Time-dependent modelling of Renewable energy communities in Small Mediterranean islands

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DIMA

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Key Research Topics

- Renewable Energy Communities
- Water-Energy Nexus
- Small Island
- Wind, Solar, CHP, Green Hydrogen
- Energy Storage
- Python Modelling of Energy Systems

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DIMA Group for Suistainable Energy

Outline

1. pyRES: python Tool for modelling of energy systems with high penetration of renewable energy sources
2. Application1 : Integrated design of an Energy Community considering the water–electricity nexus on Ponza Island
3. Application2 : Integrated design of an Energy Community considering the water–electricity nexus on Ventotene Island

PyRES is a tool developed in Python to support analysis and design of Renewable Energy Communities.

Main characteristics

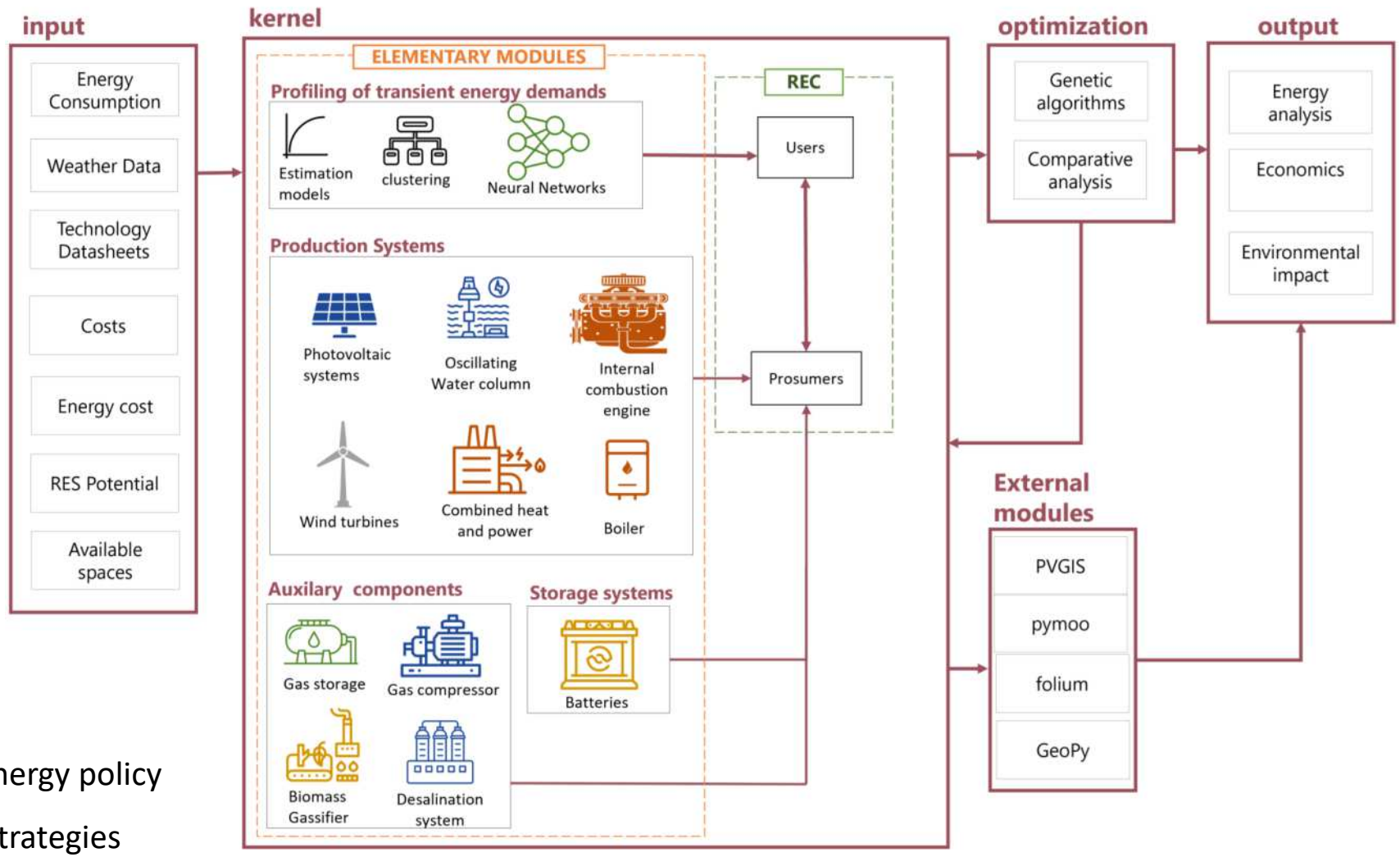
- Object-oriented programming
- Open-source

