OPTIMAL DESIGN AND SIZING OF A CER

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Course of Optimization Methods
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Università
degli Studi
della Campania
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WHAT IS AN ENERGY COMMUNITY (CER)?

An energy community, or **Renewable Energy Community** (CER), is a group of citizens, businesses, and local authorities that produce, consume, and share energy from renewable sources locally, provided they are connected to the same primary substation.

They must create a legal entity that will be responsible for administering the CER.

HOW DOES A CER WORK?

Startup: an investor identifies an available surface, pays for and builds the photovoltaic system and finally the legal entity is established.

Energy Flow: The system produces energy. Some is used directly by the building below the system, and the excess is fed into the National Grid. At the same time, members draw energy from the grid for their own needs. The GSE records the input and withdrawal. This energy is called "Shared Energy."

The Economic Flow: GSE pays for the energy fed into the grid at the market price. GSE pays the Shared Energy incentive, which arrives in the CER's bank account.

Management: The CER retains a small amount for management costs. The Community Members' Assembly decides how to use the remaining net incentive, according to three common paths: Refund, Welfare, Reinvestment.

HOW DOES A CER WORK?

Let's differentiate the members of a CER into three groups:

Producer: produces energy and does not consume it.

Consumer: consumes energy and does not produce it.

Prosumer: produces and consumes energy.

WHAT ARE THE BENEFITS OF A CER?

- **Economic**: Members benefit from government incentives for shared energy and reduce their bills thanks to virtual self-consumption.
- **Environmental**: CO_2 emissions are reduced by promoting local production and reducing transmission losses on the electricity grid.
- **Technical-Social**: From an engineering perspective, the CER helps stabilize the grid by reducing load peaks, while socially it combats energy poverty by making green energy accessible to all.

WHY IS IT SUCH A CURRENT PROBLEM?

- In recent years, the price of energy has risen, partly due to the wars in the Middle East and Ukraine. When we buy gas or oil from a country at war or under an authoritarian regime, we are literally pouring money into their state coffers.

- Today, our planet is like a chain smoker who drinks little water and eats junk food. It's **poisoned**. Switching to renewables (and Energy Communities) is like quitting smoking and starting a healthy diet.

ENERGY COMMUNITY IN THE WORLD

In **Europe**, there are now an estimated **9,000** energy communities, involving more than 1.5 million residents.

- **Germany**: It's the undisputed giant. They have over 1,700-2,000 long-standing energy cooperatives.
- **Greece**: The surprise. It has become a leader in Southern Europe with over 1,400 active communities and 1 GW of installed capacity.

Australia is a world leader in rooftop solar. The evolution there is called "Community Battery": entire neighborhoods installing a mega-battery at the end of the street to store the day's energy and use it in the evening, virtually disconnecting from the national grid.

AND IN ITALY?

The Italian landscape is in full swing; today we're talking about an industry that's taking off, albeit with some bureaucratic hurdles.

- The first CER in Italy was born in **December 2020 in *Magliano Alpi*** *(Cuneo),* It demonstrated that it could be done legally, paving the way for all the others.

Boom in Requests: With the final opening of the GSE portals, there was a surge. As of March 31, 2025, the GSE had registered approximately 4,000 applications for incorporation, and an **estimated 200-250 are fully operational**.

- The largest CER in Italy is in *Geco (Bologna).*

WHAT DOES IT MEAN TO OPTIMIZE THE SIZING OF A CER?

Optimizing the sizing of a Renewable Energy Community means finding the perfect technical and economic balance between the energy produced by the plants and the energy consumed by the community members.

IT'S NOT simply a matter of installing "as many panels as possible," but of designing the CER so that **production times coincide as closely as possible with consumption times.**

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ENERGY STARTER KIT: 1KW PV + 1KWH STORAGE

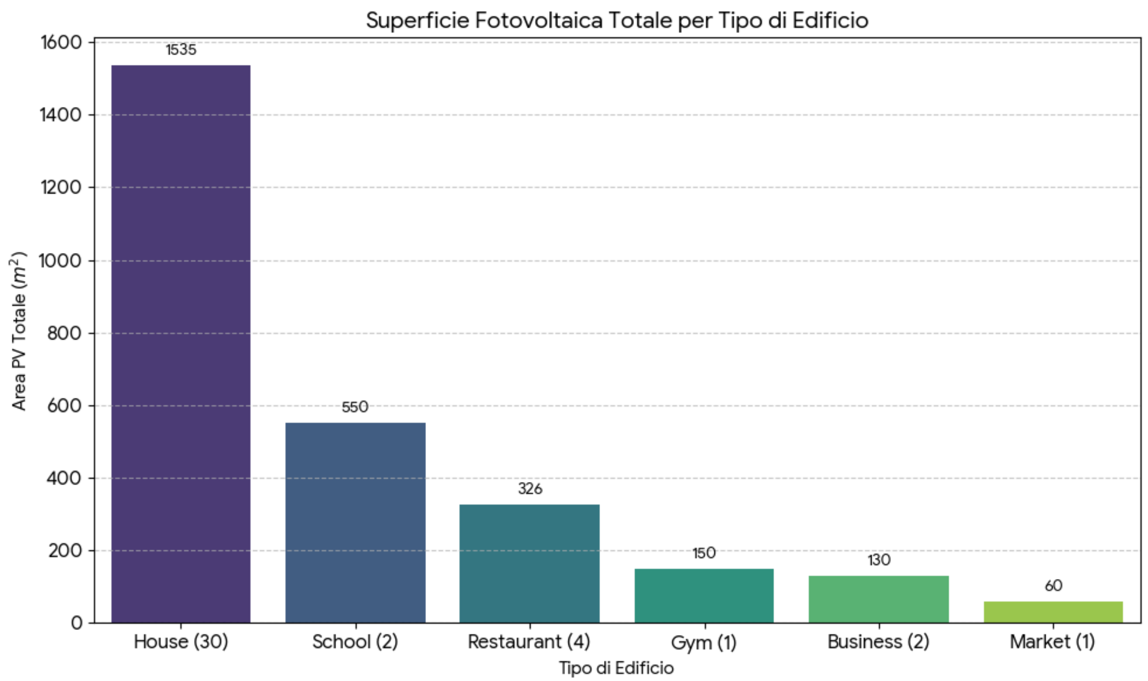
WE PRESENT THE PRICES FOR PHOTOVOLTAIC PANELS AND BATTERIES FOR THE SINGLE KWH UNIT.

