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U-DECK

Executive summary

Urban areas, due to their high population density, intensive infrastructure, and concentrated economic activities, are responsible for approximately 70% of global greenhouse gas (GHG) emissions and consume around 65% of the world's total energy. In this context, Renewable Energy Communities (RECs) have emerged as an innovative and decentralized solution capable of reducing the environmental impact of cities by enabling local production, consumption, and sharing of clean energy.

The U-DECK (Urban Decarbonization) project has developed a dual research strategy focused on both environmental sustainability and economic viability of RECs. This strategy integrates two complementary tools: a simulation tool designed to model and analyse energy flows within renewable energy communities, and a Power Purchase Agreement (PPA) tool aimed at optimizing the procurement of residual energy from renewable sources on the market.

The simulation tool allows us to create and evaluate a wide range of community configurations by altering variables such as building typologies, geographic location, and technological setups. A central focus of the simulations has been the benefits of the electrification of domestic hot water (DHW) production. When compared to conventional systems that rely on fossil fuels for hot water production, a fully electrified DHW system with integrated thermal storage can reduce greenhouse gas emissions by up to 16%. At the same time, the community's self-consumption rate increases by 13% and cost savings and the exploitation of subsidies improve by 14%.

Despite the clear benefits of local energy production, achieving complete self-sufficiency at the community level remains a highly ambitious goal. PPAs, a contractual agreement between a buyer and a renewable energy producer, represent a compelling alternative for securing renewable electricity at stable, fair prices over the long term. However, communities need support in sizing and choosing the best solutions among the available sellers' power plants. In our case study, contracted renewables cover approximately half of the community's hourly baseload. The results show how the tool makes the risk-return trade-off explicit and allows communities to select between higher expected savings and tighter, more predictable outcomes.

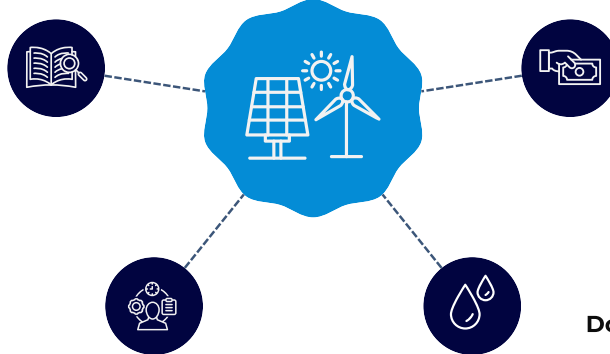
Key Words

Urban Decarbonization, Renewable Energy Community (REC), Energy Flow Simulation, Power Purchase Agreement (PPA), Self-Consumption & Thermal Storage

PROJECT AT A GLANCE

State-of-the-art analysis

- REC paradigm
- District-level energy modeling
- Technological implementations in RECs
- Nudging



PPA for REC

- agreements for renewable energy supply,
- ensuring price stability
- fostering sustainable energy development.

REC management & simulation tool

- short-term energy management
- integrates load flexibility
- long-term procurement strategies through PPA portfolio optimization.
- improve planning and operation

Domestic Hot Water (DHW)

- Shiftable electric load (while guaranteeing comfort)
- maximizes self-consumption
- smooths demand peaks
- transparent control logic.