Time resolution

- Up to 15 min

Main functions

- Reconstruction of energy metabolism
- Sizing and optimization
- Economic analysis
- Quarter-hour loads reconstruction
- Testing management strategies and energy policy
- Support the development of control strategies



Application 1

Test Case: Ponza as a typical minor island

- *Aims:*

I. To test the Italian REC incentives model in an extreme power generation scenario: a minor Mediterranean island.

II. To test the integration of the REC with a desalination system

III. To assess the potential of REC model in water-energy nexus

- *Partners*: Regione Lazio
- *Tools:* TRNSYS, pyRES, pymoo
- *Technologies*: PV, Desalination
- *Achievements:* digital twin of the system.

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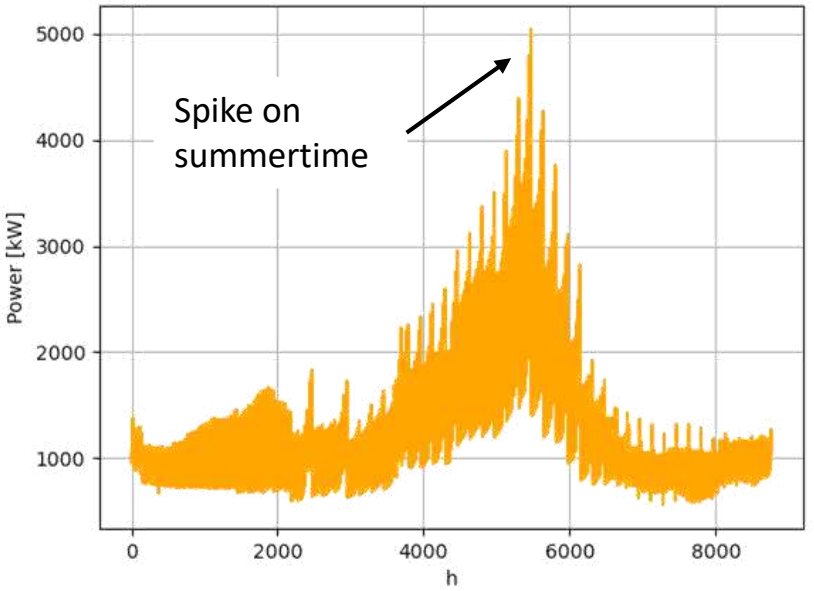
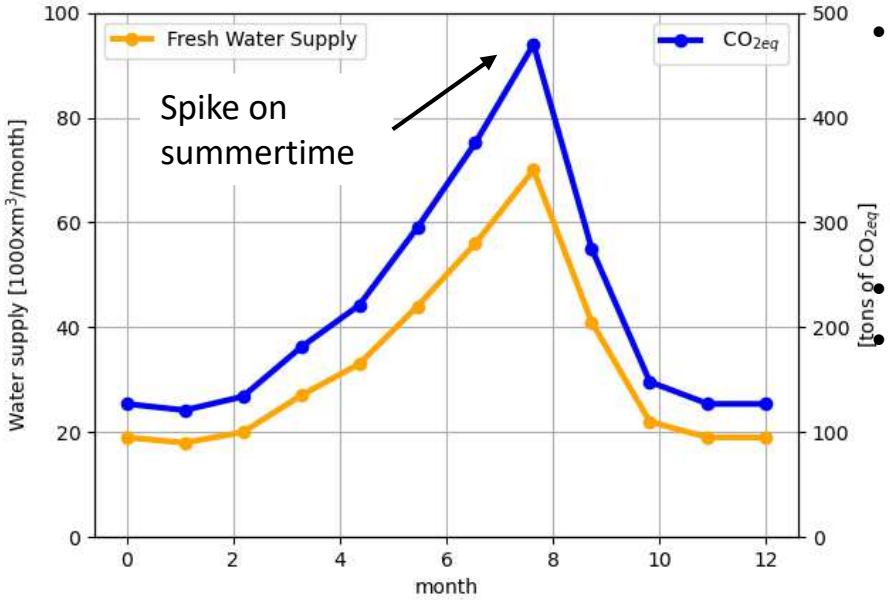


