Politecnico di Torino

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Smart Grid Project
Capacity Planning for Pv and Battery System

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Objective

What we aimed to achieve

We aimed to answer 3 key questions::

1. How can a household use solar energy to meet its own energy demand?
2. What is the best size for a solar panel system and battery storage to reduce costs?
3. How long will it take to recover the investment and start making savings?

Methodology

Steps taken in the project

01. Data Collection and Cleaning

02. Energy Demand Simulation

03. Surplus and Deficit Calculation

04. Finding the Best Panel Size

05. Optimizing Battery Size

06. Cost Analysis

07. Visualization of Results

08. Optimizing the System

Our data

Collection and Simulation

We collected data for 2022 from:

01. Electricity Price from GSE

02. Solar Generation from PVGIS

03. Investment Cost from statista

04. Energy Demand using Gym AI

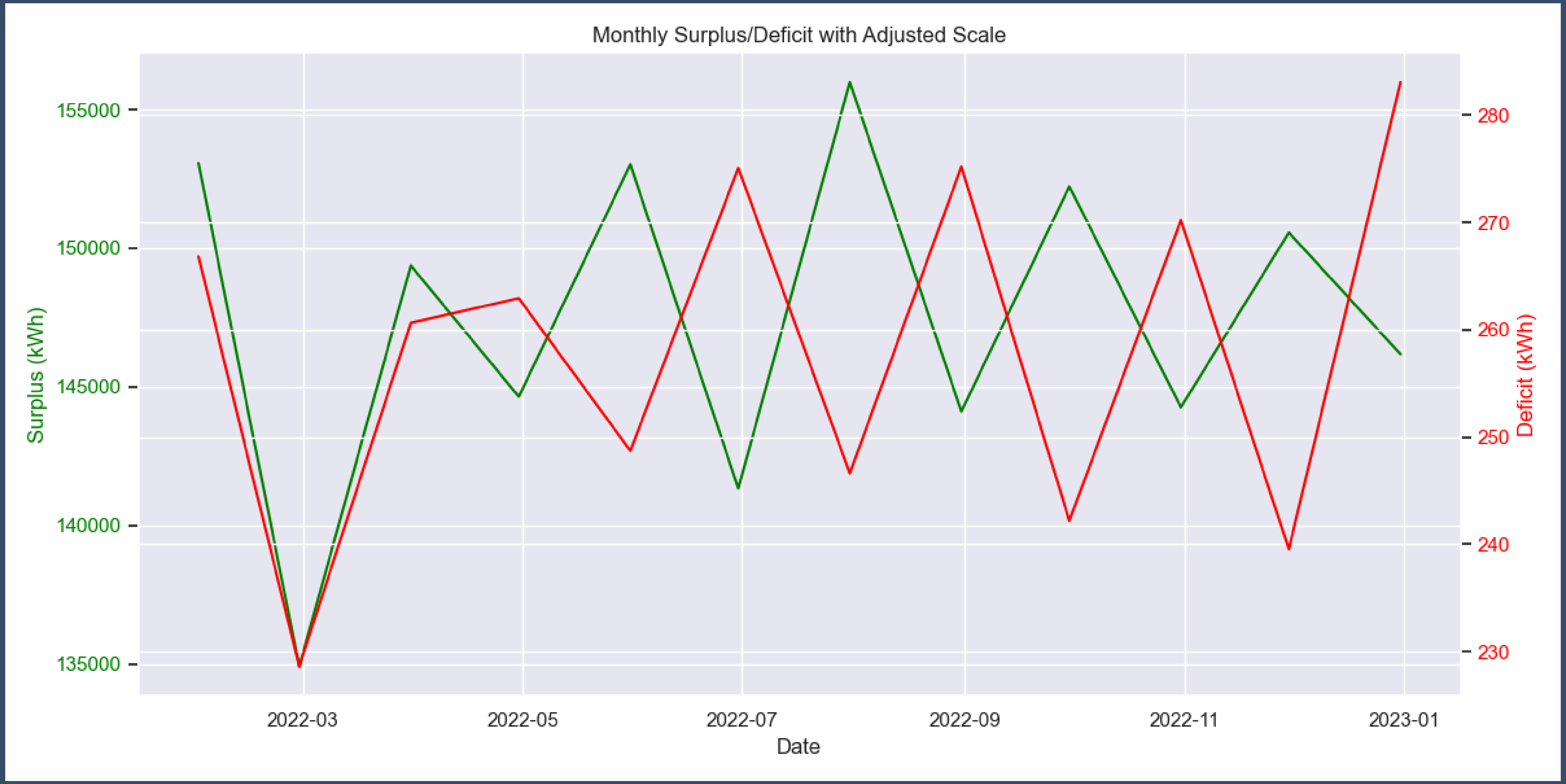
To better understand energy usage patterns, we developed a custom Gym environment to simulate hourly energy demand over the course of a year.

