Holistic framework for multi-vector load projection and stochastic system sizing for Rural Access to Energy

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open energy modelling initiative

Abstract

Robust sizing of rural micro-grids is hindered by uncertainty associated with the expected load demand and its potential evolution over time. This study couples a stochastic load generation model with a two-stage stochastic micro-grid sizing model to take into account multiple probabilistic load scenarios within a single optimisation problem. The problem is then tackled in two of its declinations: evolution over time of electrical load demand, with the inherent uncertainty of estimation of the load change through the years and the design of a proper tool to take advantage in the sizing phase of the load evolution information. The second tackled problem is the broadening of the concept of access to electricity to access to energy, with the problem of estimation of non electrical loads, as space and water heating and energy for cooking, and the subsequent design of a microgrid, or micro-energy system, to satisfy the predicted load. The results suggest how the proposed solutions ensure a benefit not only in the practical tackle of the technical problems of satisfaction of usually neglected loads but also ensure a decrease in the costs of the sized minigrid, in different declinations for the two models.

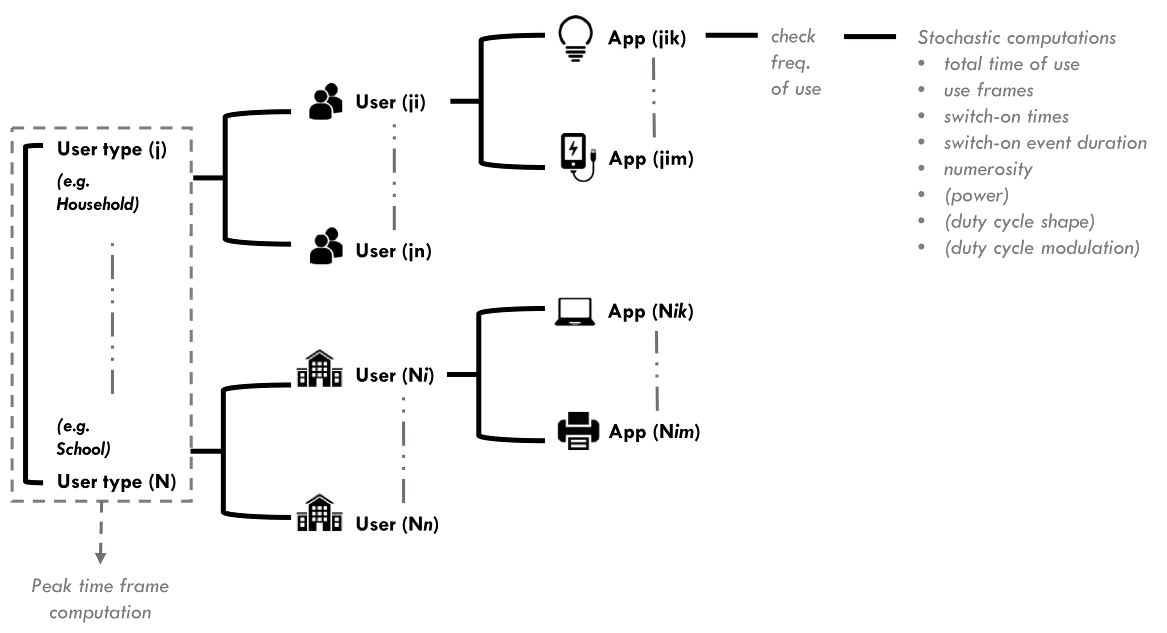
Keywords: microgrid, off-grid, rural electrification, two stage stochastic optimization, stochastic loads