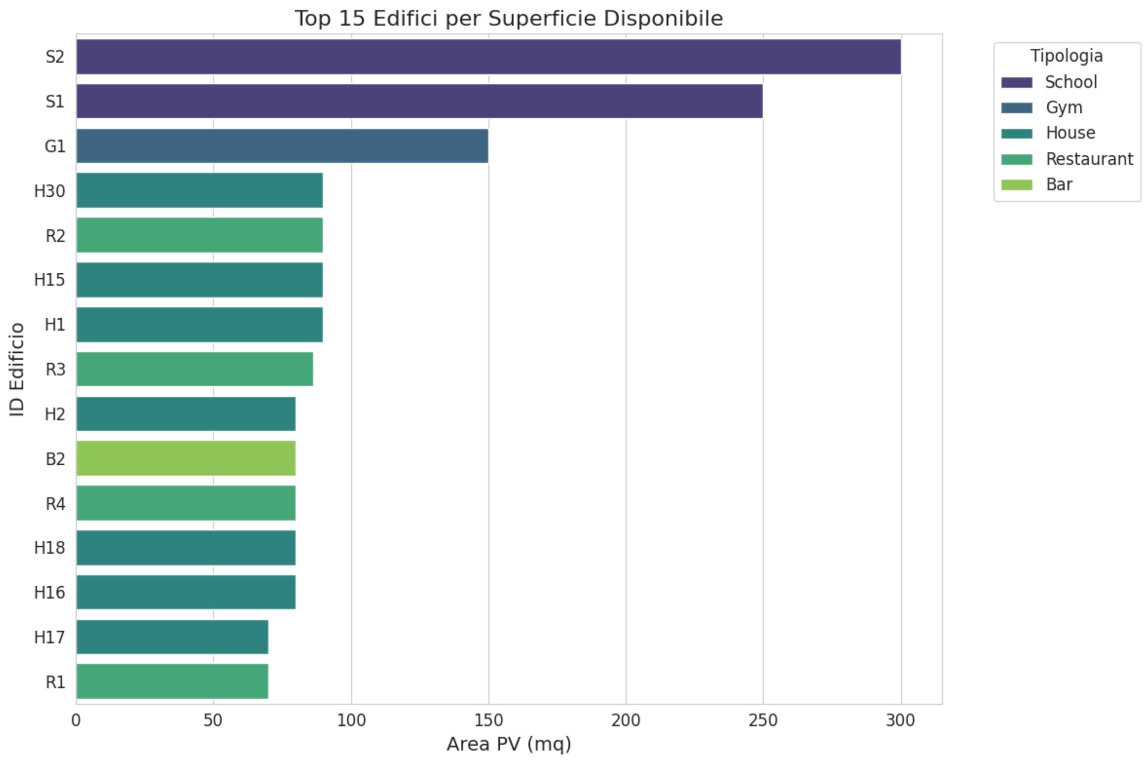
THE PRICE FOR A 1KW PHOTOVOLTAIC PANEL SYSTEM INCLUDING INSTALLATION IS €1300.

THE PRICE FOR A 1KWH BATTERY STORAGE SYSTEM INCLUDING INSTALLATION IS €500.

FROM ANALYSIS TO ACTION: DEFINING MEMBERS

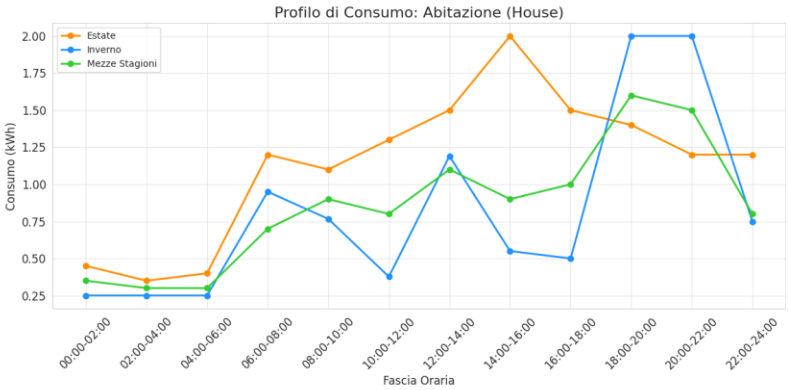
Let's define the protagonists of our CER, divided by building type and with their surface area.

