Demand-Needs Nexus in Comprehensive Off-Grid Energy Planning

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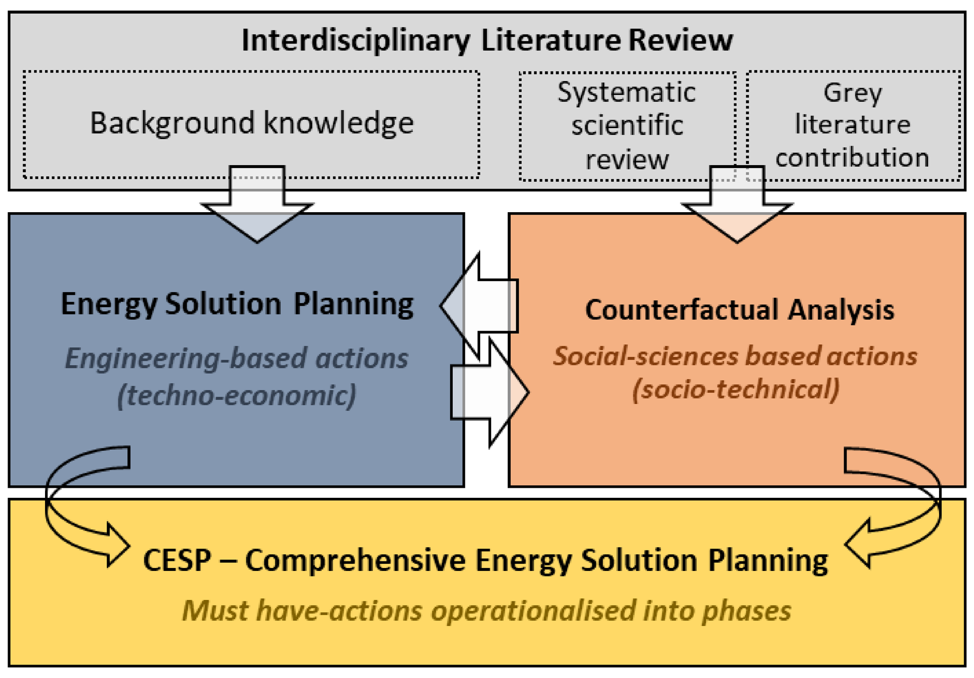
Abstract

The **Comprehensive Energy Solution Planning (CESP) framework**—a novel, evidence-based approach that integrates both **engineering and social sciences** perspectives to holistically guide energy access projects. CESP comprises sequential yet iterative phases that blend traditional engineering-driven actions with social insights, ensuring that both technical feasibility and social acceptance are factored into microgrids project planning. The CESP's focus on need-based demand estimation and socio-technical planning supports long-term energy goals, providing a robust tool for planners facing complex, dynamic environments.

