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

The Reiner Lemoine Institut (RLI)

REINER LEMOINE INSTITUT

PeopleSuN

Overview

- 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

Alliance for Rural Electrification

SUSTAINABLE DEVELOPMENT SOLUTIONS NETWORK
A GLOBAL INITIATIVE FOR THE UNITED NATIONS

Mission

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

- <u>Purpose:</u>
  - **Online tool** for **pre-feasibility studies of off-grid energy supply systems and their distribution grids in Nigeria**
- <u>How is this *different* to other existing tools?</u>
  - 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

Site and consumer selection

- Automized selection of consumers

Demand modelling

- Standardized profiles
- Households
- SMEs
- Other

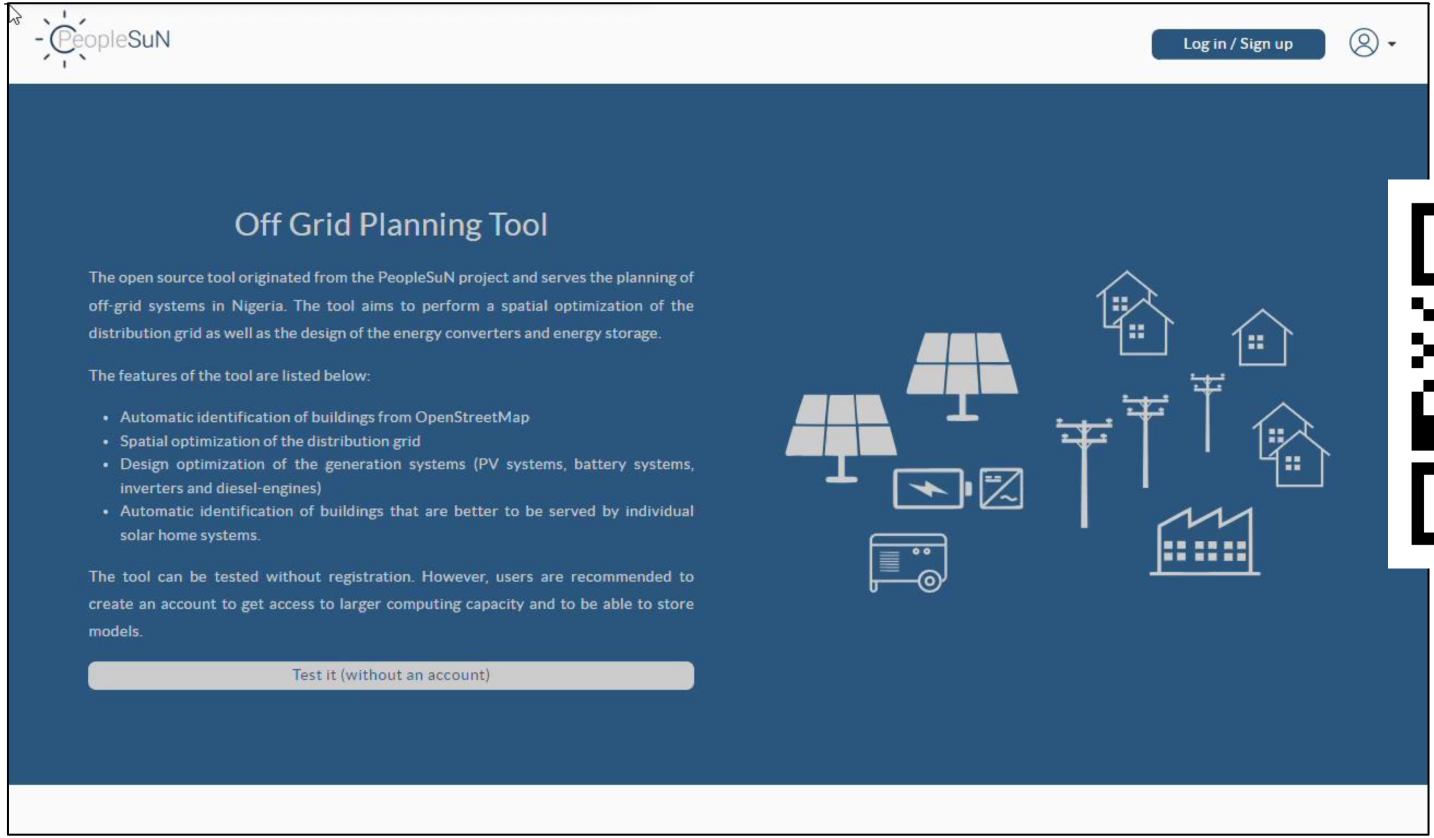
Geospatial planning

- Distribution grid layout
- SHS / Mini-Grid selection

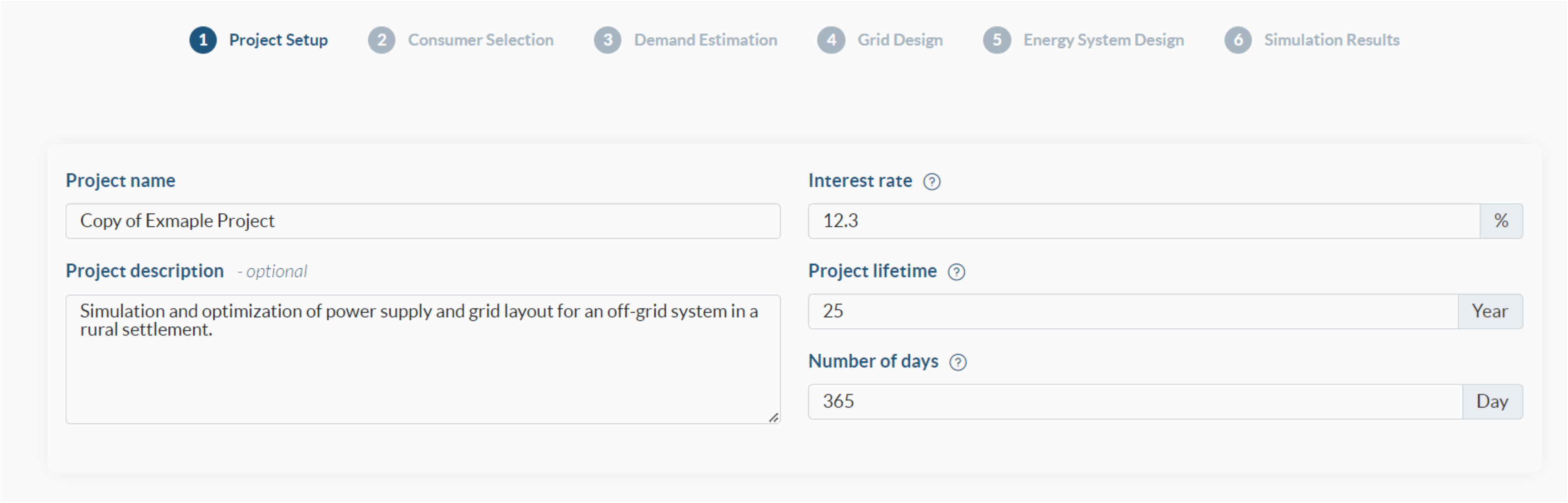
Supply optimization

- Techno-economic optimization
- Sizing of Mini-Grid components

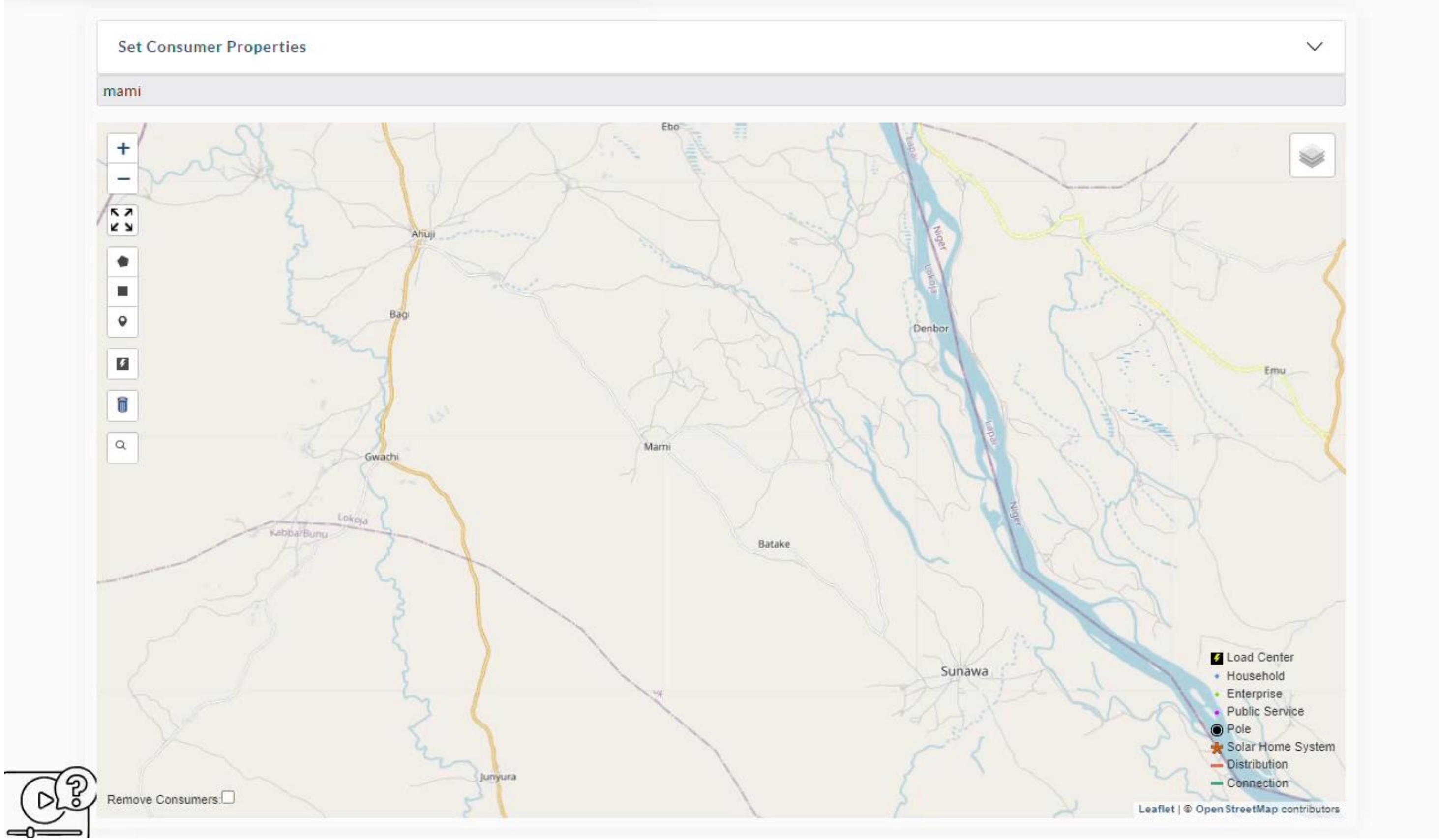
Off-Grid Planning Tool: *offgridplanner.org*