The simulation considered appliance usage, heating needs, lighting, and seasonal variations.

Surplus and Deficit Calculation

We calculated hourly and monthly energy surplus/deficit by comparing:

- Solar energy generation (from the PV system).
- Household energy demand (from the simulation).



Finding the Best Solar Panel Size

PV Size (kW)	Annual Generation (kWh)	Demand (kWh)	Surplus (kWh)
5 kW	6,000	4,800	+1,200
10 kW	12,000	4,800	+7,200

A 10 kW PV system covers the household's energy needs and generates a reasonable surplus.

Optimal balance:
10-15 kW system provides self-sufficiency and a short payback period.

Optimizing Battery Storage Size

Battery Size (kWh)	Grid Dependency (%)	Investment Cost (EUR)
500	45%	150,000
750	30%	225,000
1,000	15%	300,000
1,500	5%	450,000

A 1,000 kWh battery reduces grid dependency to 15% and ensures energy availability during peak demand.

Cost Analysis

What We Did:

Calculated the total investment cost for different combinations of PV system size and battery storage.

Estimated annual savings from reduced electricity bills and feed-in earnings from selling surplus energy.

Evaluated Payback Period and Return on Investment (ROI) to determine financial feasibility.

Mathematical Model

ROI= (annual_savings + feed_in_earnings) / total_investment_cost * 100

5 kW + 500 kWh Battery

Total Cost
210,000 €

ROI
25.3%

Annual Savings
7,500 €

Payback Period
28 Years

10 kW + 750 kWh Battery

Total Cost
300,000 €

ROI
30.0%

Annual Savings
12,000 €

Payback Period
25 Years

15 kW + 1,000 kWh Battery

Total Cost
405,000 €

ROI
35.5%

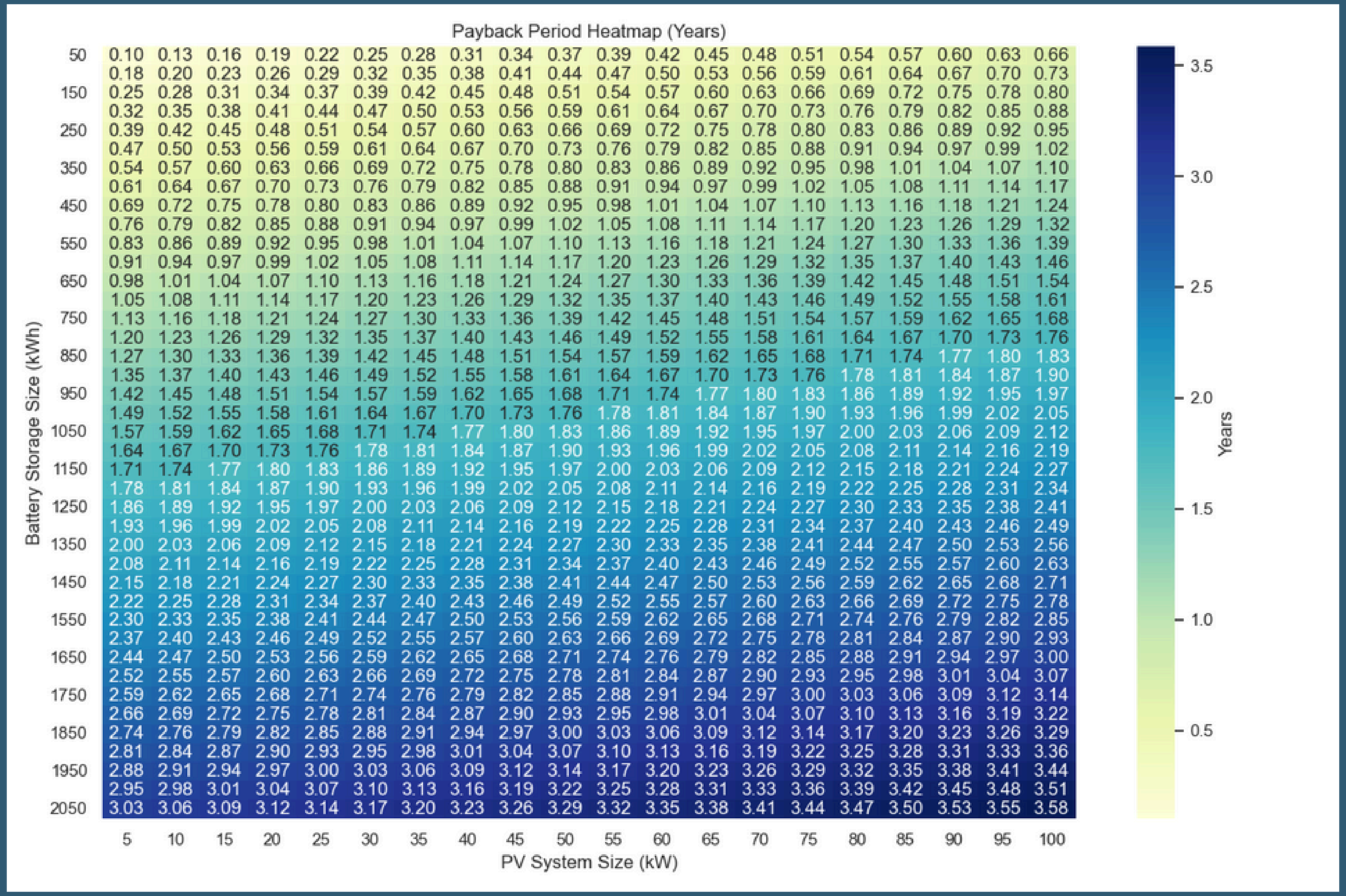
Annual Savings
15,800 €

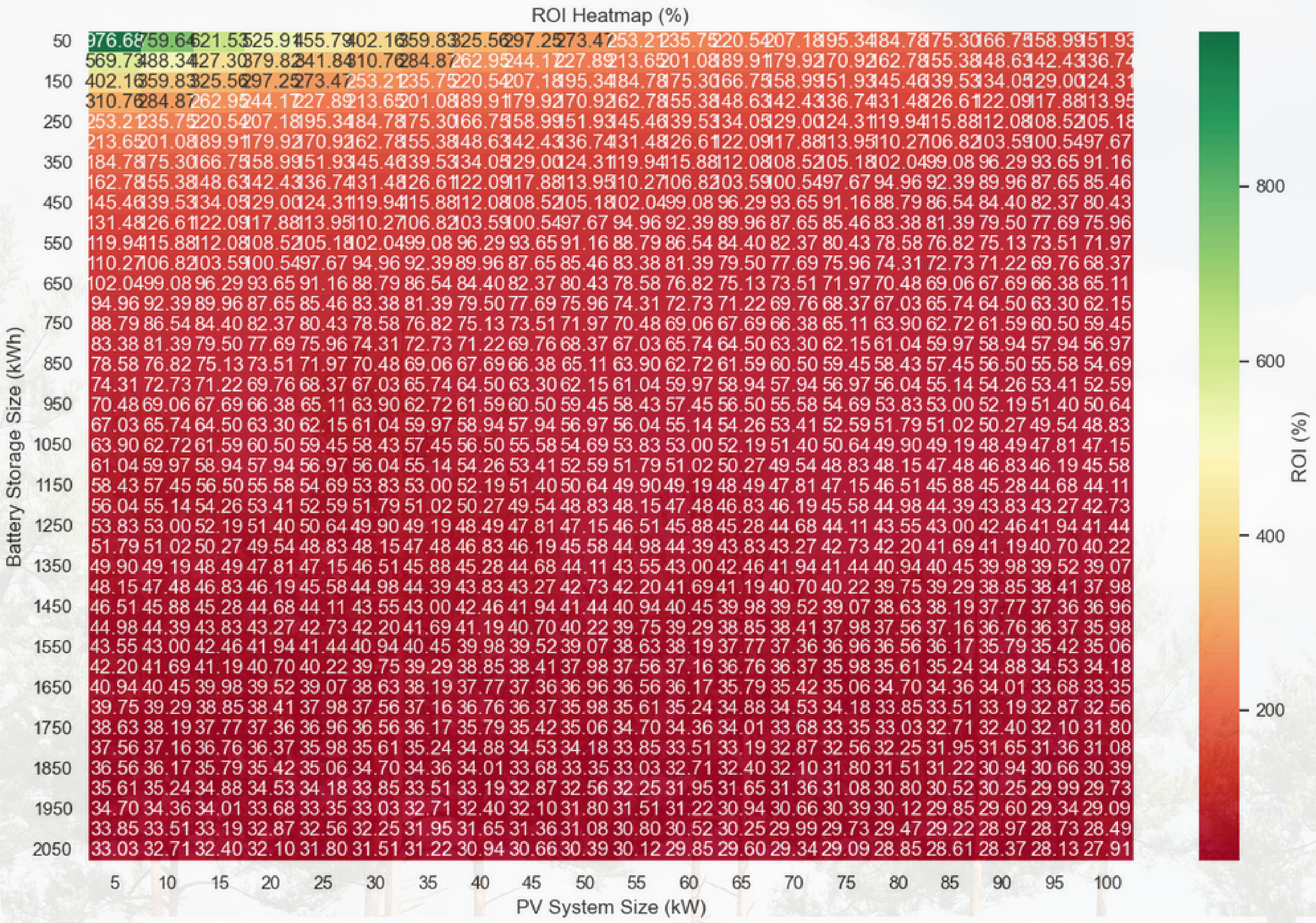
Payback Period
22.3 Years

Visualization

Payback Period Heatmap Analysis:

The optimal system configurations (shortest payback periods) tend to be around smaller PV systems (10-30 kW) combined with moderate battery sizes (150-500 kWh).





The Return on Investment (ROI) Heatmap:

the percentage of profit generated relative to the initial investment. The higher the ROI, the more profitable the system:

Green Areas represent configurations with an exceptionally high ROI (above 800%).

Red/Orange Areas show lower ROIs, indicating less profitable configurations.

Optimizing the System

PV Size (kW)	Battery Size (kWh)	Payback Period (Years)	ROI (%)
10	750	22.5	35.2
15	1,000	20.8	38.5
20	1,500	19.3	40.1

Key Insights:

The optimal combination is a 10-15 kW PV system with a 750-1,000 kWh battery.

This configuration offers:

- A short payback period (20-23 years).
- High ROI (~35-40%).
- Significant grid dependency reduction.
- Larger systems have higher costs but can generate more surplus energy for additional earnings.