Electric load for one year

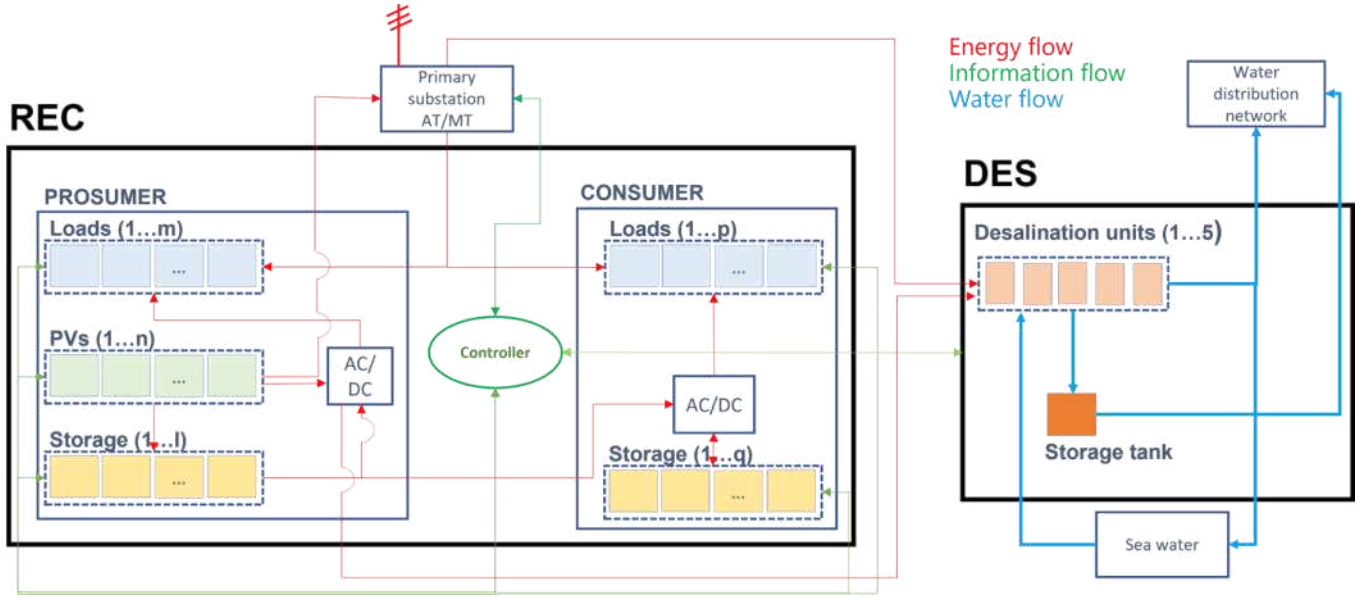


Water demand for one year

- Population spans from 3,300 to 55,000
- Environmental protection laws (limits on size and installation of RES technologies)
- A strongly seasonal electric load (peaks from 0.5 MW to 5 MW during the summer)
- Energy production covered almost exclusively by Diesel gensets (6.2 MW + 2.6 MW)
- RES penetration <5%
- Clean water supply provided via tankers from mainland (2600 tons of CO2eq/year)

Class	Description	Potential PV size [kW]	Electricity consumption [MWh/year]	Maximum number of members
1	Residential prosumers	3	4	400
2	Residential consumers	-	4	
3	Restaurants	7	21	10
4	Hotels	50	200	10

Desalination system description	
Desalination station	5 units x 300 m^3/day Water flow 5 x 12.5 m^3/h Electric power 5 x 70 kWp
	Global specific energy consumption 5.32 kWh/m^3
Water Storage	100 - 3000 m^3



The selection of the best prosumers and consumers mix was based on an NSGA-II optimization strategy

Independent variable is the number of members for each class**.** Objective functions are:

1. The maximisation of the self-consumption
2. The maximisation of the net-present-value (NPV)

Constraint is the maximum number of REC members (400)

