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SHAREN

# Renewable Energy Communities in Historic Cities

*The Perugia City-Scale Model*

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*Based on: Tarpani, Hong, Pigliautile, Zhang, Sun, Pioppi, Pisello — Energy & Buildings 338 (2025) 115709*

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# What this talk covers

## 1. The challenge

Heritage constraints vs. the renewable transition

## 2. What is a REC

Concept, actors, and the Italian context

## 3. Methodology

CityBES urban simulation + multi-objective optimization

## 4. Case study

Perugia — historic centre and suburbs, north & south

## 5. Results

Consumption, PV potential, optimal REC configurations

## 6. Outlook

From Perugia to the Mediterranean — SHAREN

MOTIVATION

# Heritage protection meets the energy transition

**40%**

of EU final energy consumption is attributed to buildings

**29%**

of global GHG emissions come from carbon-emitting electricity use



## Historic city centres are largely locked out of on-site PV

- **Architectural & landscape preservation laws** restrict rooftop modifications in historic cores
- Installing PV or other renewables on protected buildings is often difficult or prohibited
- Yet these residents and businesses **still need — and deserve** — access to clean, affordable energy
- **Renewable Energy Communities (RECs) can bridge the gap**: production where it is possible, consumption where it is needed

CONCEPT

# Renewable Energy Communities (RECs)

*Legal and social entities built on active citizen participation, combining prosumers and consumers who share locally-produced renewable energy.*

## Prosumers

**Produce and consume** — install PV and inject surplus into the shared pool

## Consumers

**Passive members** who draw on the community's shared renewable energy

## The Italian regulatory boundary conditions used in this study

- **REC members must be served by the same primary substation** (cabina primaria) — the physical boundary adopted for Perugia's north/south zones.
- A **cap** applies **to the size of each individual renewable plant** within the REC.

*Framework transposed from EU rules and still evolving — check current MASE / ARERA / GSE provisions.*

## Three benefit dimensions

Environmental — fossil substitution, lower $CO_2$

Economic — bill savings, shared self-consumption

Social — engagement & energy awareness

# From neighbourhood pilots to a city-scale method

## What's already known

- REC studies **typically optimize storage**, **control strategies** or a handful of neighbouring buildings
- Italian REC case **studies exist for small**, mostly-residential clusters (tens of buildings)
- **Heritage-site renewable integration** is recognised as **difficult**, but rarely modelled quantitatively at scale

## This study's aim

Propose and test a **replicable, urban-scale procedure to design RECs** that let suburban PV generation support historic-centre demand — for the first time **not limited to a single neighbourhood**.

### Two design objectives, held in balance:

- Maximise REC self-sufficiency
- Minimise surplus energy dumped, unshared, to the grid

# A three-stage, data-driven workflow

1

## Data collection

Building footprints & typology, QGIS dataset (GeoJSON) and site-specific climate data

2

## Simulation in CityBES

Consumption validation, demand analysis and PV simulation in CityBES / EnergyPlus

3

## Multi-objective optimization

Genetic algorithm sizes REC configurations — minimizing grid surplus, maximizing self-sufficiency

*Each stage was validated against reference building typologies (TABULA, literature benchmarks) before being used for PV and REC analysis.*

*Adapted from Fig. 2 — study workflow. Source: Tarpani et al. (2025), Energy & Buildings 338, 115709 — Fig. 2. CC BY-NC-ND 4.0.*