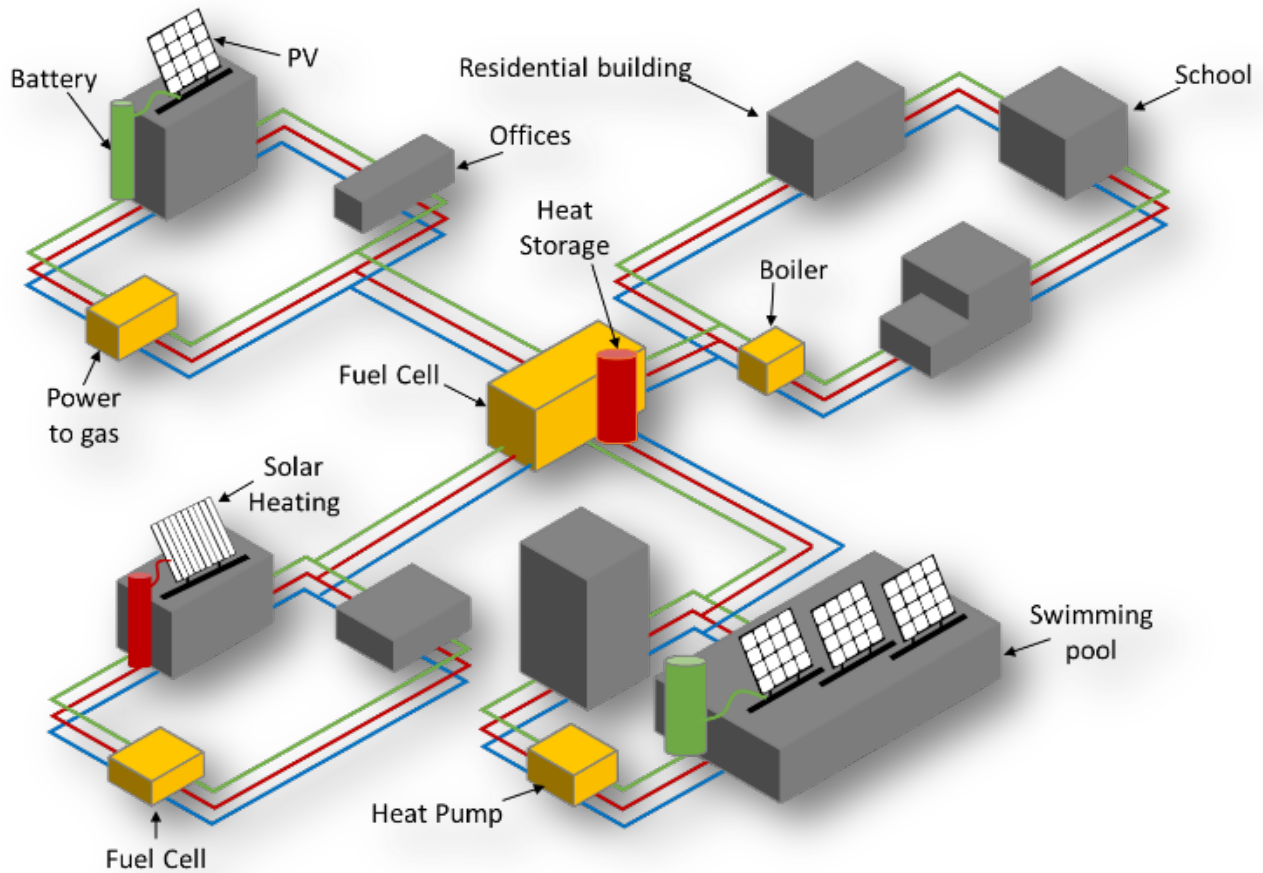


Figure 1 - Example of a REC configuration

**Project description
written by the
Principal Academic
Tutor**

Renewable Energy Communities (RECs) are places where prosumers (producers and consumers) can share the benefits of generating and exchanging local renewable energy to maximize their energy self-sufficiency. This is fostered by the diffusion of decision-making instruments able to manage complex energy systems, also unlocking new business models. The U-DECK project combined several solutions to reach urban areas decarbonization.

A REC platform provided by MAPS (namely, ROSE) hosts a set of tools to optimize both planned and real-time community operations. Internally, the objective is to maximize renewable self-production through advanced energy management systems and integrated building designs, effectively combining digital and architectural solutions. This is made possible by an advanced estimation of electric and thermal demands for the REC design, and by the exploitation of different sources of energy storage to effectively couple these demands with available solar production. Externally, the objective is to allow urban communities to contribute to off-site renewables development and to access stable electricity prices leveraging on long-term electricity purchase contracts, known as power purchase agreements (PPAs). Currently exploited only by large corporations (Google, Amazon) because of their technical and contractual complexity, PPAs can grant an access to low cost-of-capital money flows for renewable power plants developers, while ensuring a cheap, clean and predictable energy supply for buyers.

