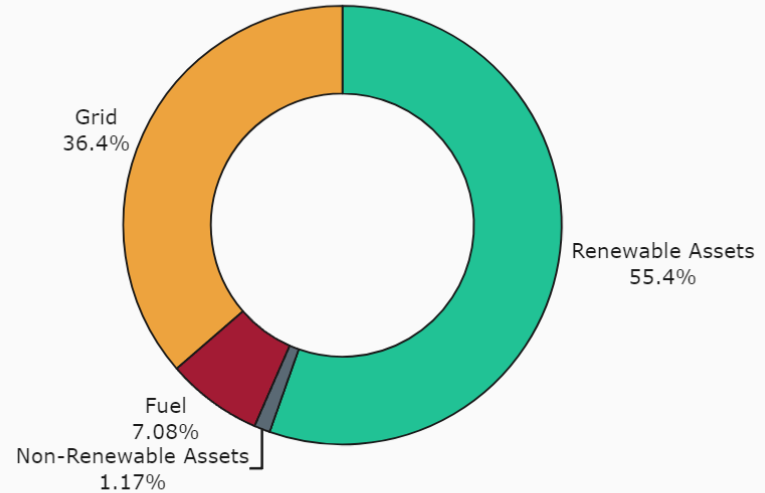


# Results – Capacity and LCOE Breakdown

### Optimal Capacity of Components

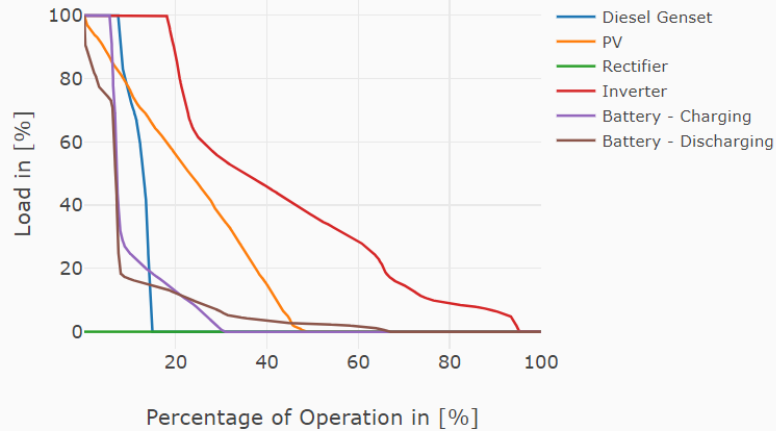


### Breakdown of the LCOE

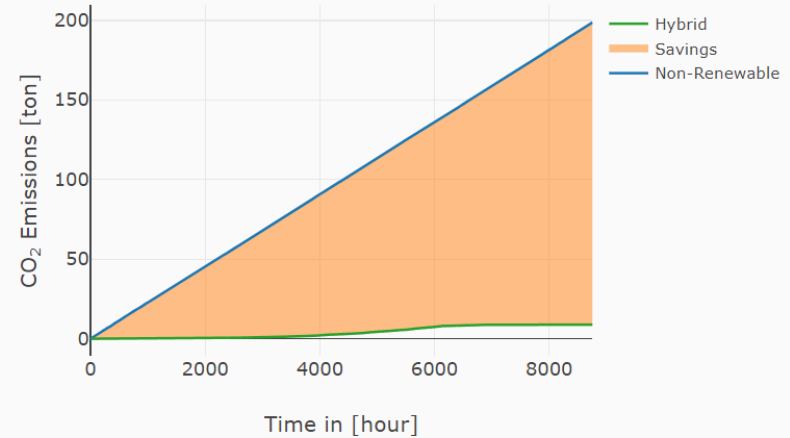


# Results – “Duration Curves” and CO2 emission savings

## Duration Curves for All Components



## Cumulative CO<sub>2</sub> Emissions



# Summary

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- ▶ Feel free to use the offgridplanner to plan and optimize your off-grid project!
- ▶ Currently validated for Nigeria, open to be adapted for other countries.
- ▶ New features possible such as wind power or hydrogen.

## Thank your for your attention!

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