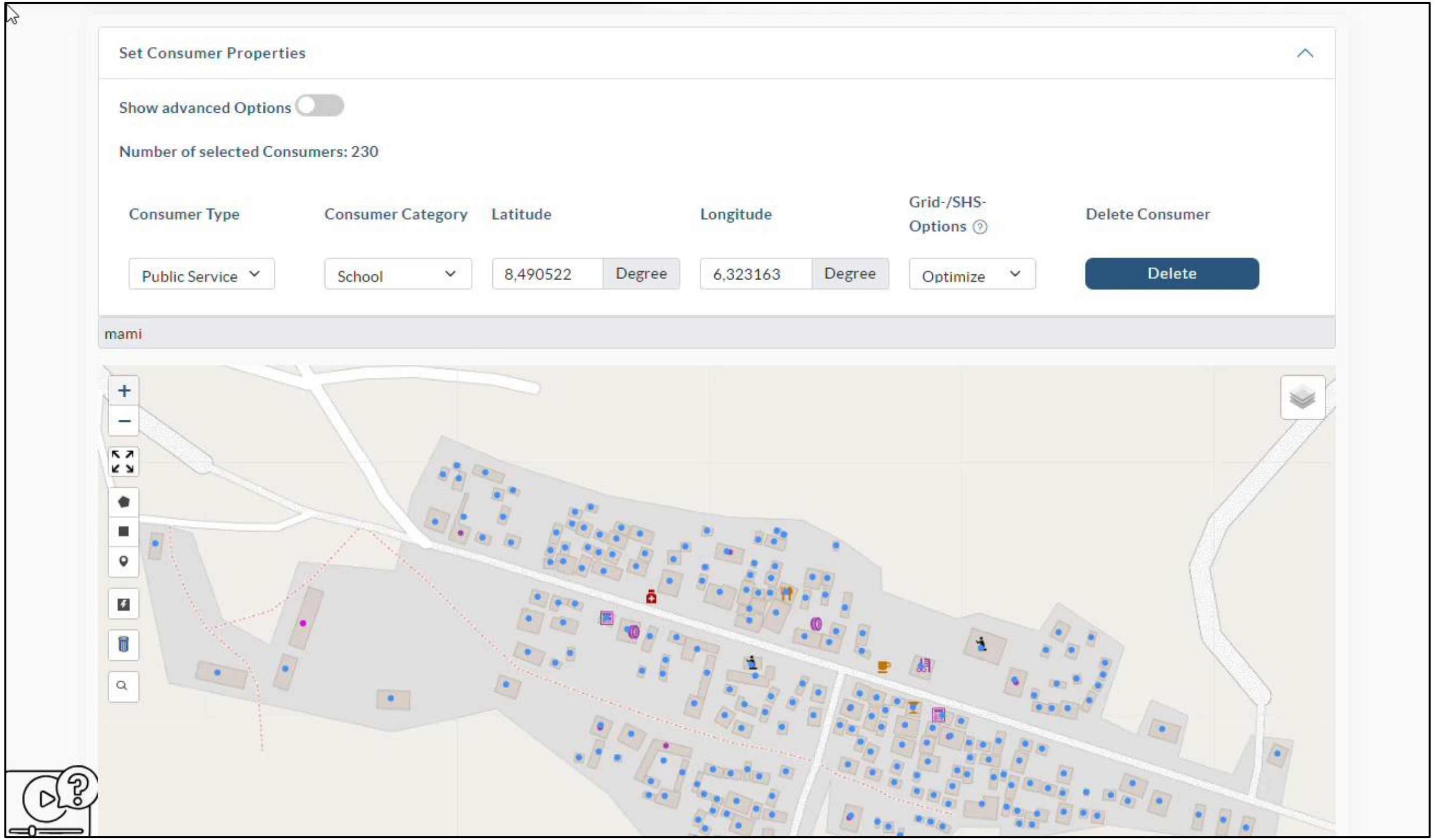
Basic Project Setup



Customer Selection and Customization with Map Tool



Consumer Specification



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

Check for updates

OPEN

DATA DESCRIPTOR

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

Setu Pelz[1,2], Narges Chinichian[2,3], Clara Neyrand[2] & Philipp Blechinger[2]

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.

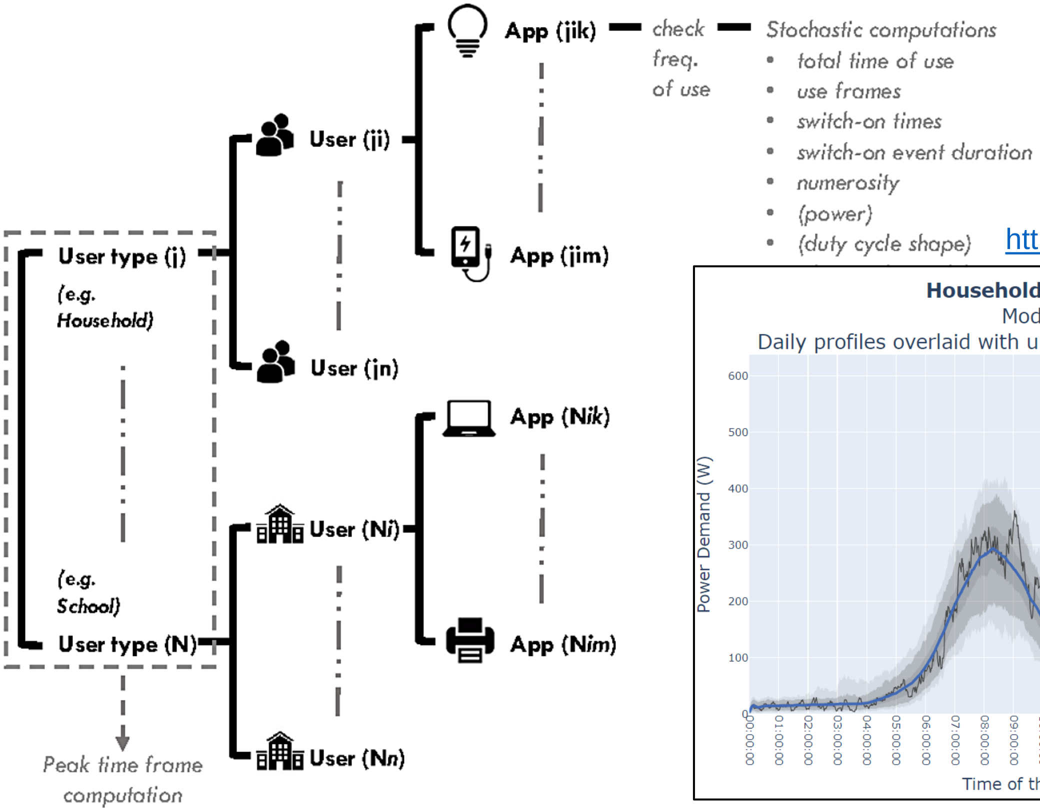
Background & Summary

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%)[1]. 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[2]. 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[3]. On average, 32.8 power outages were reported to occur in a typical month leading to an estimated 11% loss in sales value[3]. 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[4]. 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[5].

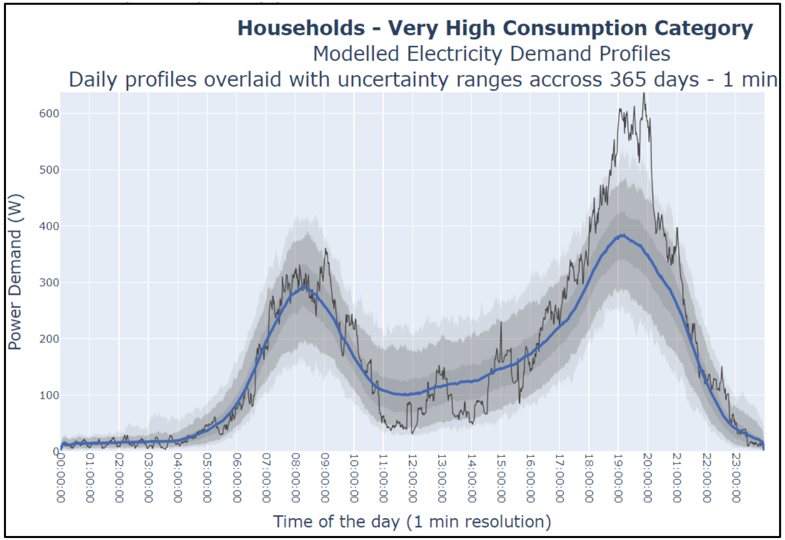
While global efforts are accelerating under the banner of achieving Sustainable Development Goal 7 (SDG7) by 2030, progress in Nigeria remains hindered by limited data availability, among other barriers. Data describing the energy access deficit in Nigeria exists (see Table 1), however, there is limited 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)’[6]. PeopleSuN is funded by the German Federal Ministry of Education and Research (BMBF) 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[7].