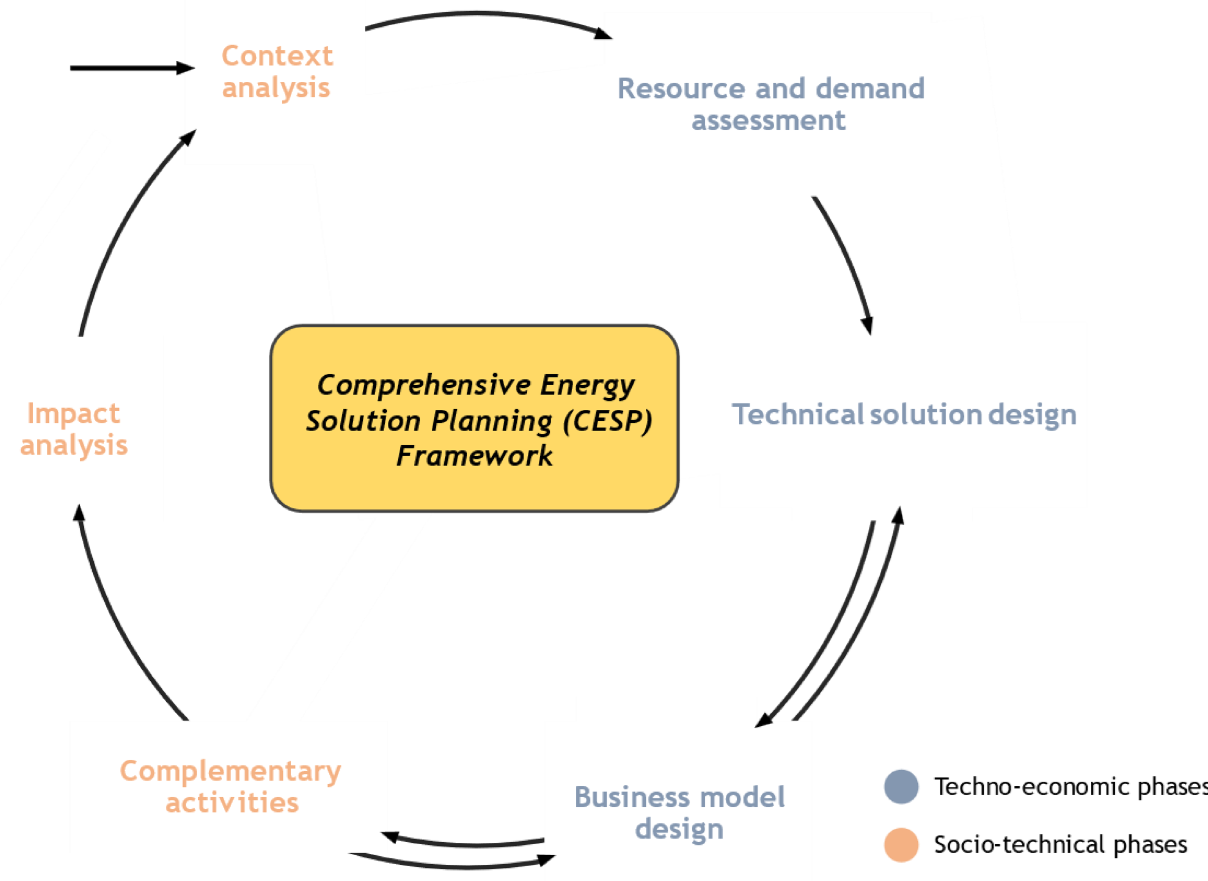
We focus here in particular on the insights that can be derived from the consideration of the **Demand–Needs Nexus**, proposing two different methodologies for demand estimation of un-electrified communities, especially in data-scarce rural settings. Introducing **a data driven methodology** designed to characterize appliance adoption and usage patterns, leveraging an **open-access database** rich in socio-economic indicators, and a set of **archetypes of rural energy users** specific to Sub-Saharan Africa, to meet the demand assessment needs of energy planners working **without extensive field data** .

Keywords: energy planning, off-grid, rural electrification, demand estimation, demand-needs nexus

The **energy solution planning** represents the state-of-art and provides must-have actions derived from the engineering practice.



The **counterfactual analysis** is used to understand the reasons for failure in energy access projects by identifying some must-have actions to prevent the failure of the intervention. Based on the missing actions, a list of social-oriented actions is given



1 Context Analysis

Regulatory Framework Assessment

Regulatory framework assessment involves identifying policies, standards, compliance requirements, legal boundaries, incentives, and procedural mechanisms to ensure project feasibility, sustainability, adherence to governance structures, and alignment with local development priorities..

Need and Priority Identification

Needs and priority identification involves assessing local energy demands, stakeholder expectations, and community aspirations to prioritize interventions, ensuring alignment with developmental goals, resource availability, and long-term sustainability of energy access projects.

2 Resource and Demand Assessment

Resource Assessment

Resource assessment involves evaluating local energy resources such as solar, wind, biomass, or hydro, determining their availability, reliability, and potential to meet current and future energy demands in the project area.