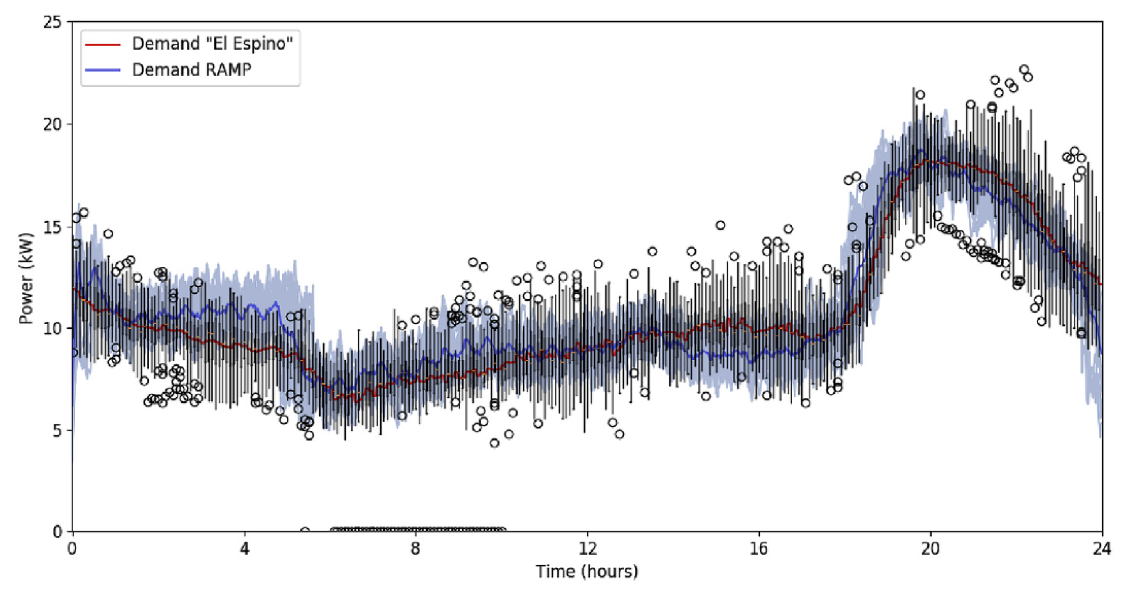
RAMP

RAMP is an open-source **bottom-up stochastic model** specifically conceived for the **generation of multi-energy load profiles** for systems located in **remote areas**.

The model is tested and validated against data obtained from a real system, showing a very good approximation of measured profiles, and an **improved accuracy** compared to existing approaches.

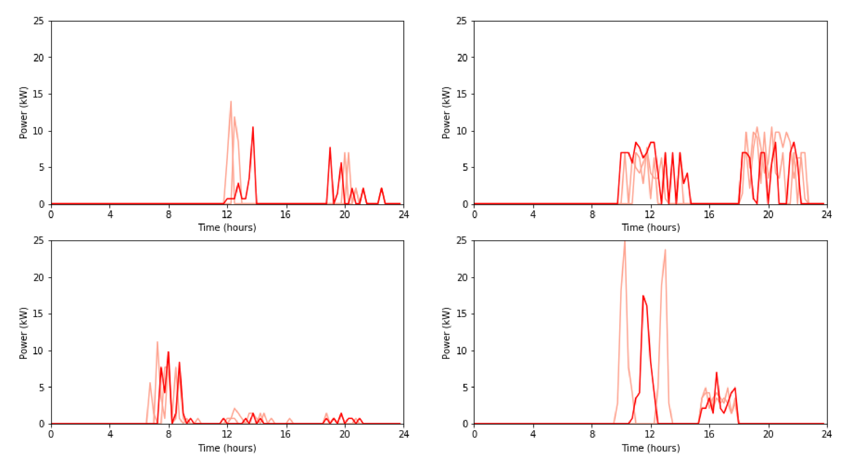
In particular, some innovative features - such as the possibility to define and modulate throughout the day appliances' duty cycles - seem to be determinant in marking a difference with previous approaches.