The project has developed along three phases:

- In a first phase, participants have reviewed and assessed the available solutions to select the most promising ones;
- In a second phase, selected solutions have been developed according to approaches typical of the diverse disciplines they pertain to (e.g., computer science, smart grids and energy systems, sustainable architecture);
- In a third phase, developed solutions have been validated through ad-hoc simulations, proving their correct operations within an artificial environment.

The results of conducted simulations have been presented in two different works at the 9th International Conference on Clean Electrical Power held in June 2025. Beyond the project activities, the ambition is to provide a further validation of developed solutions through an on-field testing, directly involving some final users in experimentations.

**Team description
by skill**

The team is composed of 5 members:

- **Angelo Minieri** – *Computer engineer* – Developed the energy management tool integrating simulation data for U-DECK.
- **Giacomo Iuculano** – *Management Engineer* – Focused on PPA strategies and portfolio optimization for community energy supply
- **Lorenzo Caravetta** – *Energy Engineer* – Worked on REC modeling and supplied datasets for the management tool integration.
- **Claudio Di Tuccio** – *Energy Engineer* – Modeled the REC and provided energy flow data to support the management tool.
- **Gio Bellone** – *Energy Engineer* – Modeled building archetypes, provided data to REC simulations, and worked on PPA analysis.

Goal

The primary goal of the U-DECK project is to design and validate an integrated energy management solution for Renewable Energy Communities (RECs) that unifies day-to-day operational control with long-term renewable procurement. The system consists of two complementary modules: an energy-flow simulation & control tool that models buildings, PV panels and flexible loads, and a PPA portfolio optimizer that procures the residual demand from off-site renewables under explicit risk-return trade-offs. Together, they enable community operators to minimize residual demand first, then procure what remains through bankable, risk-aware contracts.

Operationally, the project aims to provide a clear overview of the benefits of electrifying and intelligently scheduling hot water to absorb midday PV and flatten evening peaks, using a transparent, rule-based controller rather than black-box solvers. The simulation suite provides hourly energy balances for each building archetype and the community (imports/exports, pump use, storage state) and produces the residual-demand profile that feeds procurement. Key performance indicators (self-consumption, virtual self-consumption, CO₂ intensity and annual costs) are computed from the same runs, building a robust, replicable evidence base for decisions.

On procurement, the goal is to present the advantages of democratizing access to PPAs for communities via a bi-objective optimizer (NPV-CvaR) under pay-as-consumed (PAC) settlement. The tool presents a clear Pareto set (e.g., Max-NPV vs. Max-CvaR) and quantifies coverage of the community's baseload, curtailment, and downside protection, guiding choices between low-cost solar with proxy-storage options and more diversified wind portfolios for stability. The end state is a single decision-support platform where simulated residual demand is converted into a contract portfolio with predictable costs and verifiable carbon benefits for REC managers, planners and policymakers.

Understanding the problem

Renewable Energy Communities (RECs) promise lower emissions and bills, yet they face a structural challenge: PV generation peaks at midday while residential demand peaks in the morning and evening. The mismatch depresses local self-consumption and increases grid dependence, limiting both environmental and economic returns.

In the EU, and explicitly in Italy, RECs are recognized and incentivized. Virtual self-consumption is rewarded alongside the private savings of physical self-consumption. It is defined as the minimum between community withdrawals and injections at the grid node, and it is supported by a bonus tariff with fixed and variable components plus an ARERA premium (up to 138.5 €/MWh in the cited framework). These rules create a clear operational signal: shape community demand to align with local renewables output and maximize sharing.