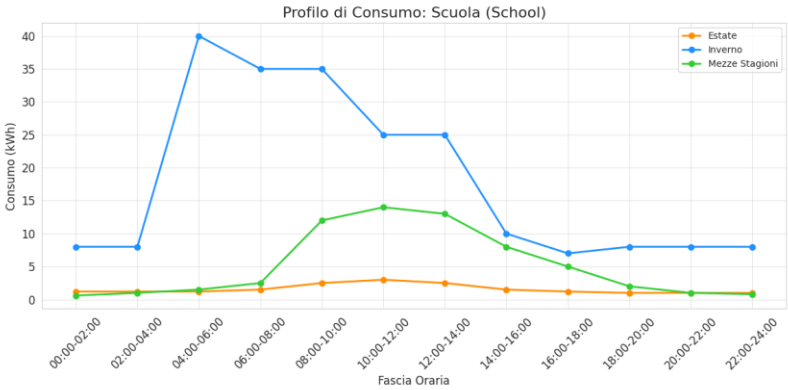


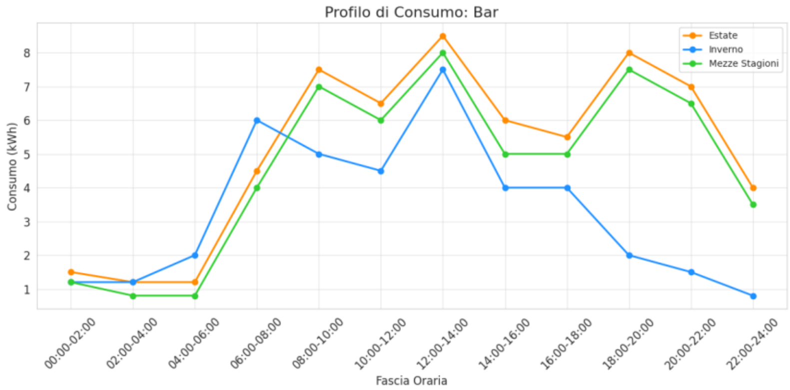


CONSUMPTION MODELS FOR OPTIMIZED CER DESIGN

This slide shows the load profiles of the various types of members of our CER.







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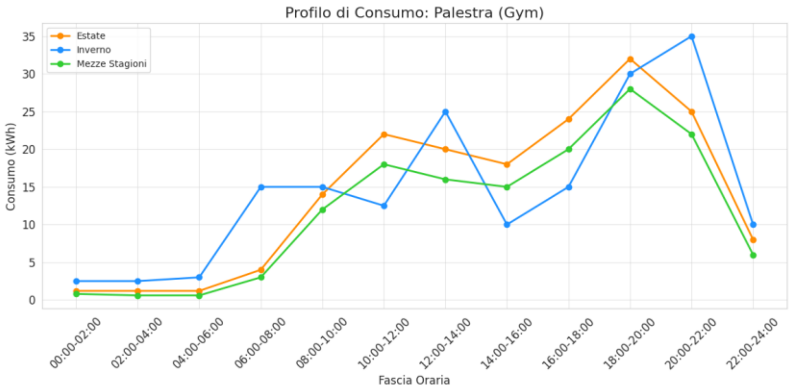
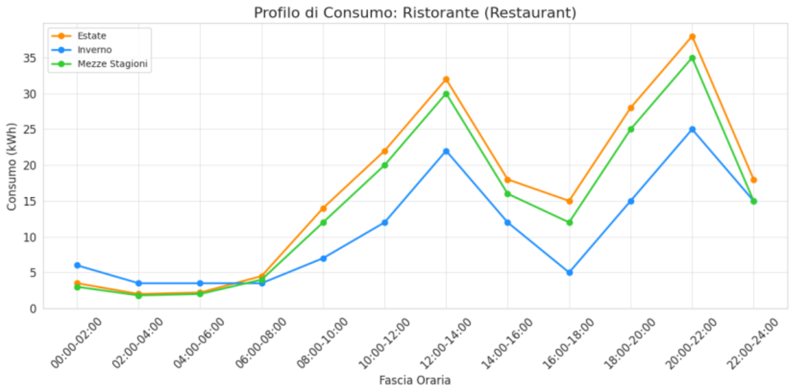
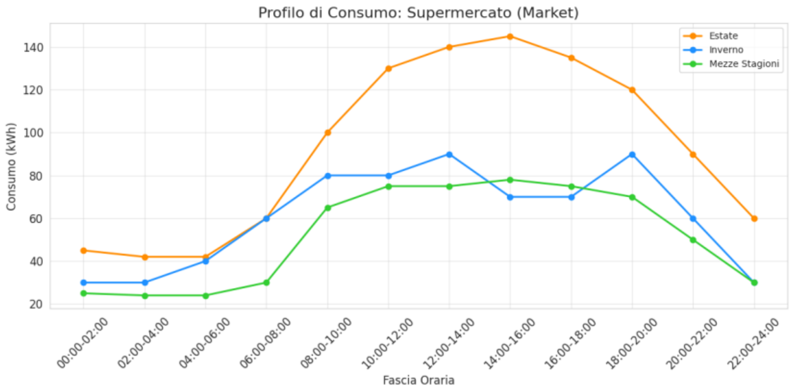
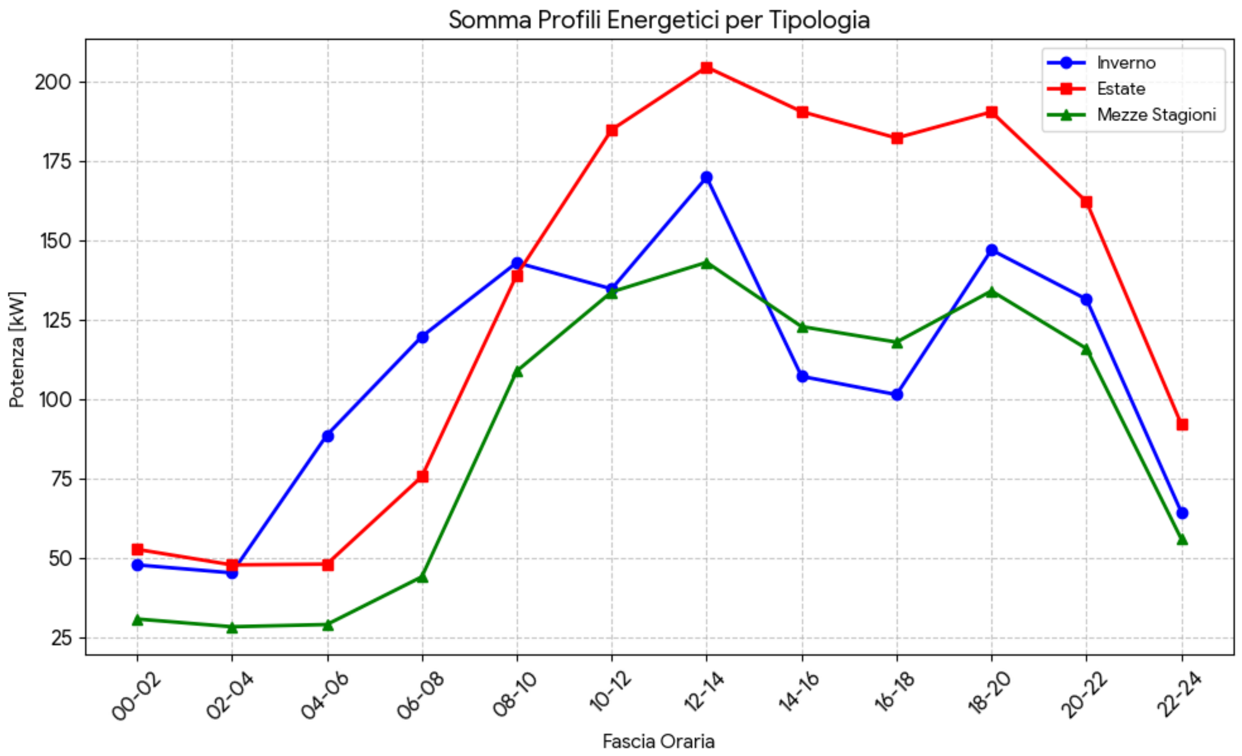