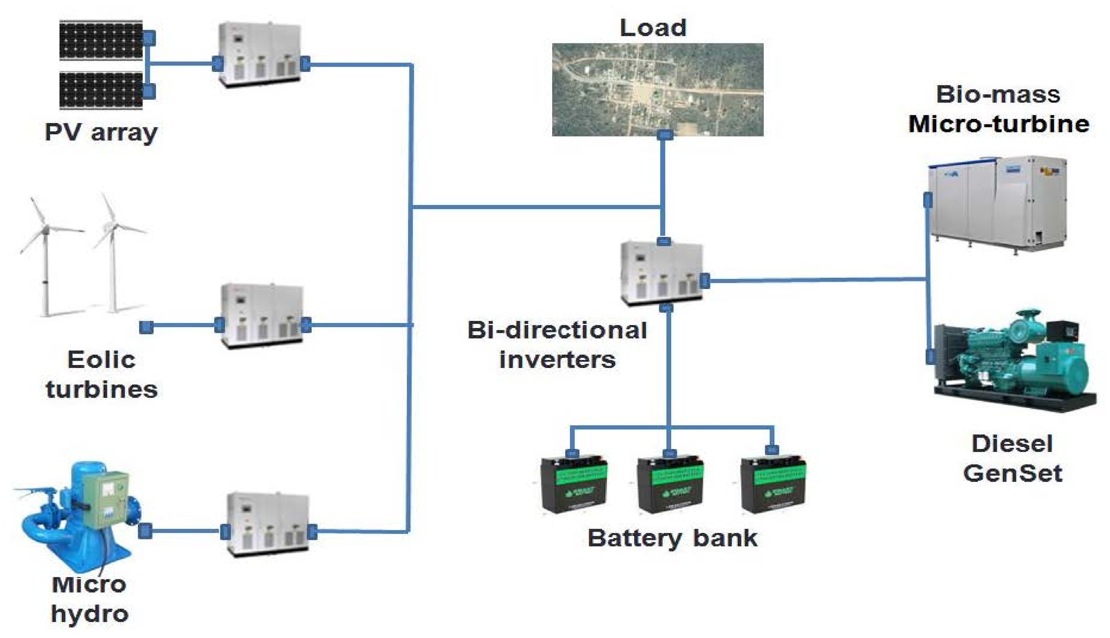




Multi-Energy Configuration

- Dependence of Power required for heating DHW on **groundwater temperature**
- Random variability of power of thermal appliances due to **non-constant behaviour** of such appliances