However, much of household load remains hard to align without active control. A pivotal, often overlooked end use is Domestic Hot Water (DHW): sizable, daily and, if electrified, time-shiftable. Without scheduling (or with gas boilers), midday PV is exported rather than used; with heat pumps, DHW can absorb surplus PV and flatten evening peaks, improving self-consumption and emissions at community scale.

Even with best-effort orchestration, a residual demand persists that local generation cannot economically cover at all hours or seasons. Today, communities typically satisfy this remainder with standard grid purchases, exposing them to price volatility and diluting decarbonization claims. A complementary instrument is the Power Purchase Agreement (PPA), which can secure long-term renewable supply at predictable prices and hedge market risk, bridging community-level flexibility with large off-site projects (solar, onshore/offshore wind, storage-linked products).

Therefore, the problem is twofold. First, operational: quantify and shift flexible loads to increase physical and virtual self-consumption under the Italian/EU incentive design. Second, procurement: translate the time-resolved residual demand into a risk-aware renewable portfolio, balancing expected savings and downside protection. Addressing both requires an integrated, hour-by-hour energy management of buildings, PV, and incentives, coupled with an Over The Counter framework that is accessible to community managers.

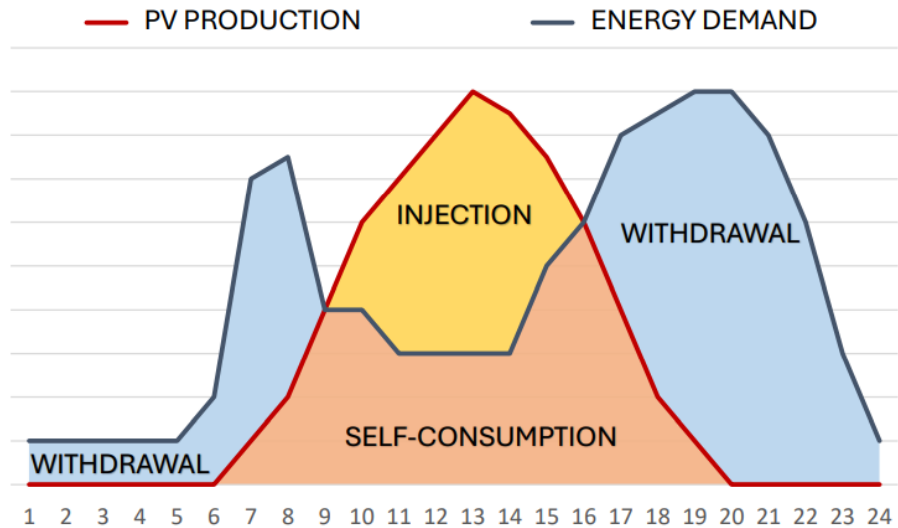


Figure 2 - Production/Consumption mismatch on an average day of the year

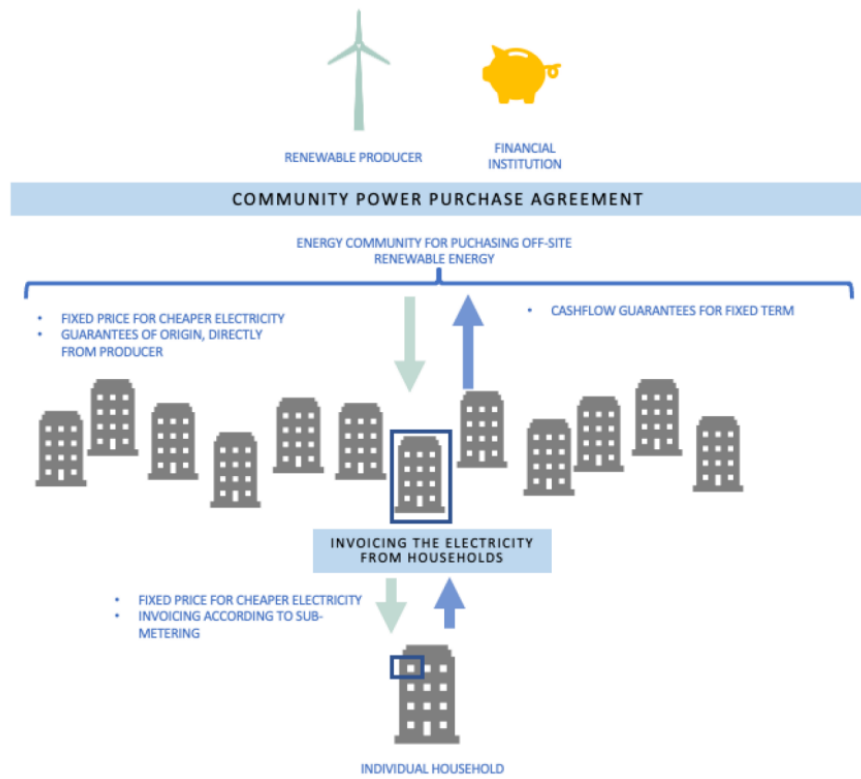


Figure 3 - Schema of PPAs agreements

Exploring the opportunities

U-DECK reframes the generation/demand mismatch as actionable levers across operations and procurement.

On the operations side it proposes electrification and smart scheduling of DHW to absorb midday PV production and shave evening consumption peaks. Because DHW is daily, sizable and shiftable, simple rule-based control is enough to boost physical self-consumption and cuts imports and emissions, without black-box optimizers or real-time controllers, creating immediate value for users (lower bills, higher autonomy) and for the community (smoother net load, verifiable CO₂ cuts). These gains stack with Italian incentives for virtual self-consumption under the cited framework, monetizing flexibility via both avoided purchases and incentive revenue and strengthening the business case for heat pumps and storage.