CONSUMPTION MODELS FOR OPTIMIZED CER DESIGN

In this graph we see the overall load profile of the entire CER.



OUTPUT OPTIMIZATION: SIZING AND LOAD MATCHING

The goal of our optimization is to ensure that the load power of the CER members' collective is equal to the power generated and stored in the batteries.

$$\max Z = \underbrace{\alpha \sum_{t=1}^{T} \min\big(\text{Offerta}(t), \text{Domanda}(t)\big)}_{\text{Guadagno da Efficienza CER}} - \underbrace{\beta \sum_{i=1}^{N} \left(C_{PV} P_{PV,i} + C_{Batt} E_{Batt,i}\right)}_{\text{Costo Investimento Annualizzato}}$$

The algorithm determines the ideal configuration for each CER node. We must establish the exact number of panels to install and the storage size, calculating the capacity needed to cover the time misalignment, in order to also **optimize costs**.

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PHISICAL CONSTRAINTS

Besides the objective function, it’s essential to determinate the phisical constraints of our formalization.

PANELS CONSTRAINTS

1. Energy Production Definition

$$P_{prod}(i,t)=P_{nom,i}\cdot Prof(t)$$

2. Spatial Constraint (Available Area)

$$P_{nom,i}\cdot 6\leq Area_i$$

3. Regulatory Constraint(CER Limit)

$$P_{nom,i}\leq 1000$$

4. Non-Negativity (Physical Reality)

$$P_{nom,i}\geq 0$$

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PHISICAL CONSTRAINTS

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BATTERIES CONSTRAINTS

Discrete Sizing (Size Choice)

$$E_{nom,i} = K_i \cdot M_{size,i}$$

State of Charge Limits (DoD)

$$0.10 \cdot E_{nom,i} \leq SOC(i,t) \leq 1.00 \cdot E_{nom,i}$$

Power Constraints (C-Rate 0.5)

$$P_{ch}(i,t) \leq 0.5 \cdot E_{nom,i}$$
$$P_{dis}(i,t) \leq 0.5 \cdot E_{nom,i}$$

Dynamic Energy Balance (2h Step)

$$SOC(i,t+1) = SOC(i,t) + 2 \cdot \left(P_{ch}(i,t) \cdot 0.97 - \frac{P_{dis}(i,t)}{0.97}\right)$$

Charge/Discharge Exclusivity (Big-M)

$$P_{ch}(i,t) \leq M \cdot y(i,t)$$
$$P_{dis}(i,t) \leq M \cdot \left(1 - y(i,t)\right)$$

Cyclicity (Boundary Condition)

$$SOC(i,T) = SOC(i,0)$$

ECONOMIC CONSTRAINTS

Despite the economic question is included in the objective function, it’s important to take a look at the total budget of out CER.

BUDGET CONSTRAINTS

$$\sum_{i=1}^{N} (1300 \cdot P_{PV,i} + 500 \cdot E_{Batt,i}) \leq 200000$$

Final considerations on constraints; these are tough constraints that must be strictly respected, especially the financial one, **no one wants to spend more** than they have set themselves.

THE RESOLUTION ALGORITHM: BRANCH AND CUT

It is a hybrid algorithm that combines two strategies to solve complex problems where the variables must be integers:

- **Branch**: Divides the huge problem into smaller, more manageable subproblems (creates a decision tree).

- **Cut**: Uses mathematics (cutting planes) to eliminate entire sections of the tree that are guaranteed not to contain the optimal solution, dramatically speeding up the computation.

WHY BRANCH AND CUT? PRECISION AND RELIABILITY

1. Global Optimality Guarantee	2. Efficient Management of Complex Constraints	3. Optimized Performance
✓ Unlike many heuristics, Branch and Cut guarantees to find the global optimal solution, essential for a reliable investment or operational strategy.	✓ The ability to add cuts allows you to efficiently manage the constraints typical of CERs.	✓ It is the baseline algorithm in most commercial MILP solvers and is highly optimized for quickly solving large-scale problems, such as hourly optimization over a yearly time horizon.