[1]International Institute for Applied Systems Analysis, Laxenburg, Austria. [2]Off-Grid Systems, Reiner Lemoine Institut (RLI), Berlin, Germany. [3]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

Watch video tutorial for further explanation of this parameter

Pole

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

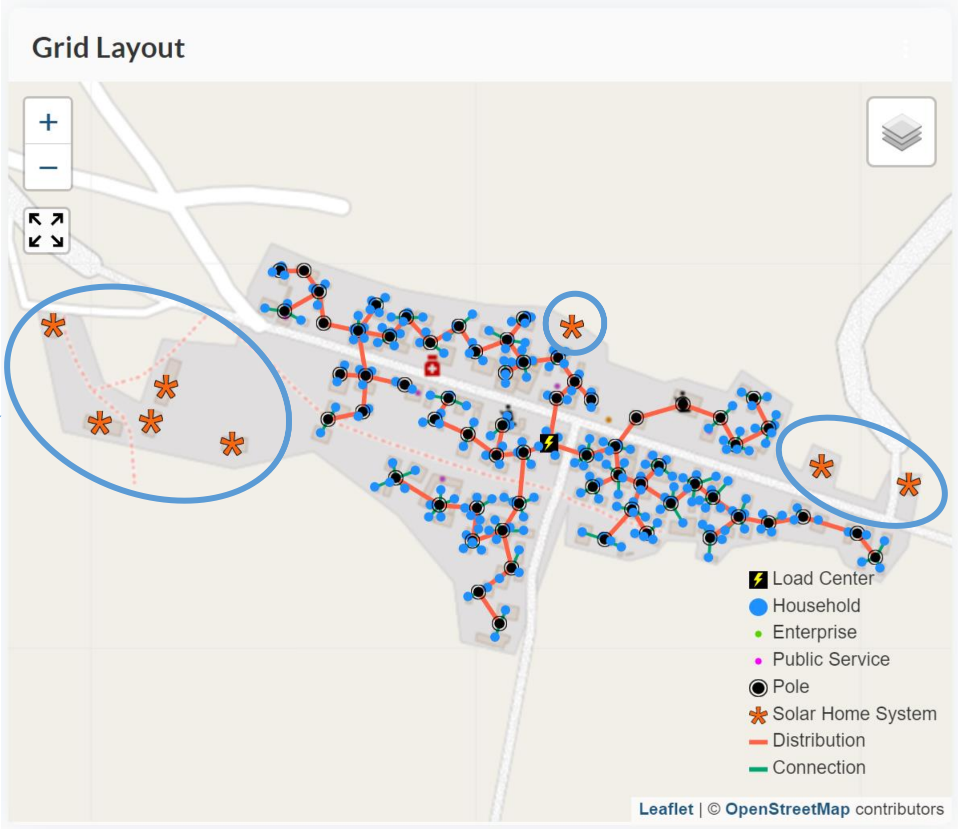
Connection Cost

Connection Cost ?	140	USD/con

Solar Home Systems – Mixed with mini-grid

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

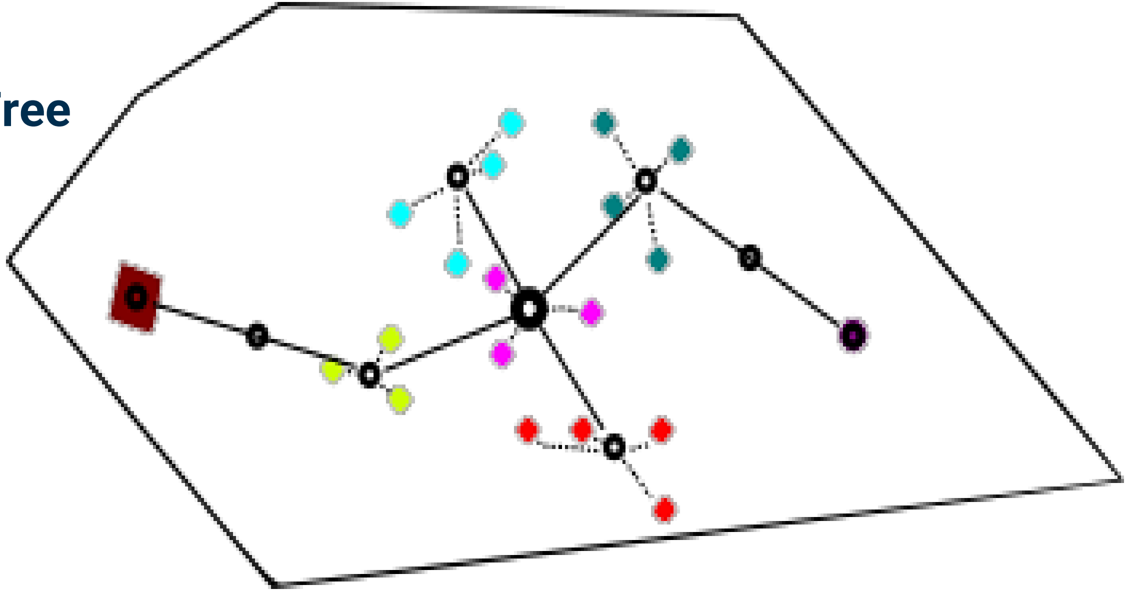
- Selecting candidates for exclusion from mini-grid connections for consumers with very high individual connection costs compared to their consumption and suggests as to supply with solar home systems *(threshold selectable by user)*
- Customers identified as candidates for connection with SHS instead 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:

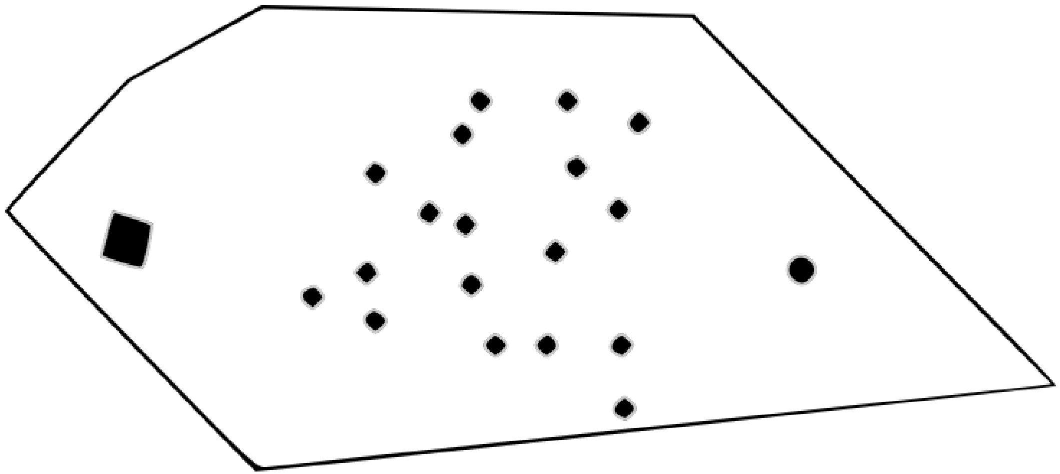
- **Cost minimization** algorithm
- **K-means** clustering
- Adapted **Minimum Spanning Tree**
- Cable span **length limits**
- All components **costed**