On the procurement side, U-DECK opens to long-term renewable PPAs using pay-as-consumed (PAC) settlement and a bi-objective optimizer (NPV-CvaR). Communities can choose along a Pareto frontier between higher expected savings and tighter downside protection: profit-oriented mixes tilt to low-cost PV and proxy-storage; risk-averse ones diversify into onshore/offshore wind for stability. Contracted renewables cover a substantial share of baseload and stabilize costs, with curtailment and residuals quantified hour-by-hour to avoid shape risk.

Generating a solution

U-Deck implements a two-module system:

Module A – Energy-flow simulation & control. A library of building archetypes and PV layouts generates hourly demand/production. DHW is modeled as gas baseline, instantaneous heat pump, or heat pump + thermal storage. A transparent controller applies three rules: charge on PV surplus; ensure comfort by topping up before the evening peak if storage is low; serve draws from storage first. Outputs include per-POD and community balances (import/exports, pump use, storage SoC), physical/virtual self-consumption, annualized costs and CO₂ emissions, and the residual-demand profile.

Module B – PPA portfolio optimization. The residual profile feeds a PAC-oriented optimizer with solar/wind and proxy-storage templates; prices, indexation, and balancing clauses are parametrized. A bi-objective model (maximize NPV; minimize CvaR) yields a Pareto frontier so managers can trade upside for downside protection. The solver quantifies hourly coverage, curtailment, and remaining grid exposure to prevent hidden shape risk.

Integration & delivery. A simple pipeline links input → hourly simulation → residual profile → optimizer → procurement plan with KPIs and stress tests. A lightweight dashboard summarizes REC assumptions, operational gains from DHW control, the chosen PPA mix/hedge level, and consolidated outcomes (bill impact, CO₂ emissions, incentive revenue).

Design choices satisfied: Minimize first, then procure; few robust control rules with comfort guarantees; **contract diversity** (PV, wind, proxy-storage) to stabilize costs/coverage; **accounting** of emissions and energy flows for verifiable impact and incentives computations.

Although developed on an Italian REC case, parameters/archetypes are editable, enabling fast adaptation to other climates, tariffs, and products while preserving the same evidence-based workflow from simulation to contract.

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