ECONOMIC INCENTIVES: A STARTING PUSH

❖ **The Incentive Tariff**: This is the main incentive that reflects the true spirit of the CER. It rewards shared energy. It consists of two elements:

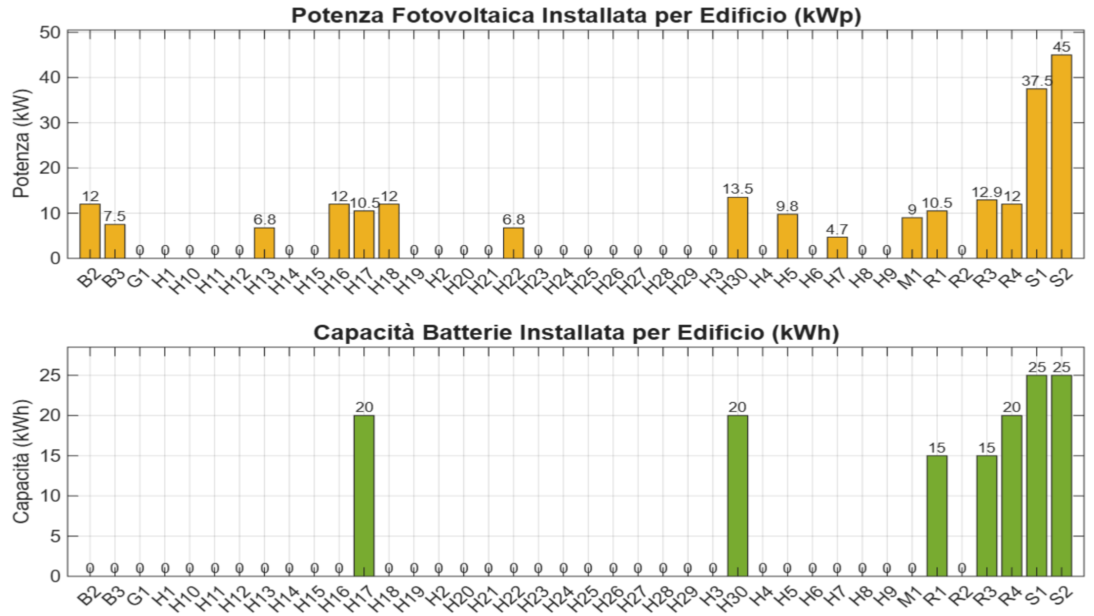
- The Premium Tariff: which is a base rate per MWh, depending on the installed power and geographic area.
- Charge Refund: An additional rate established by ARERA/GSE to reduce system costs.

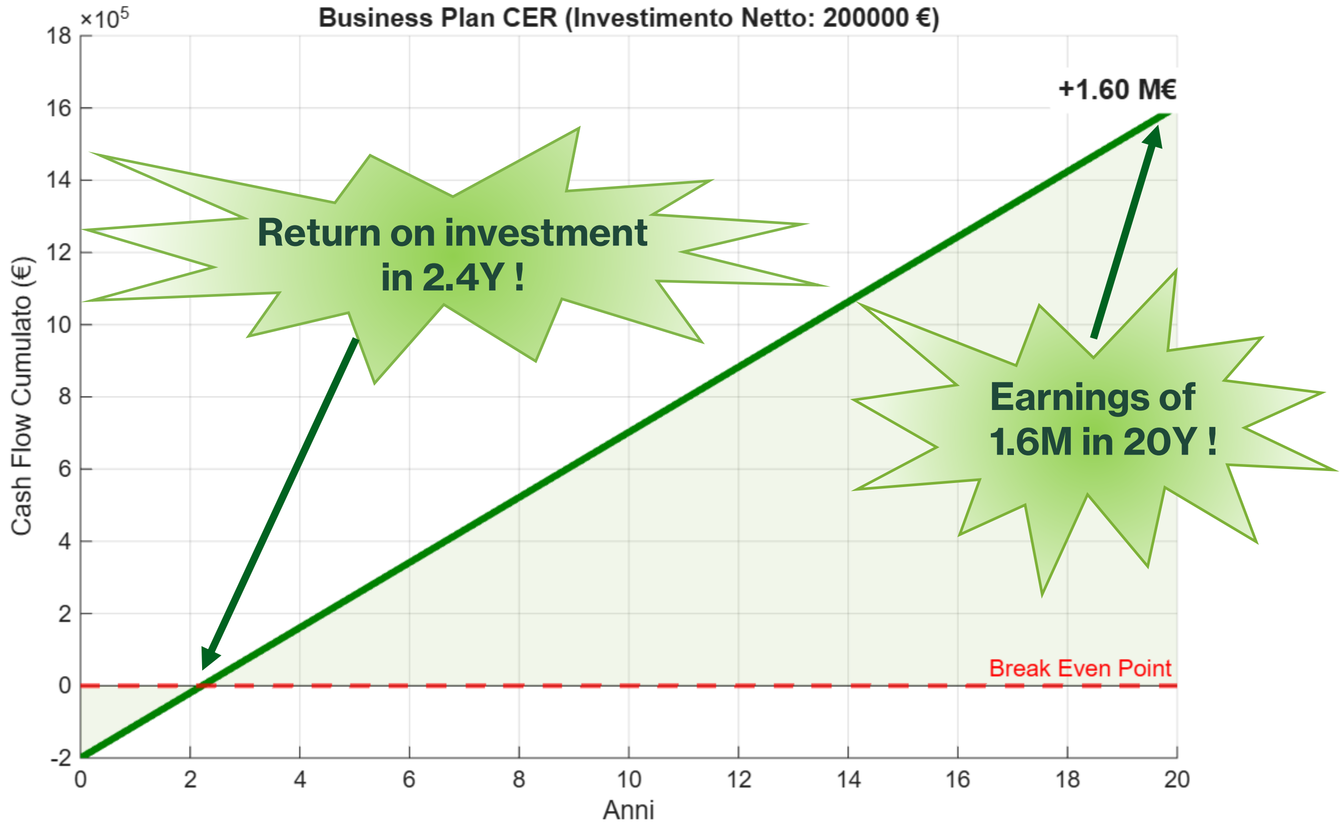
❖ **Non-repayable grant**: This incentive is aimed at communities in municipalities with fewer than 5.000 inhabitants and serves to cover part of the initial investment. Up to 40% of eligible costs.