Spatial Optimization of the Distribution Grid

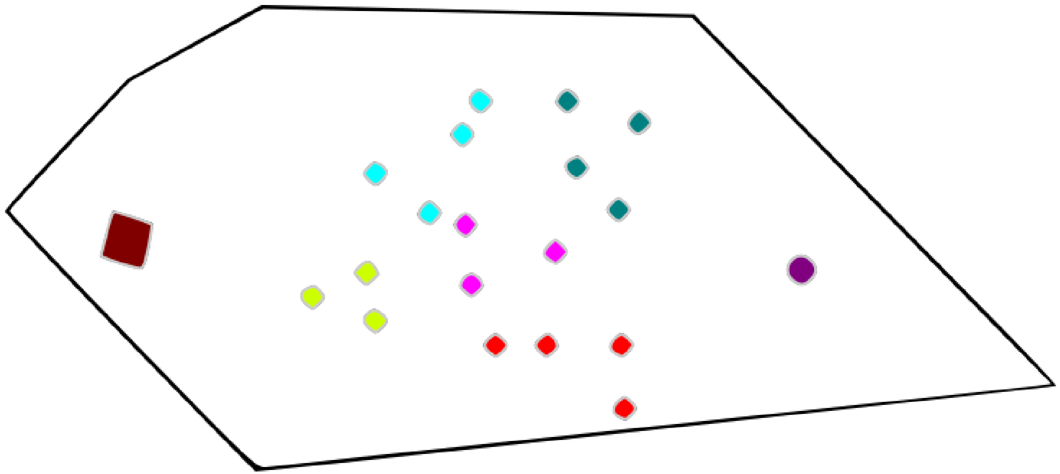
Approximate Distribution Grid Optimization Approach:

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



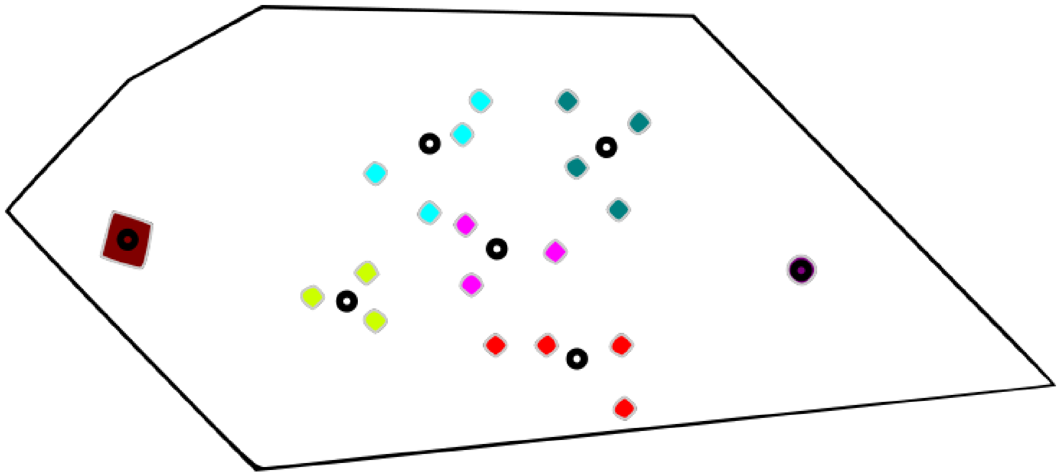
Spatial Optimization of the Distribution Grid

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



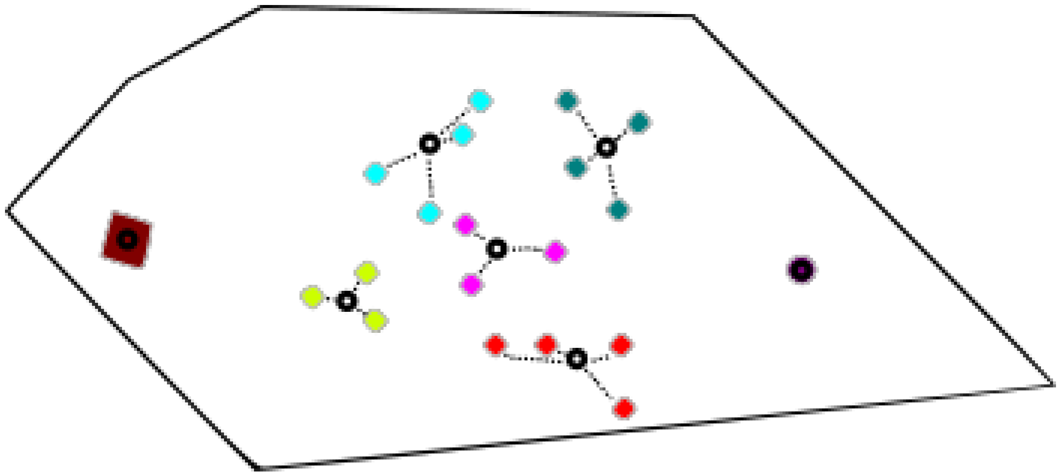
Spatial Optimization of the Distribution Grid

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



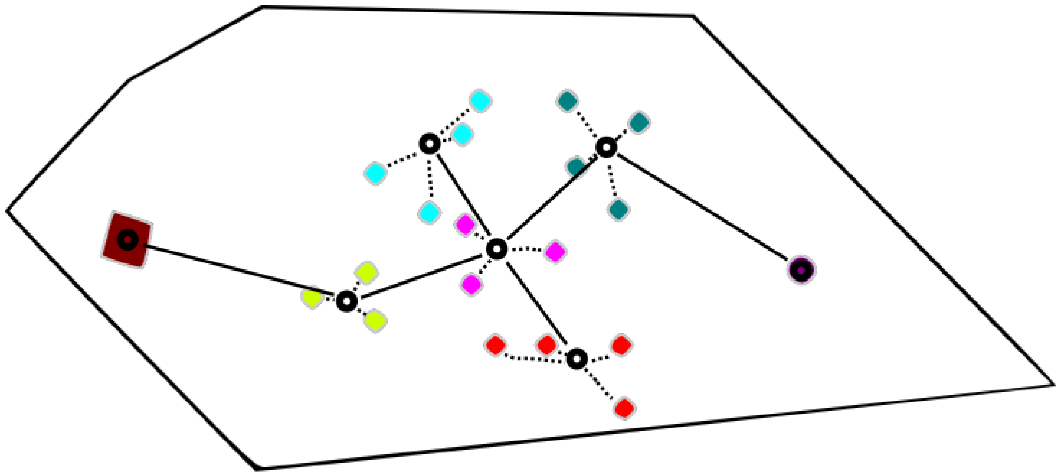
Spatial Optimization of the Distribution Grid