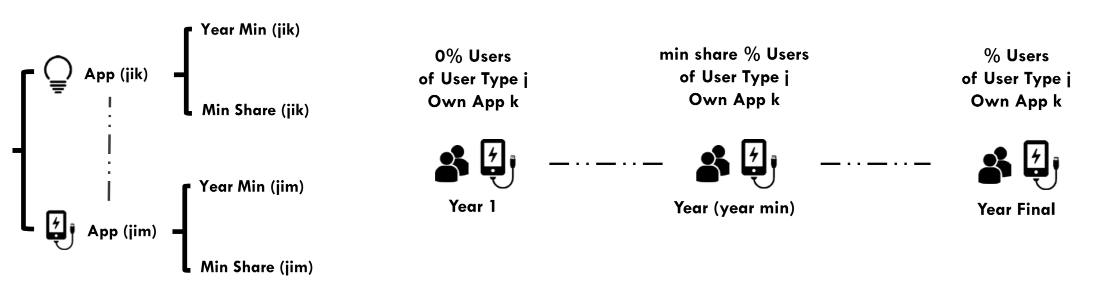




Multi-Year Configuration

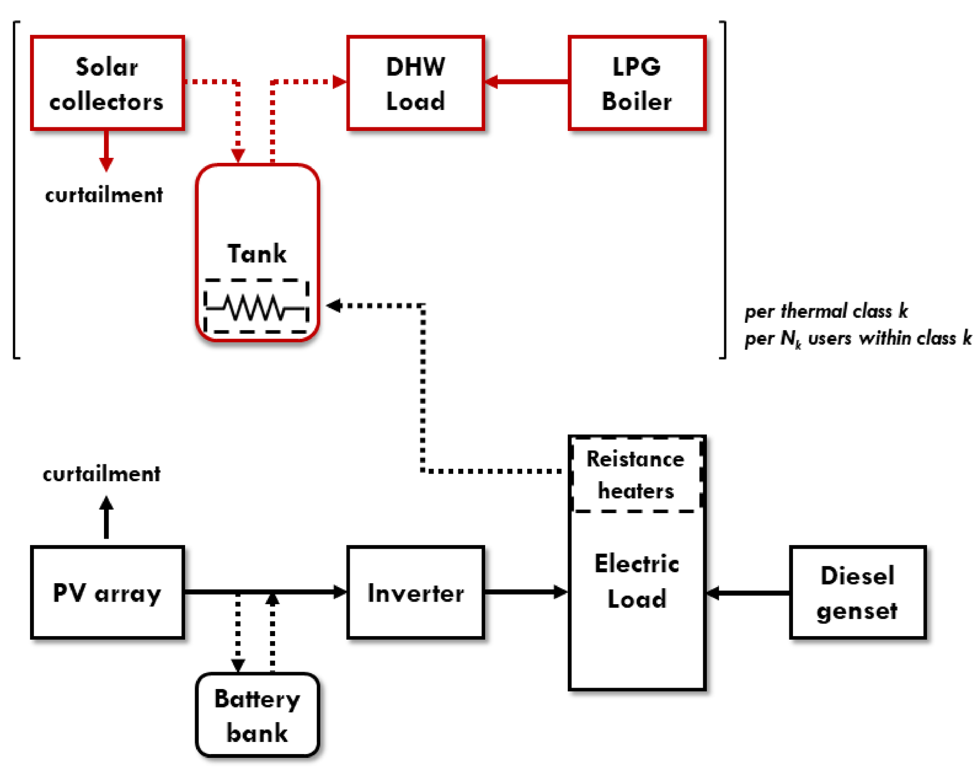
Two novel appliance's attributes to account for long term **load evolution**:

- **year of appearance** of the appliance (first year in which the appliance is assumed to be available as an option for a given class of users)
- **minimum share** (share of ownership of the appliance at the year of appearance)

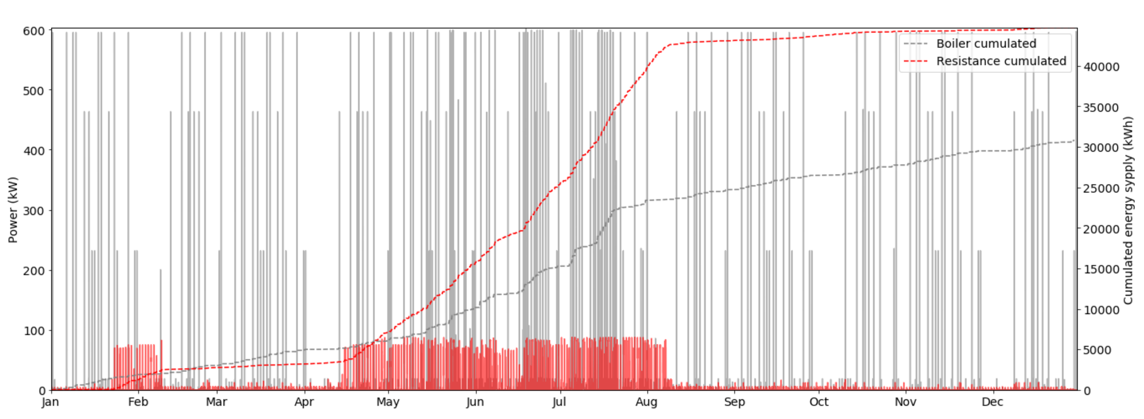


Multi-Energy Formulation

This approach tackles the issue of optimal **microgrid sizing** taking into account not only access to electricity but **access to energy** as a broader problem, in areas where temperatures can drop drastically the access to water and space heating facilities is pivotal and considering the **two issues integrated** in one gives clear advantages.