Demand Assessment

Demand assessment involves analyzing current energy usage, forecasting future demand growth, and identifying patterns to design tailored, sustainable energy solutions that address community needs and support local development.

3 Technological Solution Design

Technical Solution Identification

Technological solution identification involves selecting appropriate energy technologies, considering local resource availability, demand patterns, socio-economic context, and feasibility to ensure reliable, cost-effective, and sustainable energy access solutions for the community.

Technical Sizing

Technical sizing involves determining the optimal capacity of energy generation, storage, and distribution systems to meet projected demand, ensuring cost-efficiency, reliability, and alignment with local resource availability and project objectives.

4 Business Model Design

Business Model Identification

Business model identification involves selecting frameworks for energy delivery, ensuring financial sustainability, scalability, and alignment with local socio-economic contexts to support long-term project success and stakeholder engagement.

Business Model Formulation

Business model formulation involves designing financial strategies, tariff structures, and operational frameworks to ensure affordability, sustainability, and effective energy service delivery tailored to community needs and local market conditions.

5 Complementary Activities

Complementary activities involve integrating capacity building, microfinance access, market development, and community engagement to enhance energy project sustainability. These efforts stimulate local economic growth, promote productive energy use, and maximize long-term socio-economic benefits beyond energy provision. By addressing skills development, supporting small enterprises, and facilitating access to markets, complementary activities ensure the energy intervention becomes a catalyst for broader community development and resilience, aligning with local priorities and reinforcing the sustainability of energy access solutions.

6 Impact Analysis

Impact analysis involves systematically evaluating the outcomes of an energy project across economic, social, and environmental dimensions to measure its effectiveness. This process identifies both direct and indirect impacts, ensuring alignment with objectives and providing critical feedback for future projects. By incorporating robust metrics, stakeholder feedback, and evidence-based frameworks, impact analysis ensures transparency, accountability, and the ability to adapt interventions to maximize benefits. Additionally, it evaluates long-term project sustainability, highlights lessons learned, and fosters continuous improvement in planning and implementation practices for energy access initiatives.

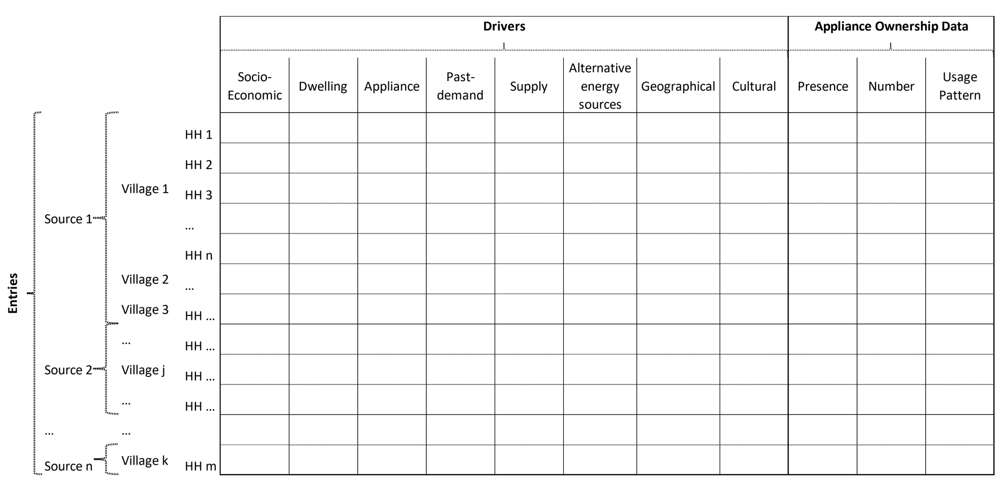
Data-driven prediction of appliance ownership in un-electrified communities