- Each consumer is then connected to its cluster pole



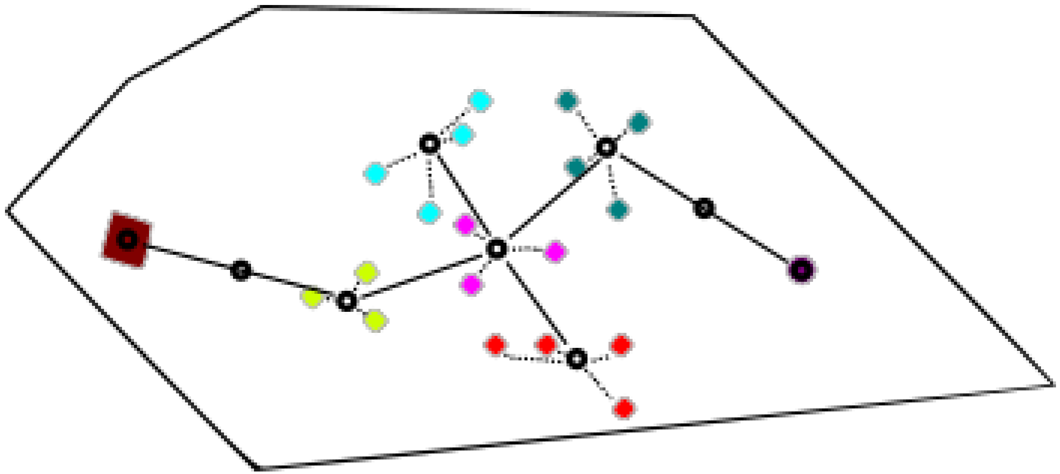
Spatial Optimization of the Distribution Grid

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



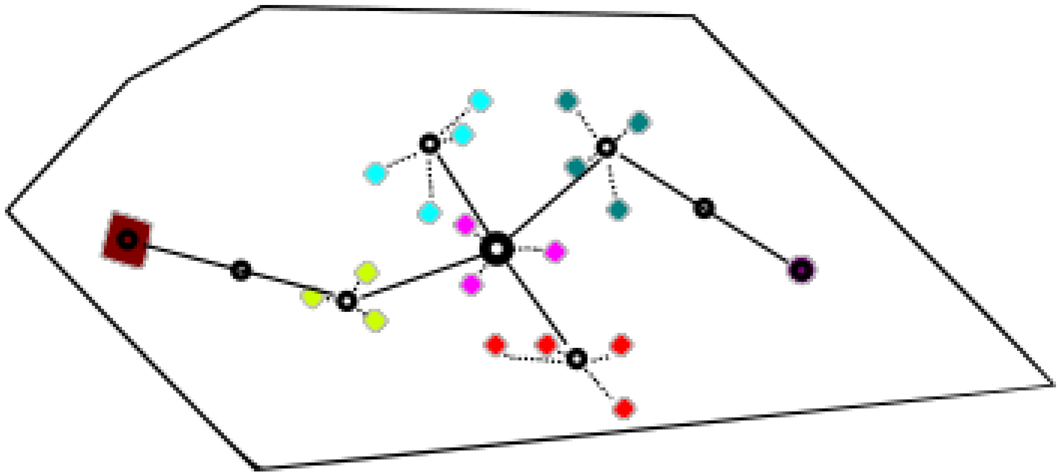
Spatial Optimization of the Distribution Grid