Results show that the **integration of multiple energy vectors** and storage options allows to identify least-cost **optimal solutions** that remain unreachable within a single-sector perspective A "Multi-Energy" or "Smart Energy System" perspective is thus critical to achieve overall optimal energy systems configurations.



MicroGridsPy

MicroGridsPy is an open-source two-stage stochastic optimization framework for sizing of isolated microgrids in rural contexts capable of performing LP/MILP optimizations.

Objective Function: Minimization of the expected Net present cost

$$Inv + \sum_{s=1}^{S}\left(\sum_{y=1}^{Y}\frac{YC_s}{(1+e)^y}\cdot I_s^{occurrence}\right)$$

Optimization variables:

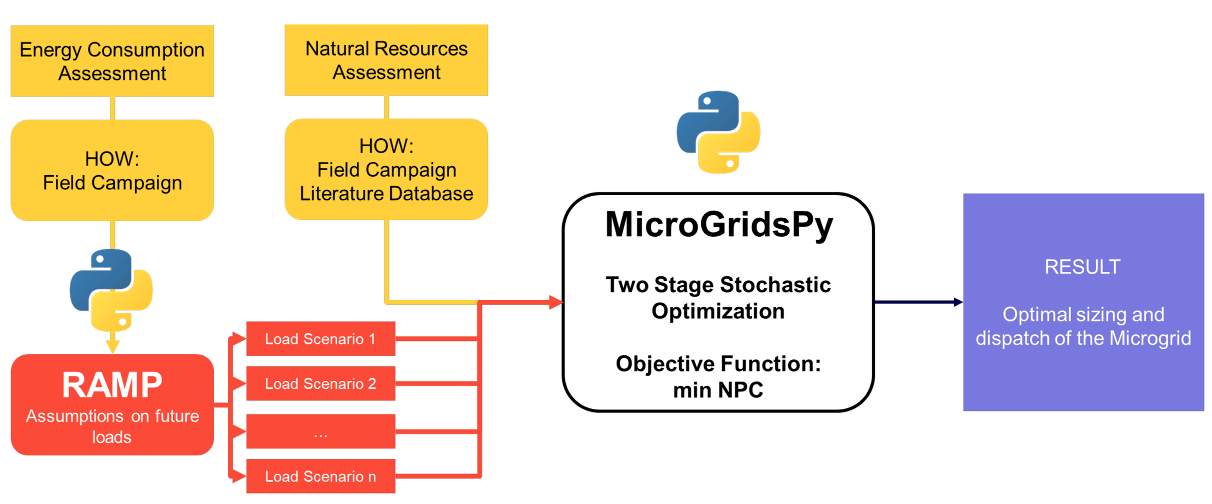
- Nominal Capacities of the **combustion generators, storage systems and renewable sources**.
- Energies flows of the different energy sources.

Constrained to:

- Energy constraints.
- Economic constraints.
- Technological constraints.