OPTIMIZATION RESULTS: WITH INCENTIVES

These are the optimization results, considering the 40% incentives for cities with less than 5.000 inhabitants, with an initial investment of €200.000.

- **Total PV power**: 223 kW.
- **Total batteries capacity**: 140 kWh.





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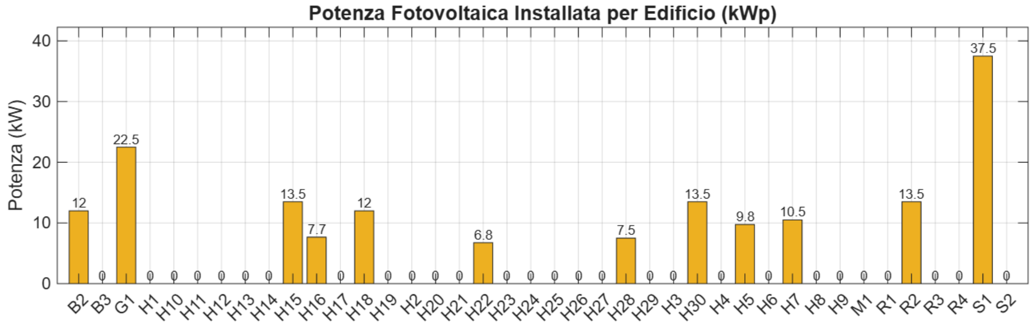
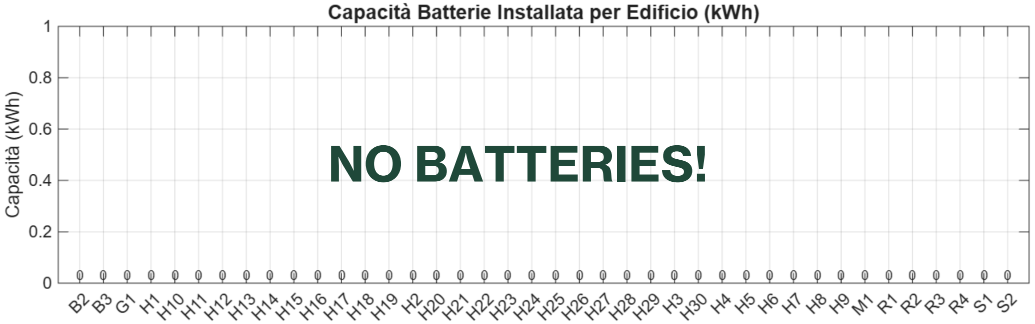
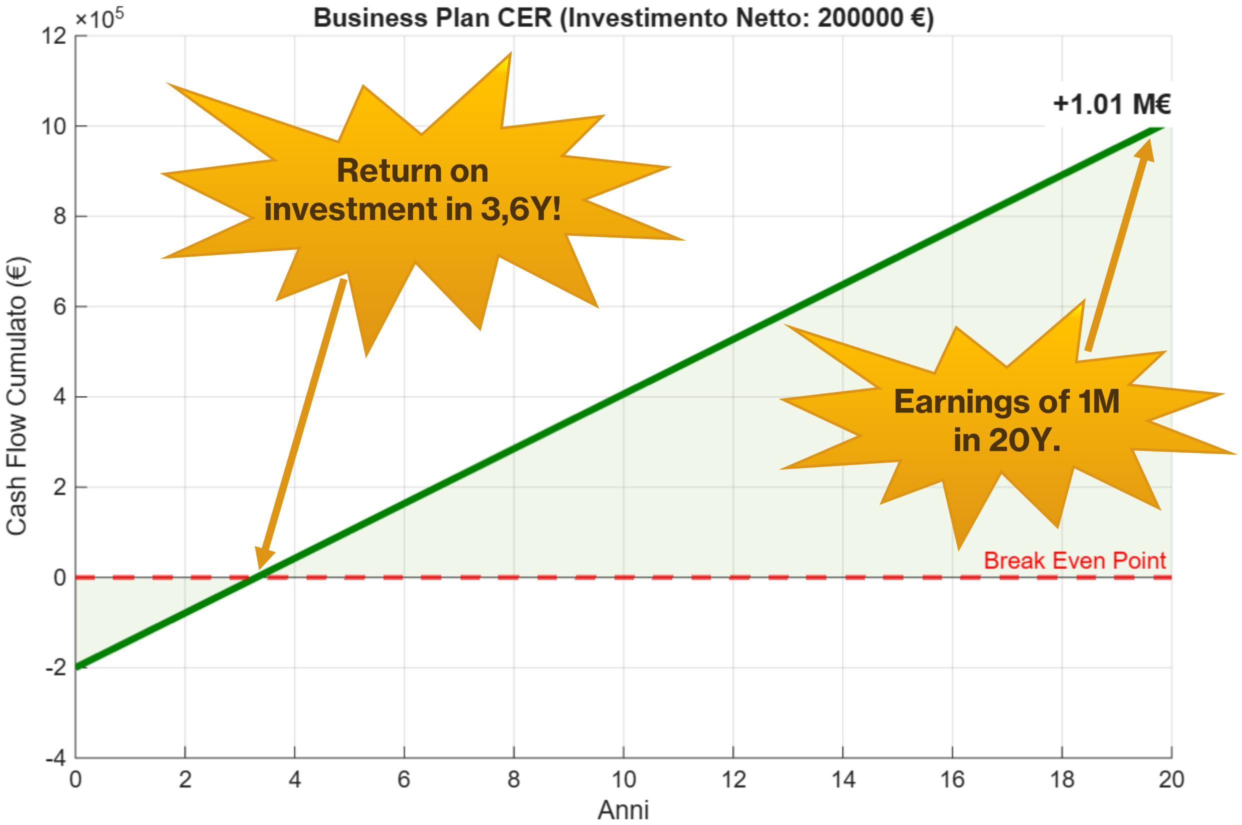
OPTIMIZATION RESULTS: NO INCENTIVES

Without considering any incentives, with the same initial investment, results are

- **Total PV power**: 158 kW.
- **Total batteries capacity**: 0kWh.