- Addition of intermediate poles to prevent unacceptable cable lengths

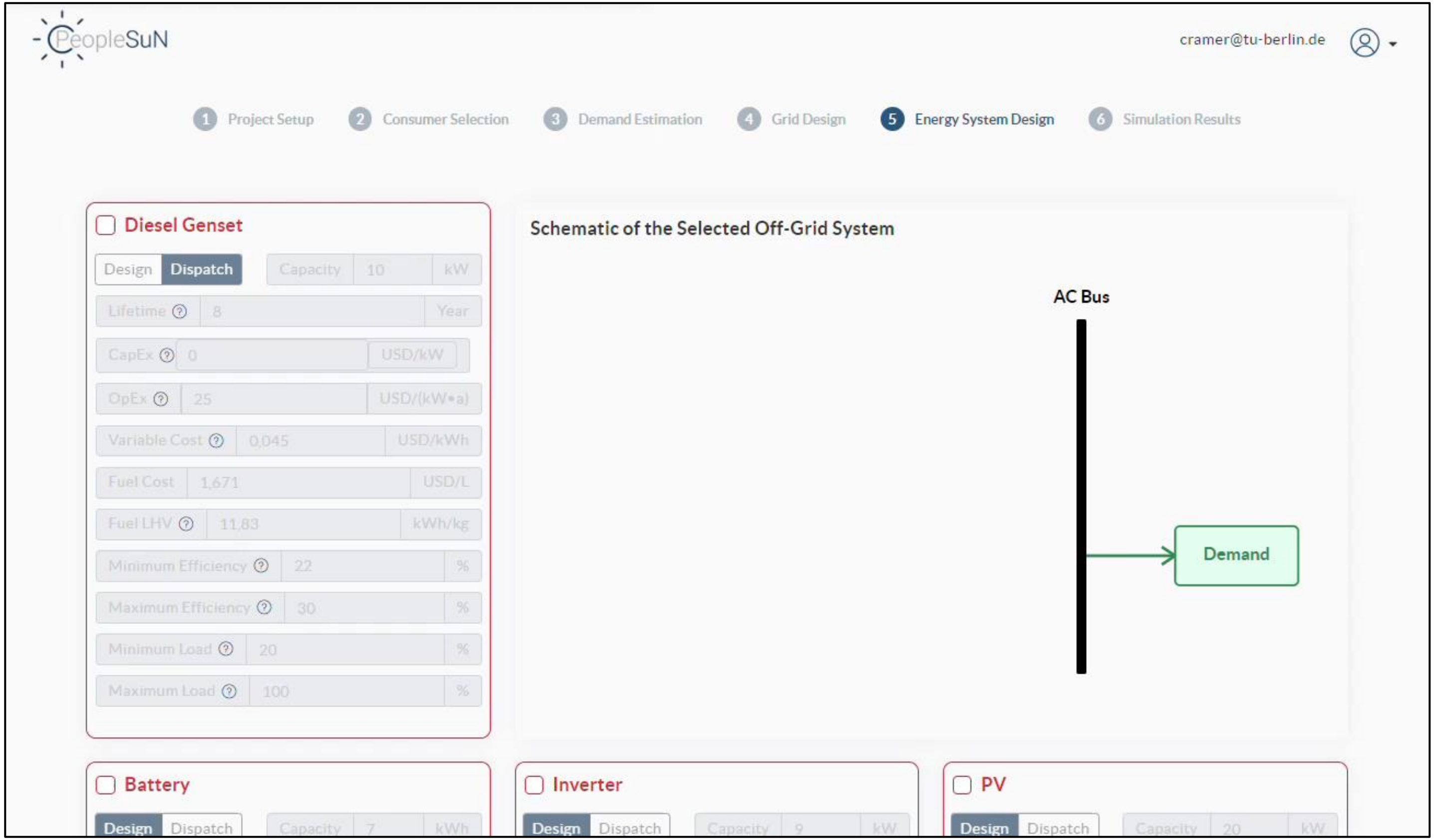


Spatial Optimization of the Distribution Grid

- 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



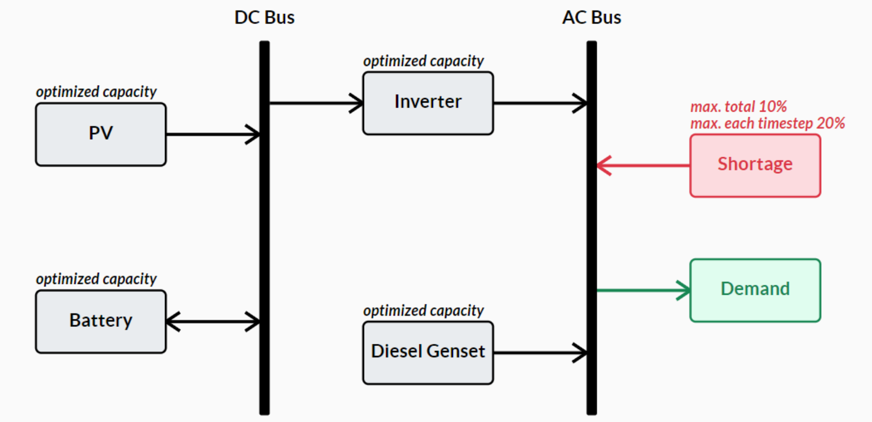
Energy Supply System

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

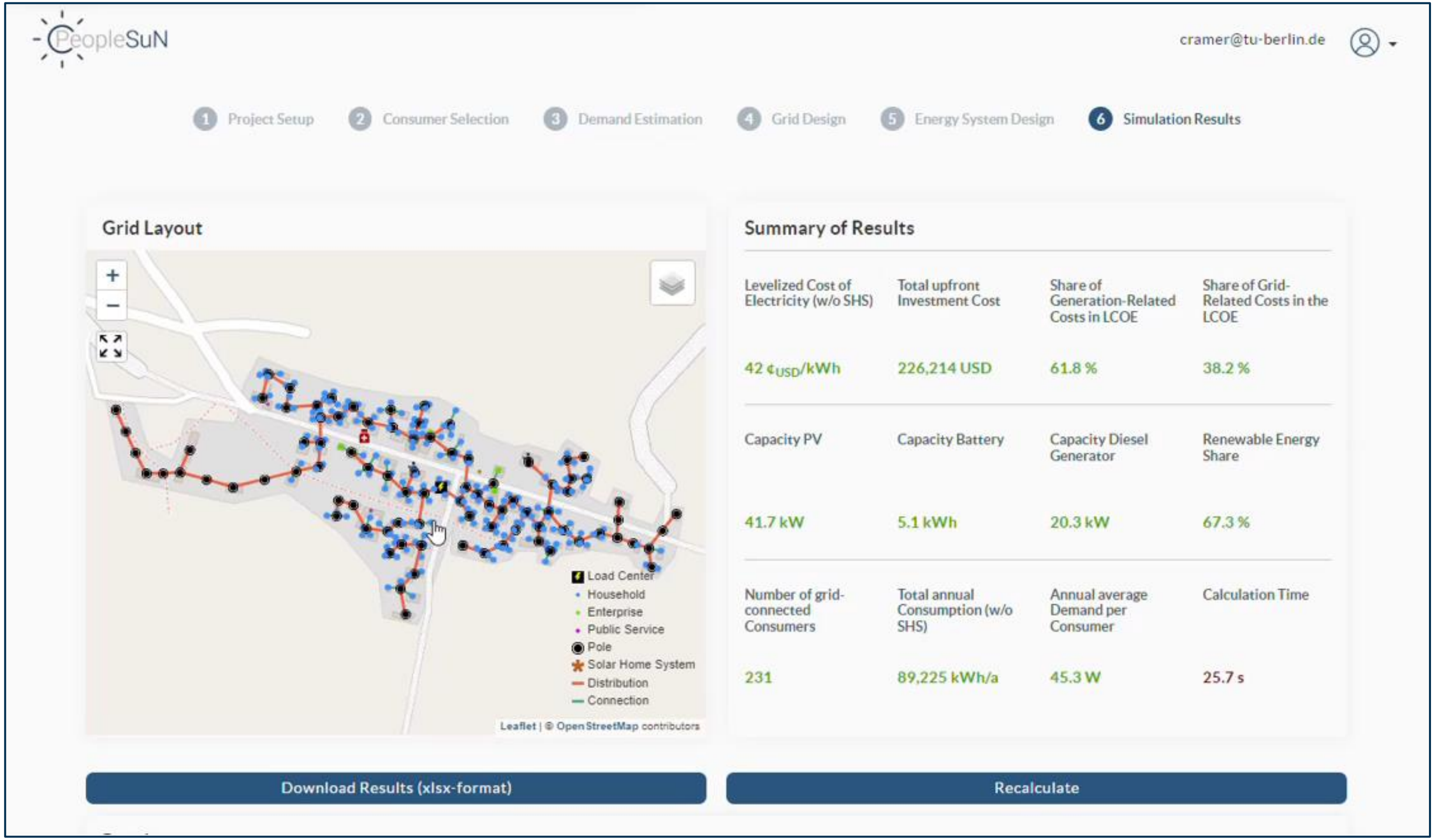
Optimized Capacity | Fixed Capacity

Capacity	20	kW
Lifetime	25	Year
CapEx	441	USD/kW