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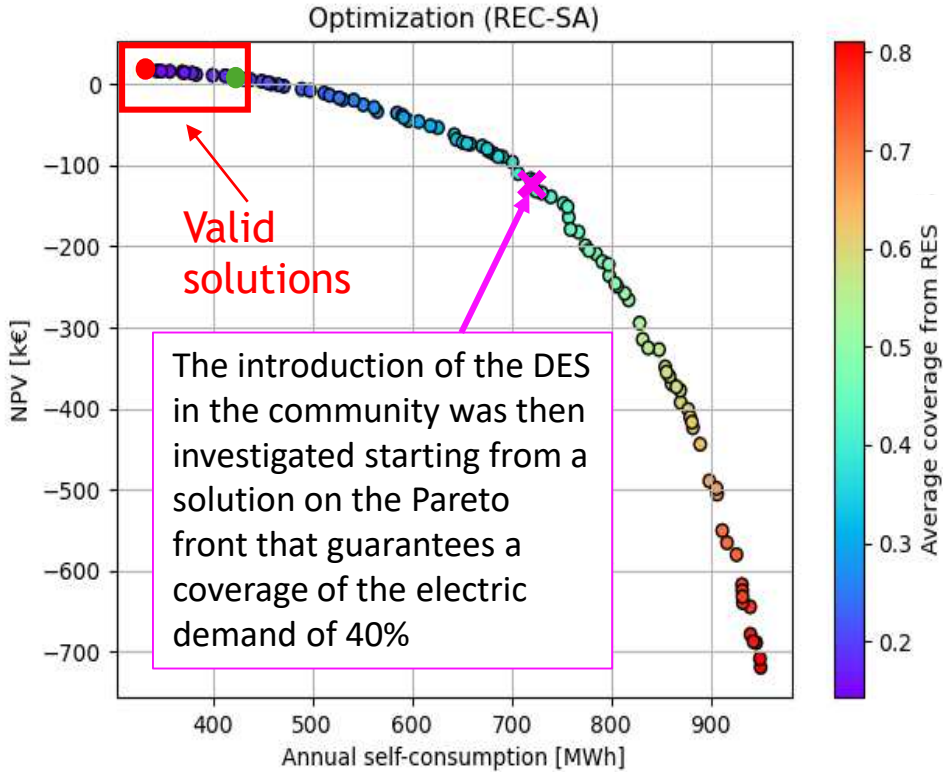

