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XXXVII Cycle

Modeling and optimization of Renewable Energy Communities as multi-energy systems

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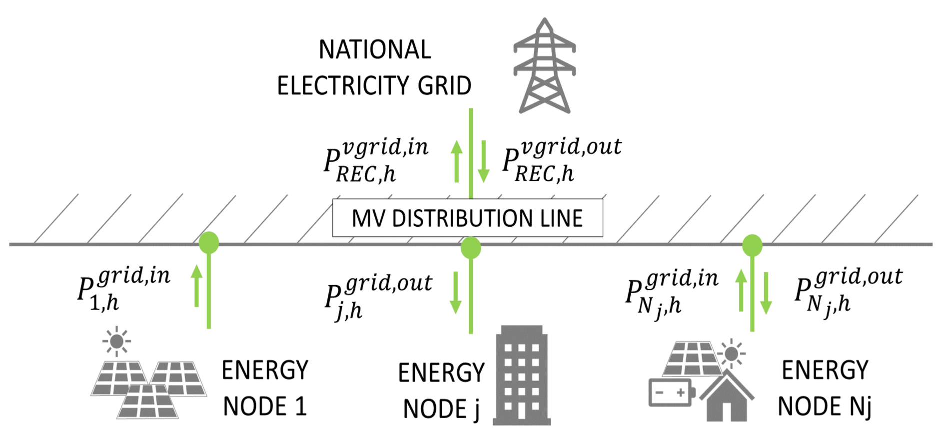
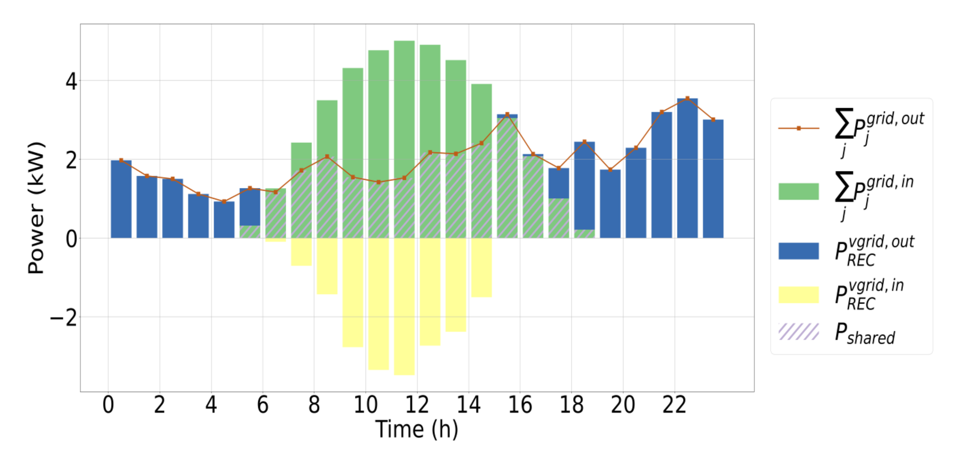
Research context and motivation

- Renewable Energy Communities (RECs) have been introduced in Europe to address the **unexpressed potential** of citizens and local communities and their role in reaching EU's decentralization, decarbonization and sustainability goals. Hence, RECs' objective is to increase their production and consumption from Renewable Energy Sources (RES) .
- The mechanism of **energy sharing** is deemed to be the enabling factor**.** RECs are indeed ensembles of end users and local producers, who exchange energy to increase benefits (their owns and the system's) from RES self-consumption and to allow it in contexts where it was not possible due to regulatory gaps (e.g., multi-apartment buildings).
- In Italy, energy sharing only involves electricity and it is **virtual**, that is REC members can exchange electricity through the public distribution grids. Shared energy is accounted as the **hourly minimum** value between the total injections and the withdrawals into/from the grid.



- According to ARERA, (virtually) shared energy corresponds to physical consumption within the RECs boundaries (i.e., the MV distribution grid). Hence, it decreases the electricity flowing from/towards the national grid. However, in a virtual scheme, this is a pure **matter of accounting**. To achieve this aim, REC members are economically incentivized to share the electricity they produce.
- Building on the knowledge gained in the past years by the research group CADEMA (especially my supervisor prof. Maurizio Repetto and co-supervisor dr. Paolo Lazzeroni) in the multi-energy sector and in the optimization fields, this research wants to investigate to what extent the RECs framework can enable the creation of independent energy clusters (in the view of a **truly decentralized** system) and what instruments are suitable for this task.