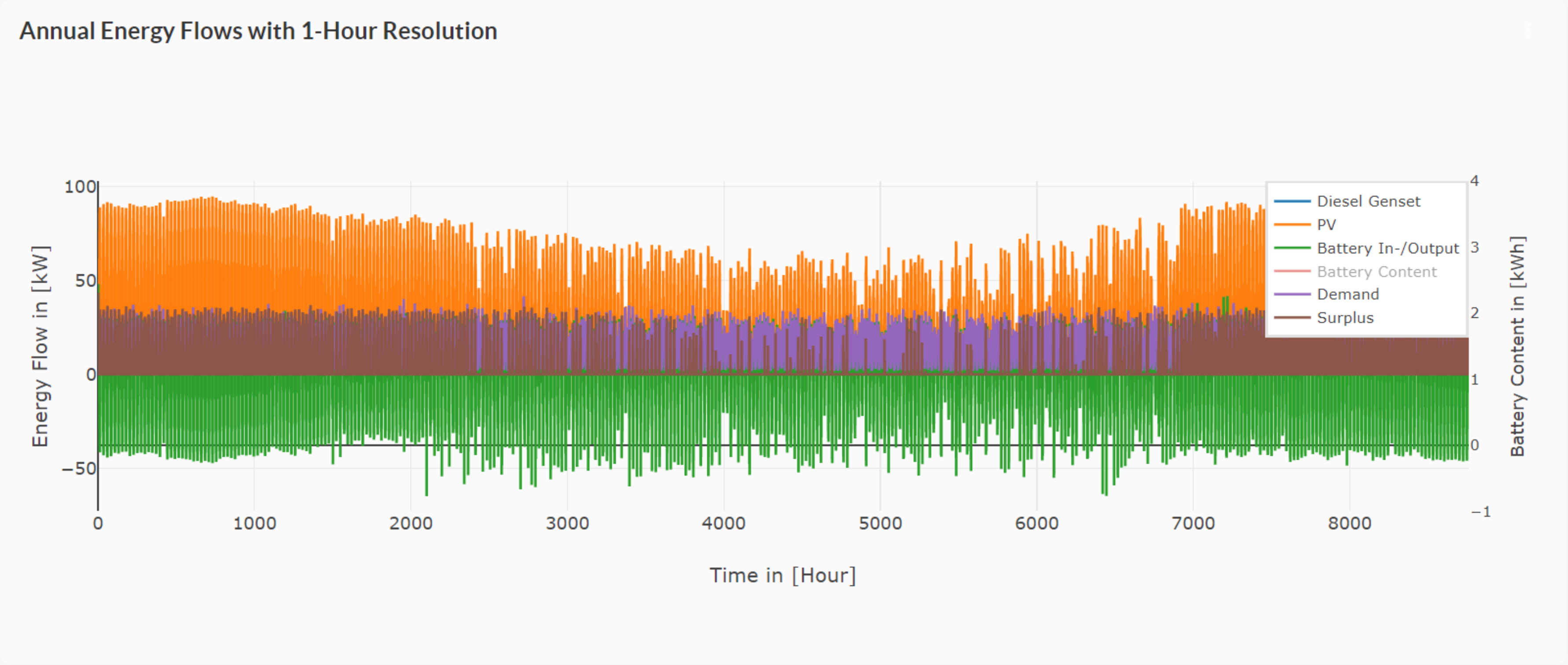
Shortage

Max. Total Shortage	10	%
Max. Shortage Each Timestep	20	%
Shortage Penalty Cost	0.8	USD/kWh

Results – Many different metrics - Downloadable

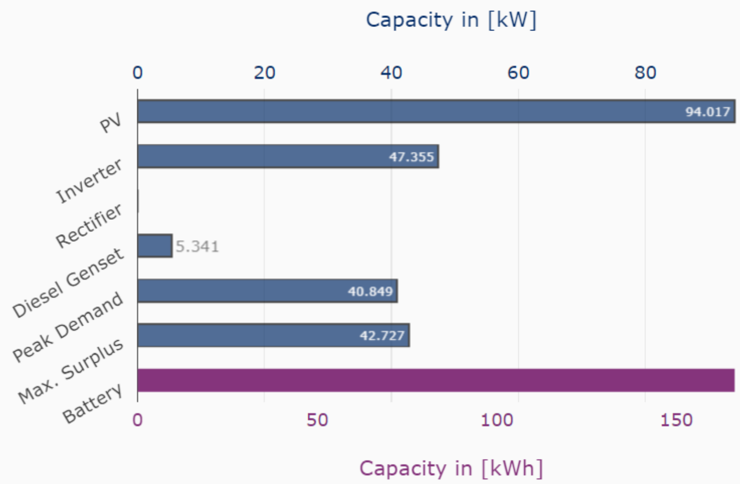


Results – Energy Flows of All Components

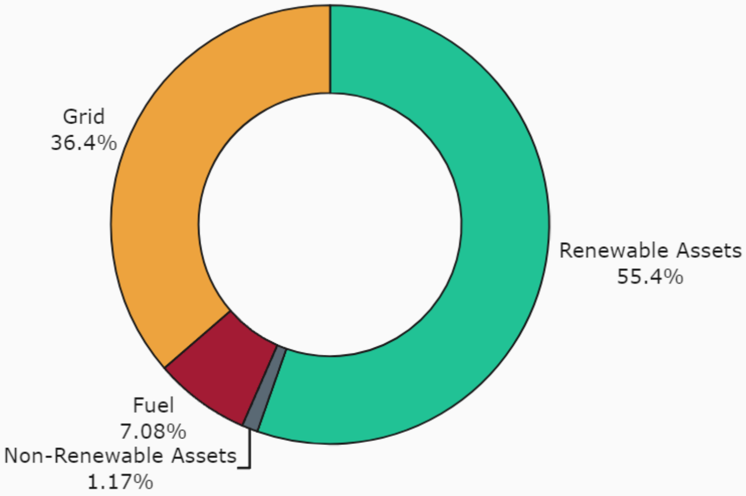


Results – Capacity and LCOE Breakdown

Optimal Capacity of Components

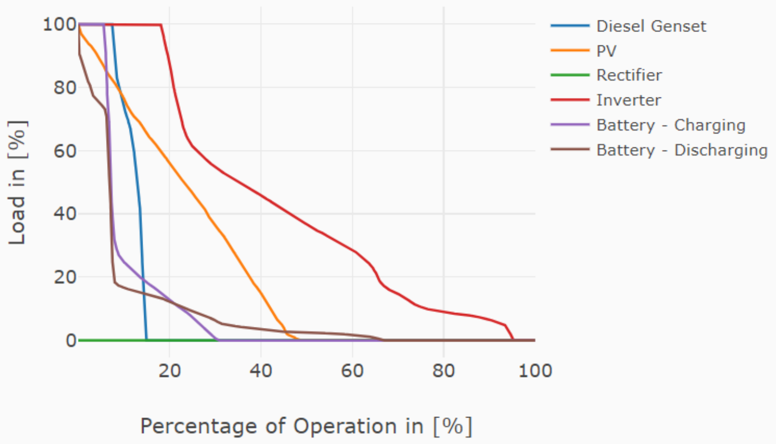


Breakdown of the LCOE