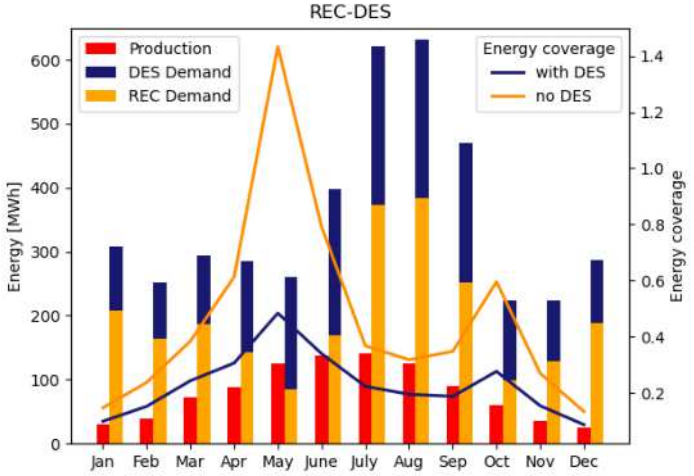

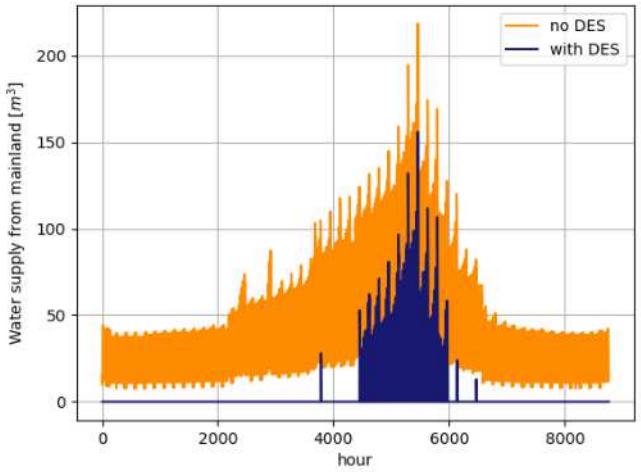

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	DES	REC w/o DES	REC with DES	
Supply from mainland [1000 m^3]	34	388	34	
DES water production [1000 m^3]	354	-	354	
Electricity withdrawn from the grid by DES [MWh]	1876	-	1679	
CO_2 emissions from water supply [tons CO_{2eq}]	228	2602	228	
CO_2 emissions from water production [tons CO_{2eq}]	813	-	727	
Total CO_2 emissions [tons CO_{2eq}]	1041	2602	955	
REC energy production [MWh/year]		968	968	
REC energy demand [MWh/year]		2379	2379	
Self-consumption [MWh/year]	-	730	927	+ 27%
Surplus energy [MWh/year]	-	238	41	
Initial investment [k€]		1200	1200	
Return on tariff [k€]		113	144	
Awards on self-consumption [k€]		1518	1926	
Revenues from the sale of surplus energy [k€]		234	42	
NPV [k€]		-134	34	+ 25%

1. A desalination plant with a storage system in the REC increases self-consumption (+27%) and NPV (+25%)

2. In REC-DES: reduction of **60%** of CO_2 emissions for water supply, with a further **10%** cut of emissions related to Diesel gensets

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The Renewable Energy Community on Ventotene island

Aims:

1. to analyse and design a REC on the island of Ventotene

2. To integrate a desalination system as a deferrable load to optimize the use of locally produced renewable energy

- Population of 700 inhabitants
- Environmental protection laws (limits on size and installation of RES technologies)

Energy

- A strongly seasonal electric demand
- Energy production covered almost exclusively by Diesel gensets (480 kW)
- RES penetration <5%

Water

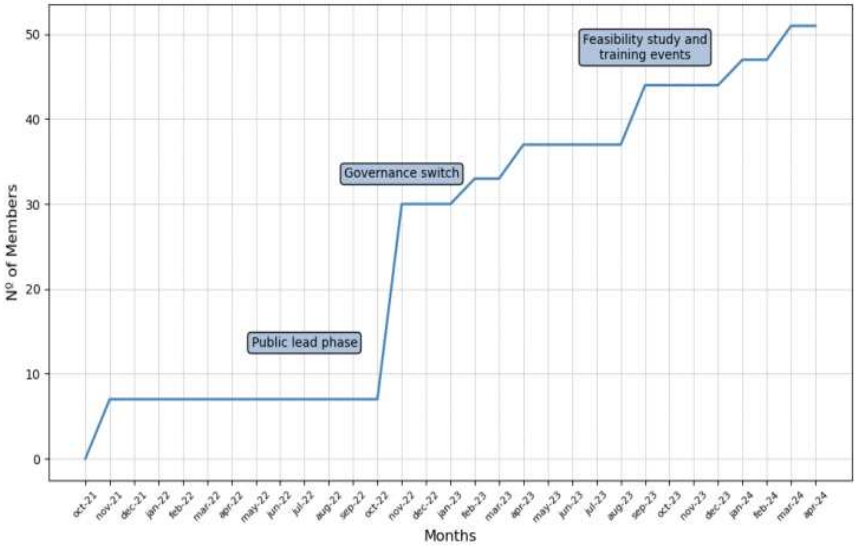
- High availability of the solar source (1150 W/m^2)

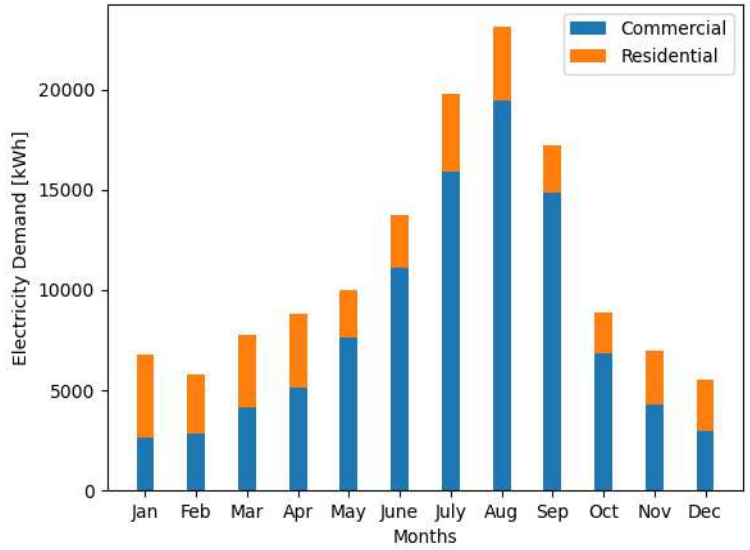
- Clean water supply is fully met by a desalination systems supported by a water storage. (202 000 m^3)