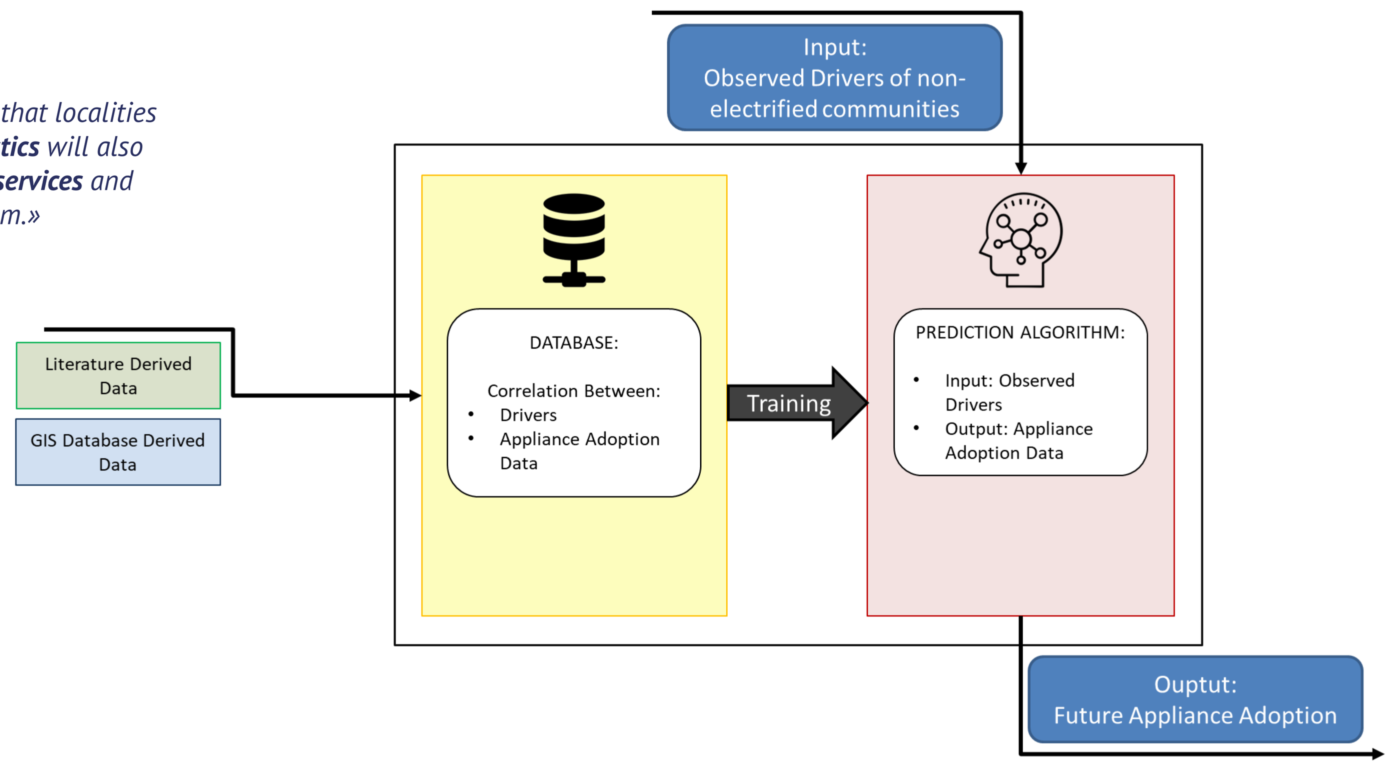
Blodgett et al., 2017

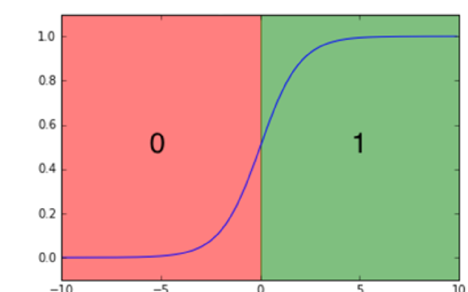
*«If **data sets** are **widely available**, these results suggest that mini-grid developers can use them to **better predict consumption** than the common survey approach.»*

Fabini et al., 2014

*«…in this approach is the assumption that localities that **share socioeconomic characteristics** will also have **similar demand for electricity services** and similar ability to pay for them.»*