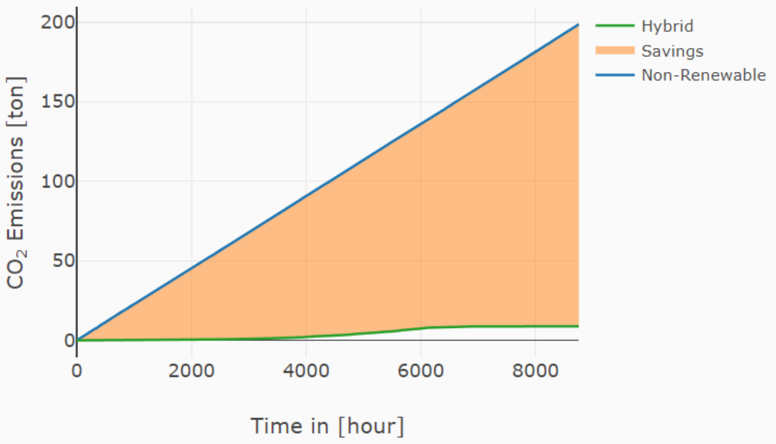


Results – “Duration Curves” and CO2 emission savings

Duration Curves for All Components



Cumulative CO_2 Emissions



Summary

- 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!

Dr.-Ing. Philipp Blechinger
Head of Unit
Off-Grid Systems

Reiner Lemoine Institut gGmbH
Rudower Chaussee 12
12489 Berlin

Tel.: +49 30 1208 434 40

E-Mail: philipp.blechinger@rl-institut.de
www.reiner-lemoine-institut.de