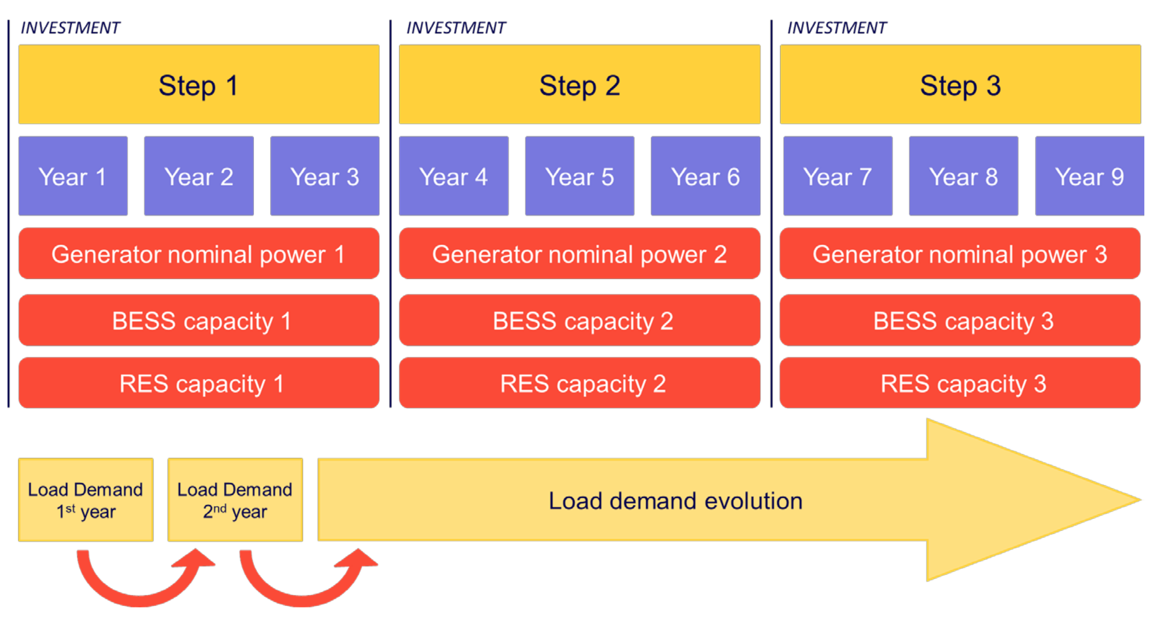
Optimization characteristics:

- **LP/MILP** two stage stochastic optimization.
- Time step **1 hour**.
- Perfect foresight of irradiation and temperature.
- **Uncertainty in the demand and renewable energy**

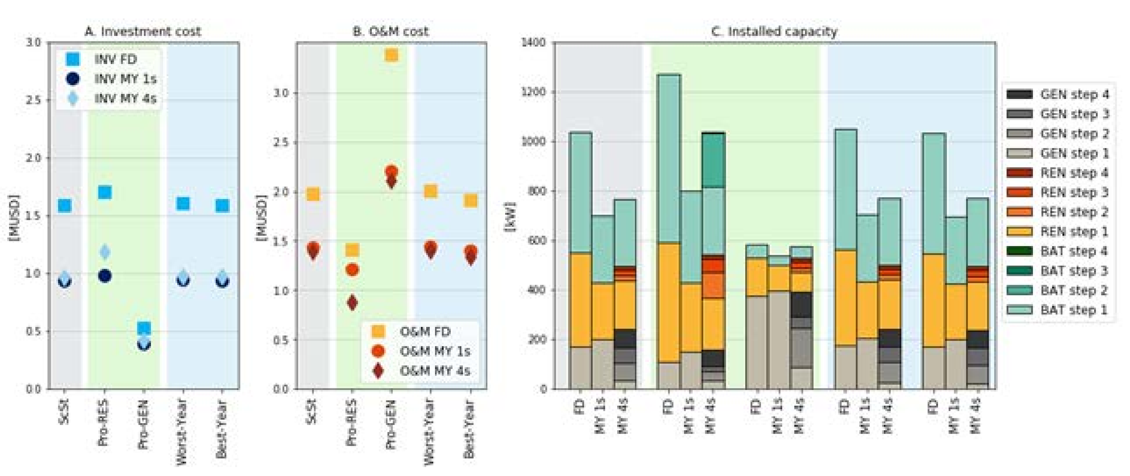


Multi-Year Capacity-Expansion Formulation

This approach tackles the issue of optimal **microgrid sizing in light of the evolution of energy demand** over time, which is likely to occur in newly electrified rural contexts as a result of the **modification of users' lifestyles.**



Results show that the **multi-year** formulation alone allows to **reduce the installed capacity** of the optimised system, and therefore its capital cost. The **capacity-expansion** strategy allows to further reduce the computed NPC. What is more, the adoption of the proposed strategy diminishes the **upfront investment** cost thanks to the partial deferral of the installation, and increases the final-step installed capacity. The capacity-expansion approach also allows the O&M costs to be reduced throughout the lifetime of the system when a stochastic approach is adopted for optimization.



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