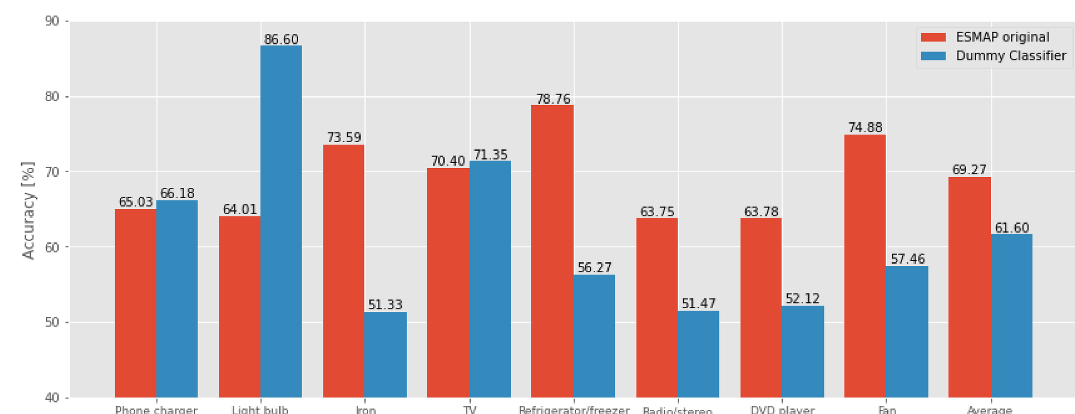




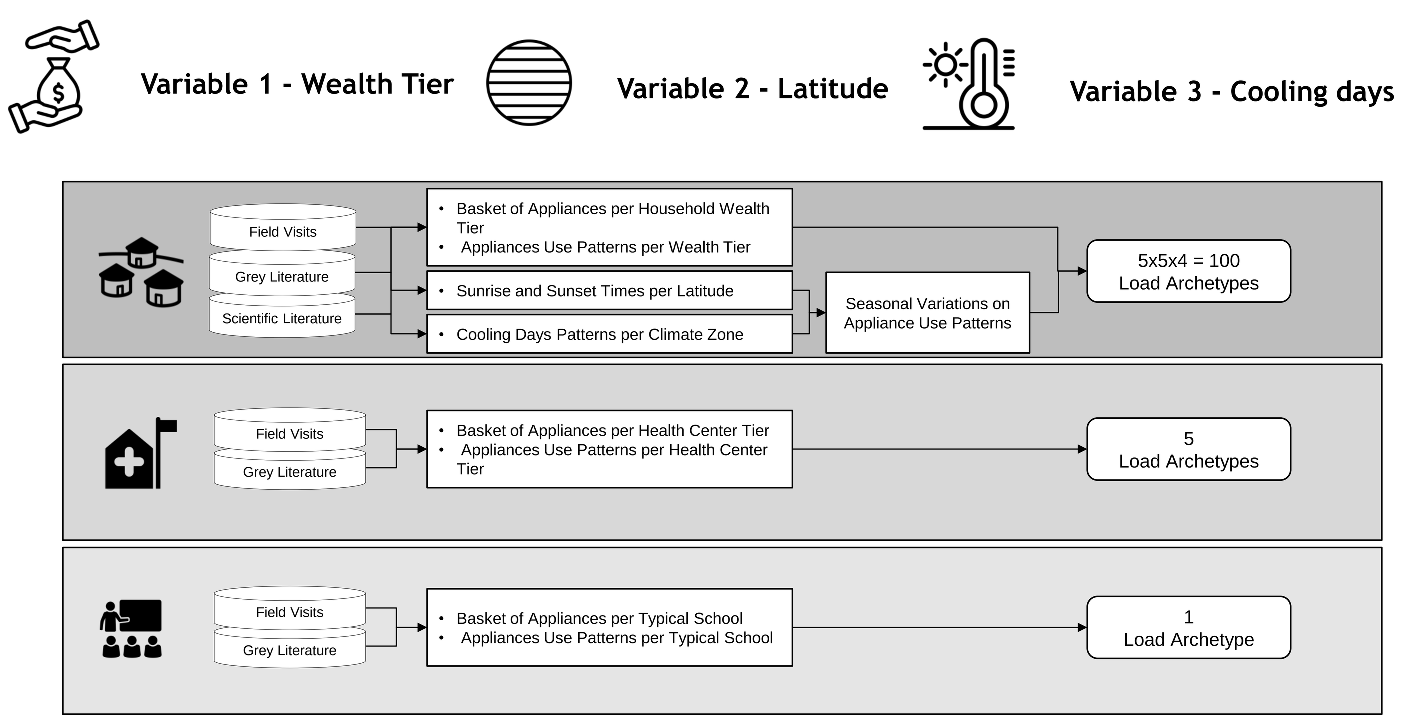


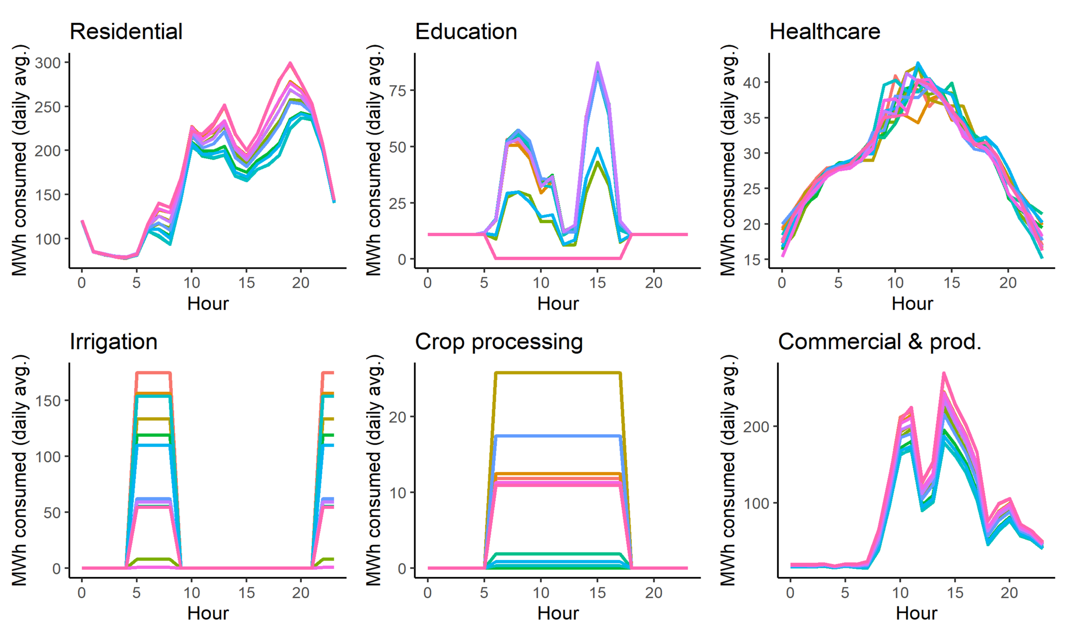
$$y = \frac{1}{1 - e^{-(\beta_0+\beta_1 \cdot X_1+\beta_2 \cdot X_2+\cdots+\beta_n \cdot X_n)}}$$

$$\begin{cases} h_{\bar{\beta}}(\bar{X}) \geq 0.5 \rightarrow y_{pred} = 1 \\ h_{\bar{\beta}}(\bar{X}) < 0.5 \rightarrow y_{pred} = 0 \end{cases}$$



Archetypes of Rural Users in Sub-Saharan Africa for Load Demand Estimation





Work in Progress ...

... Productive Uses of Energy

Variable 1 - Crop Type

Variable 2 - Climate Type
- 2a - Evapotranspiration
- 2b - Precipitation Patterns
- 2c - Harvest Schedules

Variable 3 - Water Depth

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