Addressed research questions/problems

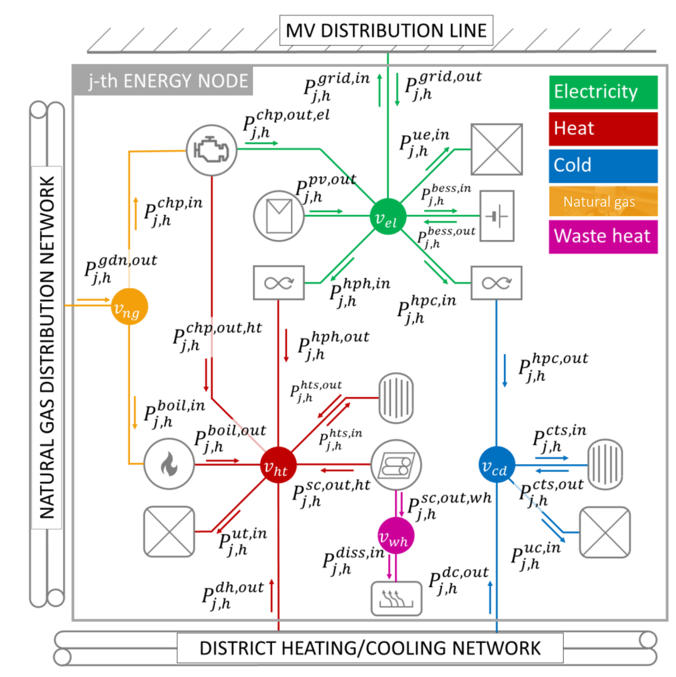
- Let us call "local consumption" the mix of electricity sharing and physical (on-site) consumption of self-produced energy (in the latter case, any energy form). For the RECs' and the energy system's gains, **maximization** of the local consumption should be pursued both at design and operational phases. However, most RES are **intermittent**, hence their production cannot be controlled and must be consumed instantaneously, one way or another. "*Maybe next week*" is not allowed here.
- To **adapt** the consumption to the RES availability, one can: 1. act directly on the loads to change the electricity demand; 2. change it by electrifying other energy consumption; 3. store over-generation for later use.
- While considering the second two options, namely sectors coupling and energy storage, the main research problem was how to **choose between**, or how to **combine**, them, assessing their effectiveness in minimizing the effects of time mismatching between RES production and end-users' energy demand in a REC.
- For this task, a **general framework** was needed, to model RECs as multi-node, multi-energy systems considering technical, operative and regulatory constraints. Due to the elements, and uncertainty in RES generation, energy prices and demand, these systems are complex to manage. Thus, part of the investigation was devoted to understanding whether **traditional approaches** from multi-energy systems were suitable or not.