The Renewable Energy Community on Ventotene island

- The process of establishing the Ventotene REC lasted 3 years and was influenced by government actions
- A technical-economic feasibility study was financed by the Lazio Region and developed by the REC itself between July and September 2023
- The consumption dataset collected refers to real data extrapolated directly from the 2nd generation electricity meters of the 29 PODs.

ID	Type	occupants	Annual Demand [MWh]	Peak power [kW]	Net area for PV [m²]
1	Hotel	50	45.74	20	190
2	Hotel	50	25.158	20	200
3	Carpentry	2	1.130	4.5	100
4	Town hall	30	2.493	25	170
5	Restaurant	30	2.090	20	190
6	Farm	30	5.851	6	66
7	Residential	4	1.860	3	126
8	Residential	3	3.382	3	61
9	Residential	3	1.454	3	75
10	Residential	4	3.520	3	90
11	Residential	5	4.809	3	39
12	Residential	4	2.831	3	117





Scenarios

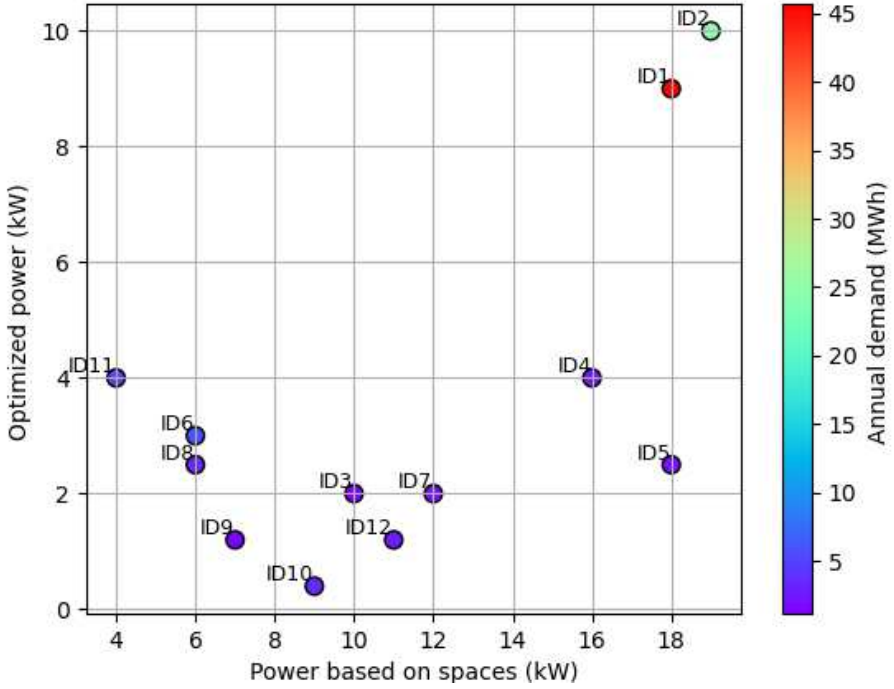
Scenario	PV Sizing Basis	DES Integration	Control Logic
***Baseline* Scenario**			
REC0	Optimization*	✗	–
REC1	Rooftop Space Availability	✗	–
W-E Nexus Scenario			
REC2	Rooftop Space Availability	✓	Water Consumption Data
REC3	Rooftop Space Availability	✓	Smart Solar Alignment