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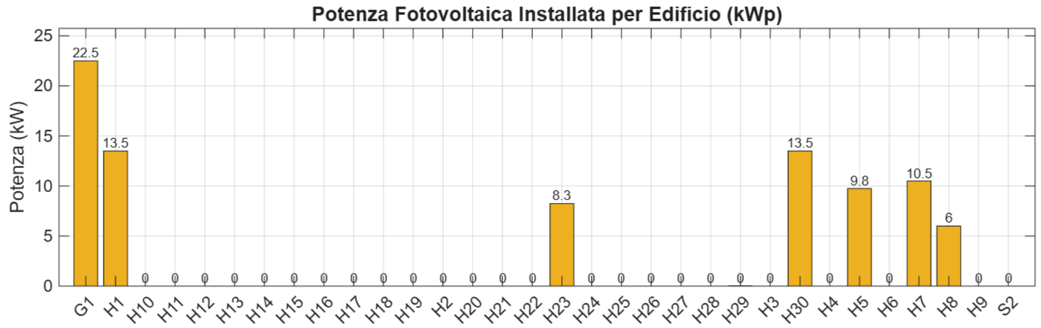
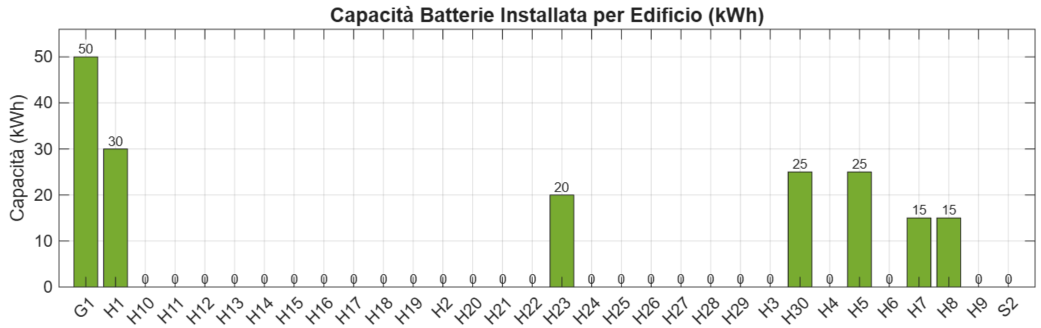
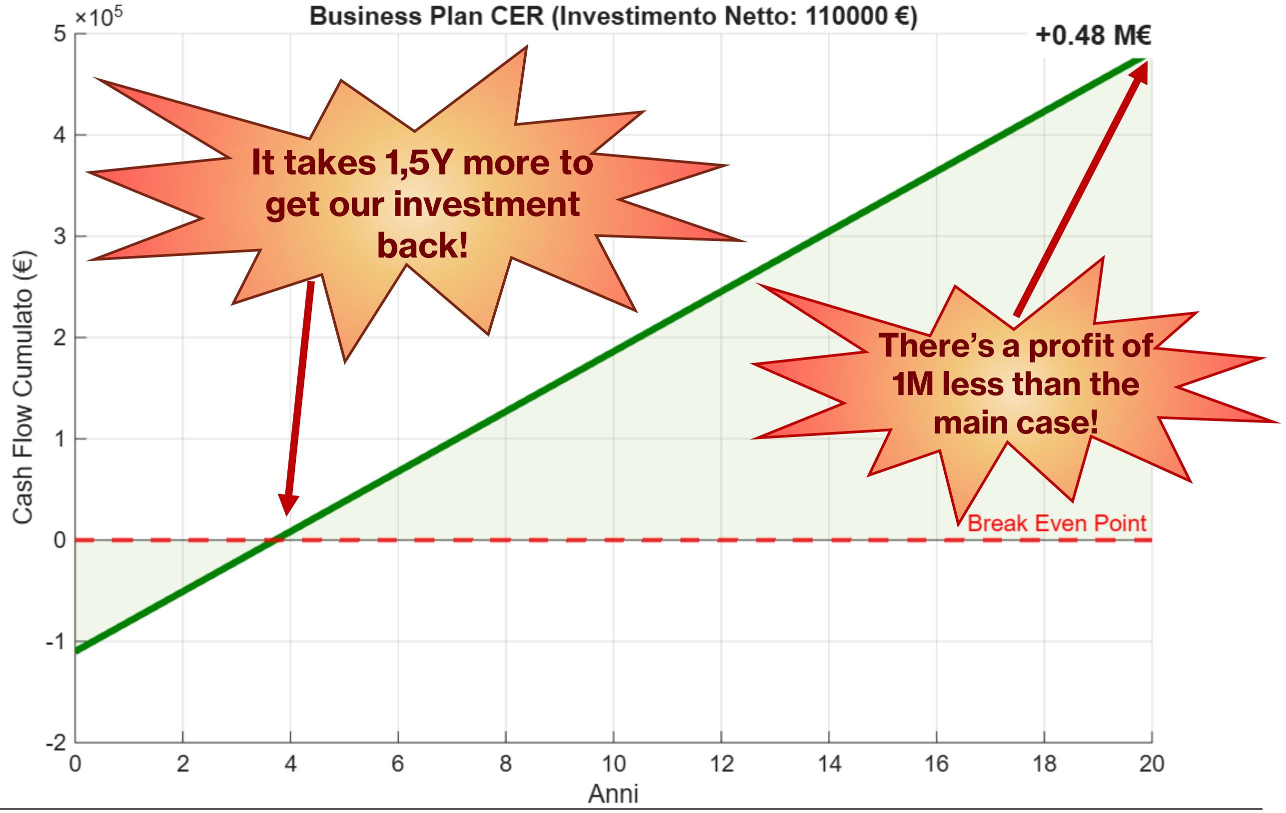
THE POWER OF DIVERSITY: IS SIZE JUST A NUMBER?