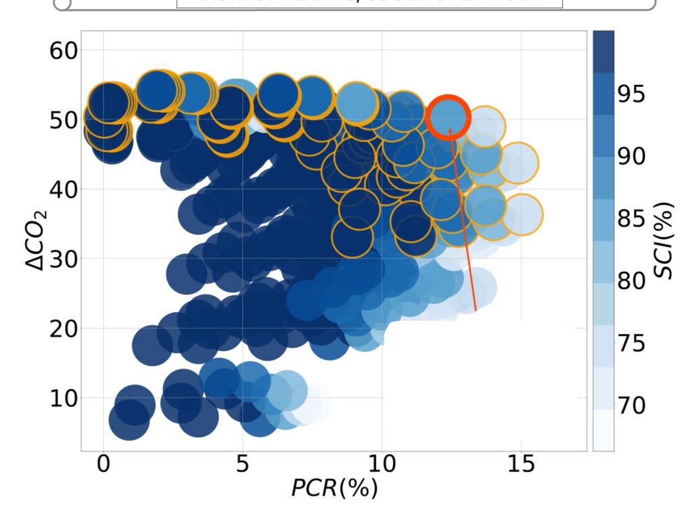
Submitted and published works

- A. Canova, P. Lazzeroni, G. Lorenti, F. Moraglio, A. Porcelli and M. Repetto, "Decarbonizing residential energy consumption under the Italian collective self-consumption regulation," *Sustainable Cities and Societies*, Vol. ahead-of-print, No. ahead-of-print, 2022.
- P. Lazzeroni, G. Lorenti, F. Moraglio and M. Repetto, "Modeling of renewable energy communities: the recoupled approach," in *2022 IEEE 46th Annual Computers, Software, and Applications Conference (COMPSAC)*, 2022, pp. 1349–1354.
- G. Lorenti, I. Mariuzzo, F. Moraglio, and M. Repetto, "Heuristic optimization applied to ANN training for predicting renewable energy sources production", *COMPEL - The international journal for computation and mathematics in electrical and electronic engineering*, Vol. ahead-of-print No. ahead-of-print, 2022.
- G. Lorenti, F. Moraglio and M. Repetto, "Understanding Reinforcement Learning Control in Cyber-Physical Energy Systems," in *10th Workshop on Modelling and Simulation of Cyber-Physical Energy Systems (MSCPES)*, 2022, pp. 1-6.

Novel contributions

- Assuming applying traditional methods and techniques to a new context is also "novelty", then:
- Identified a general and flexible model of RECs as multi-node, multi-energy systems, implemented into an open-source Python-based code (**RECoupled**) to optimize and preliminarily design case studies.
- Assessed heating-electricity coupling in RECs: while (generally) improving performances w.r.t. electricity-only scenarios, this alone is **not enough** to achieve totally self-sufficient and self-consuming clusters (in an economy and technology efficient way).
- Investigated RECs **capacity to dampen** the effects of increasing energy prices on consumers: due to the current regulation, advantages are mainly related to the values of physical self-consumption.
- *Rational modeling: RECs are interconnected, collective energy systems and should be studied as such, but regulatory constraint must be considered!*





Adopted methodologies

- **Optimization** of (hourly) energy flows within and between nodes of RECs in typical days, considering RES production, energy demand and prices as known inputs (no uncertainty). In this case, "traditional" optimization techniques (mixed-integer-linear-programming) are suitable enough, but state-of-the-art solvers are needed (e.g. Gurobi, commercial).
- **Machine learning** techniques, e.g. clustering to extract patterns in the input quantities.
- Key-Performance Indices (KPIs) approach: use **simple indicators** for effective and easy-to-grasp evaluations.
- **Multi-objective** analysis of RECs design, considering energy, environmental and economic KPIs to identify Pareto fronts.

Future work

- Application of this methodology to **real case studies**, thus assessing what are the problems arising when passing from theory to practice.
- **Further investigation** of options in terms of technologies and energy vectors for RECs to increase self-sufficiency and local consumption of RES in an efficient way (e.g., hydrogen for longer-term storage).
- Tackle the **"real time"** problem: how to manage these systems when information suffers from great uncertainty and fast responses are needed? What techniques are suitable?

List of attended classes

- 01RGBRV – Optimization methods for engineering problems (06/06/2022, 30 hours)
- 01LXBRW – Life Cycle Assessment (LCA) (19/06/2022, 25 hours)
- 01DVURW – SDG 13 - Climate action (06/07/2022, 8 hours)

Soft skills

- 01UNXRV – Thinking out of the box (08/11/2021, 1 hour)
- 01UNVRV – Navigating the hiring process: CV, tests, interview (08/11/2021, 2 hours)
- 01SWPRV – Time management (09/11/2021, 2 hours)
- 01RISRV – Public speaking (10/11/2021, 5 hours)
- 02LWHRV – Communication (11/11/2021, 5 hours)
- 01UNYRV – Personal branding (12/11/2021, 1 hour)
- 08IXTRV – Project management (19/11/202, 5 hours)

External training activities

- 24th Stage Scuola Nazionale Dottorandi di Elettrotecnica "Ferdinando Gasparini" (Virtual, January 24-28, 2022, 36 hours)
- PhD workshop on "Data-Driven Surrogate Models" at the 20th International IGTE Symposium 2022 (Graz, September 19-23, 2022, 20 hours)

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