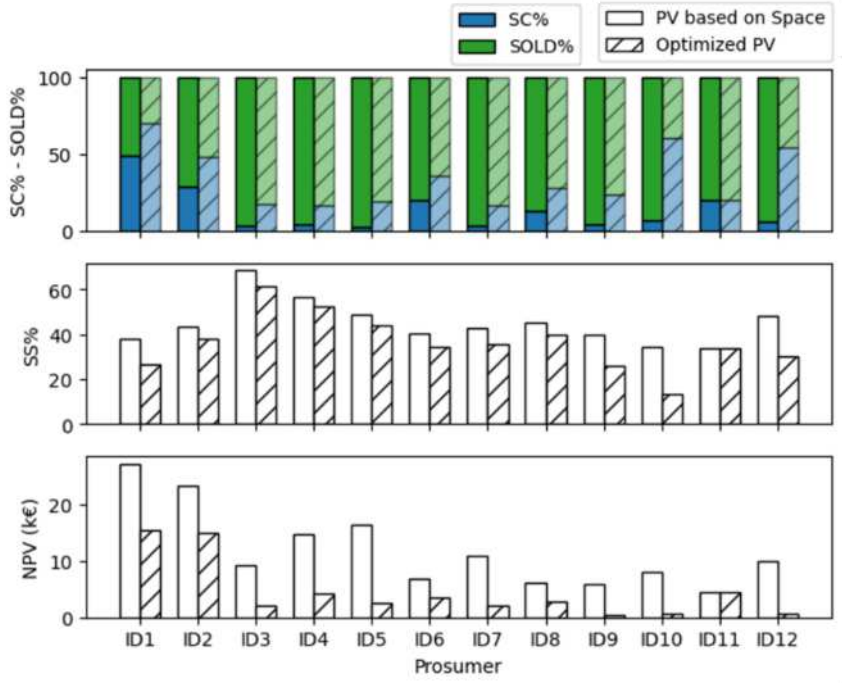
*An optimization problem is carried out using a NSGA-II optimization algorithms, with the aim to size the prosumers' photovoltaic systems. The problem is solved integrating pyRES with pymoo library and it is formulated as follows:

- the installed power (PV)
- the objective functions (F_1, F_2)
- The algorithm selects solutions that maximizes self-consumption while minimizing the initial investment ($CAPEX$).
- Constraint G_2 ensures that self-consumption (SC) is at least 10% of the production (P) to exclude unfeasible solutions.

$$\begin{cases} F_1 = \max(SC) \\ F_2 = \min(CAPEX) \\ G_1: 0 \leq PV \leq PV_{max} \\ G_2: SC_{\%} > 0.1 \end{cases}$$

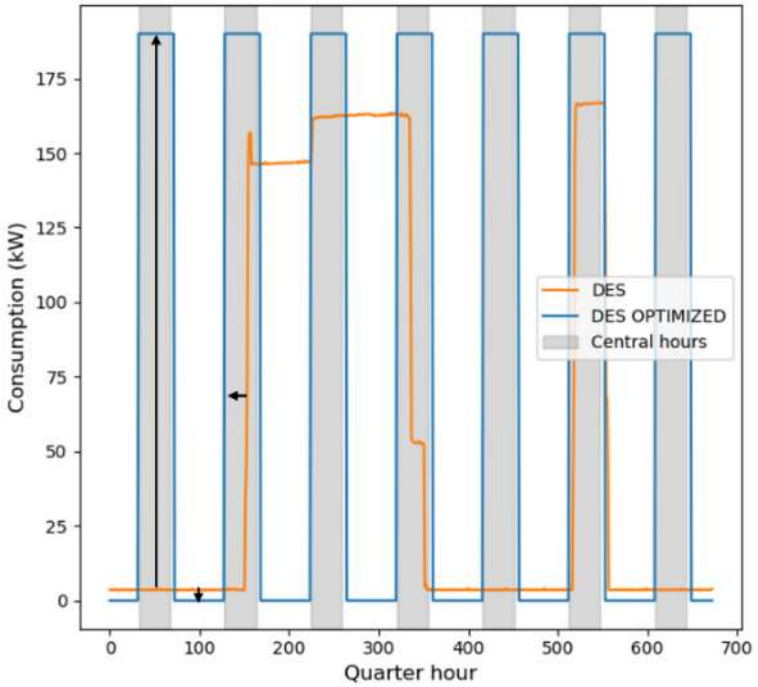
all prosumers - optimized and space-based PV configurations