Make a new scenario, where have been removed from our CER restaurants, shops and other predominantly daytime users. Initial investment of €110.000 and PNRR incentives.

- **Total PV power**: 84 kW.
- **Total batteries capacity**: 180 kWh.







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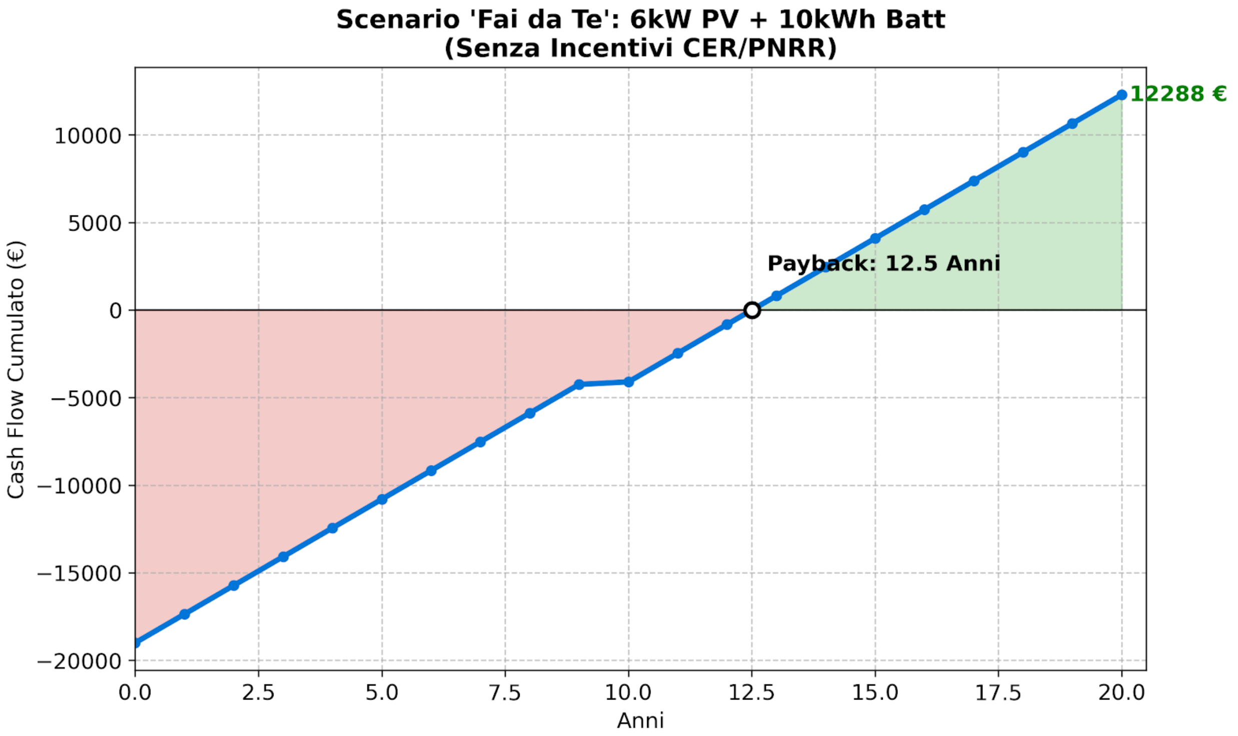
WHY NOT JUST GO ALONE?

Going alone is like *'leaving money on the table'.*

- **Extra Income Stream** Earn exclusive cash incentives on shared energy (unavailable to individuals).
- **Lower Investment Risk** Access to strategic grants (**40% PNRR** non-repayable funds).
- **Superior ROI & Payback** Drastically shorter payback period compared to standalone installations
- **Efficiency via Synergy** The "Virtual Battery" effect minimizes the need for expensive physical storage.



THE PROBLEM OF OPTIMAL MANAGEMENT

While sizing answers the question **"how big should the plant be?"**, optimal management answers **"how do I make it run minute by minute to maximize profit?"**

In real-world management, variables (weather and consumption) change every moment. Optimal management acts in real time to:

- ✓ **Maximize collective self-consumption:** Shift flexible loads during peak production.
- ✓ **Energy arbitrage:** Decide whether to charge batteries, discharge them, or sell energy to the grid based on local prices.
- ✓ **Peak shaving:** Reduce peak demand to reduce grid charges.

THE IT BEHIND OPTIMAL MANAGEMENT

If sizing is the skeleton, *computing is the brain* sending signals to the muscles.

A mathematical reply of the community resides in the cloud. Here, the algorithm not only works with current data, but also simulates the future. The integration of the Weather API allows for forecasting photovoltaic production. The software resolves thousands of variables every few minutes to find the path that minimizes costs for all members.

- **The Energy Traffic Light :**

The optimization algorithm predicts that tomorrow at 12:00 PM (FE) there will be a peak in solar production that will not be covered by consumption.

- **Gamification and Dynamic Pricing:**

To encourage users to follow recommendations, the software implements game mechanisms.

- **Direct Automation (User-less):**

This is the highest level of computing. The user doesn't have to do anything.

THANK YOU
FOR YOUR ATTENTION !

FOR FURTHER INFORMATION:
Link GitHub

OUR TEAM

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