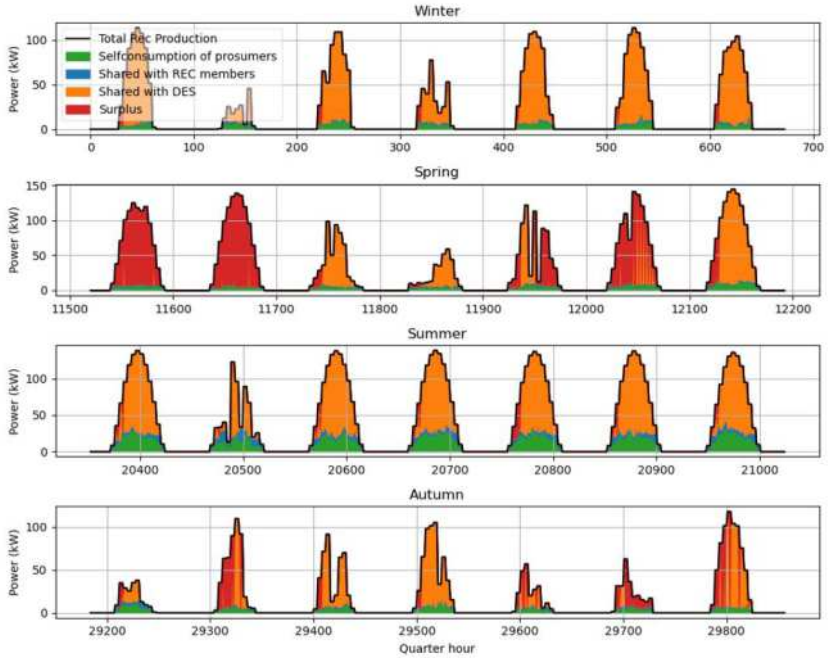


- In the optimized case, systems are sized conservatively, with power capacity lower than the maximum allowed by available space, to avoid excess of energy production during winter months with low demand.
- Most points fall within the lower range, between 2.5 and 10 kW.
- This means that the systems are relatively small, highlighting the challenge of balancing system capacity when summer consumption reaching up to 10 times that of winter.

Weekly electricity demand of DES -Winter



Energy metabolism of the REC in the best scenario



- In the optimized case, the system optimizes the use of the existing water storage on the island, allowing water produced during the day to be stored and subsequently distributed based on actual demand.

- The use of the desalination system plays a key role in maximizing the sharing of produced energy, especially in winter when self-consumption by prosumers and sharing with REC members is lower due to reduced consumption.

Summary

< +100% + 25%

	REC0	REC1	REC2	REC3
PV Power (kWp)	41.8	136	136	136
Number of members	23	23	23 + DES	23 + DES
Demand (MWh/year)	125	125	894	894
Production (MWh/year)	80	268	268	268
Self-consumption (MWh/year)	32	41	41	41
Sold to supplier (MWh/year)	48	227	227	227
Surplus (MWh/year)	35	214	67	26
Bought from supplier (MWh/year)	93	84	853	853
Shared energy (MWh/year)	13	13	160	201
REC Annual incentives (€/year)	1616	1639	19796	24927
NPV-REC (k€)	23	23	280	353
NPV-TOT (k€)	77	166	365	437
DES hours_on	-	-	8652	4054
Water production (m^3)	-	-	202376	202700
Saved_emissions (tCO_2)	32	39	144	173

- In the REC0 production systems are sized to maximize self-consumption and minimize initial investment at prosumer level.
- The approach adopted in REC1 enabled an increase in production capacity and self-sufficiency, despite the higher energy surplus.
- This issue can be mitigated by integrating a desalination system into the REC (***W-E Nexus Scenario***).
- This scenario significantly improves both economic and environmental performance. In REC2, the shared energy increases from 13 to 160 MWh/year and the total community incentive from 1,639 to 19,769 €/year without increasing the capital expenditures.
- In the REC3 a controller is added, leading to a further 25% increase in shared energy and the respective incentive.

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Relevant Publications

1. Corsini, A. et al. 2023. **Challenges of renewable energy communities on small Mediterranean islands: A case study on Ponza island**. Renewable Energy, 215.
2. Pizzuti, I. et al. 2024. **Integration of photovoltaic panels and biomass-fuelled CHP in an Italian renewable energy community**. Energy Conversion and Management: X, 24.
3. Tajalli-Ardekani, E. et al, 2024. **A Rome district transition towards optimal and sustainable heat and power generation.** Applied Thermal Engineering, 255.
4. Pizzuti, I. et al., 2025. **Energy Storage and Management of Offshore Wind-Based Green Hydrogen Production.** Processes 13(3).