# Building a reliable urban energy model



## Building-stock dataset

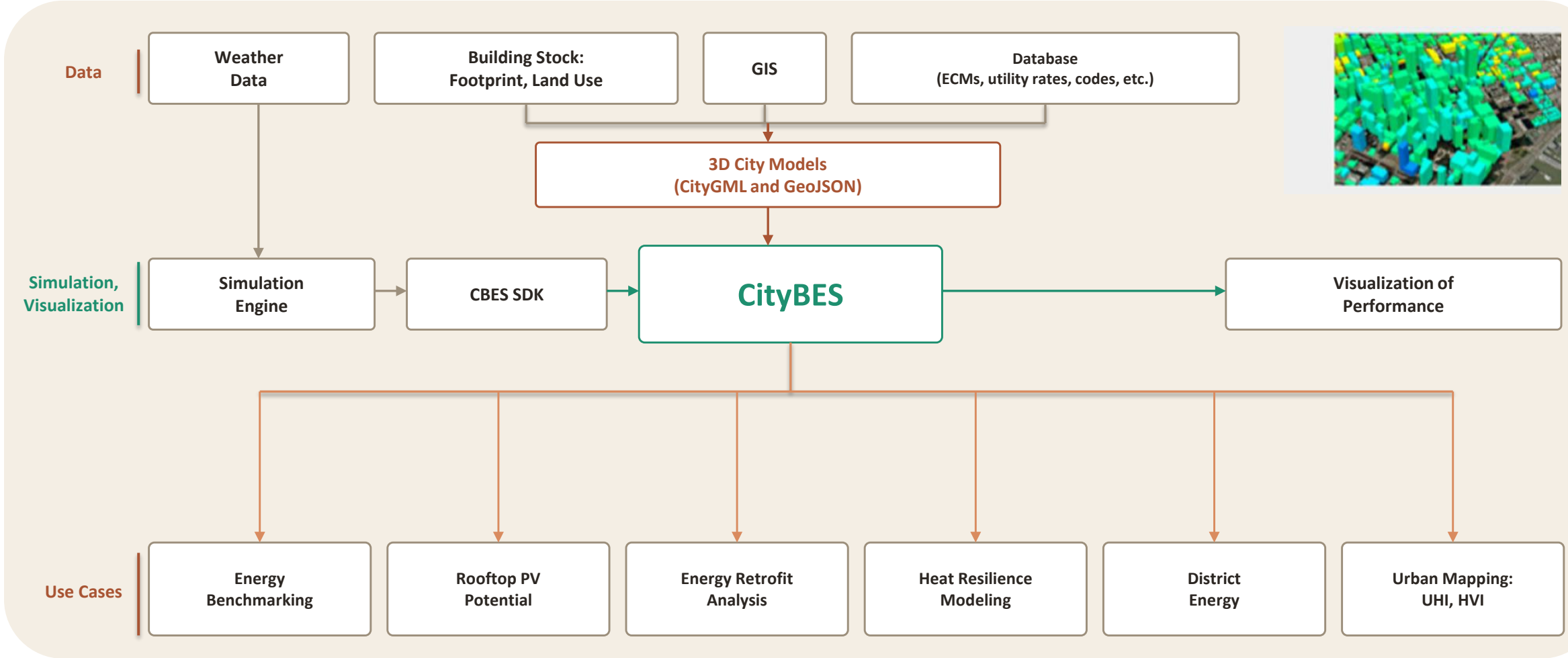
- **Type** · single/multi-family, small/medium/large office, small/medium retail
- **Year built**, number of **storeys**, **height**, **total floor area**
- Sourced from the **national geoportal** & UmbriaGeo, supplemented with Google Maps / Earth
- **Site-specific TMY3 climate file**, updated with local weather-station data



## CityBES (LBNL)

- **Web-based urban / district building-performance platform**
- CBES SDK, built on OpenStudio, with prototypes per building typology
- **EnergyPlus simulation engine** for hourly demand & retrofit / PV analysis
- Outputs: energy benchmarking, PV potential, retrofit, resilience, district-energy use cases — mapped in full on the next slide

# How the pieces fit together




*Adapted from Fig. 1 — CityBES software framework. Source: Tarpani et al. (2025), Energy & Buildings 338, 115709 — Fig. 1. CC BY-NC-ND 4.0.*

CASE STUDY

# Perugia, central Italy

**~200,000 inhabitants** · Cfa climate — temperate, hot summers (Köppen–Geiger) · historic centre under architectural & landscape preservation constraints

*Two zones, each served by **one primary energy substation**:*

### Northern area

**1,316** buildings — 617 historic centre + 699 suburbs

### Southern area

**1,298** buildings — 572 historic centre + 726 suburbs

*Both zones straddle the historic-centre / suburban boundary, letting each REC pair heritage-constrained demand with suburban PV potential inside a single primary-substation area — mapped on the next slide.*

CASE STUDY · GEOGRAPHY

# Where the two RECs actually sit

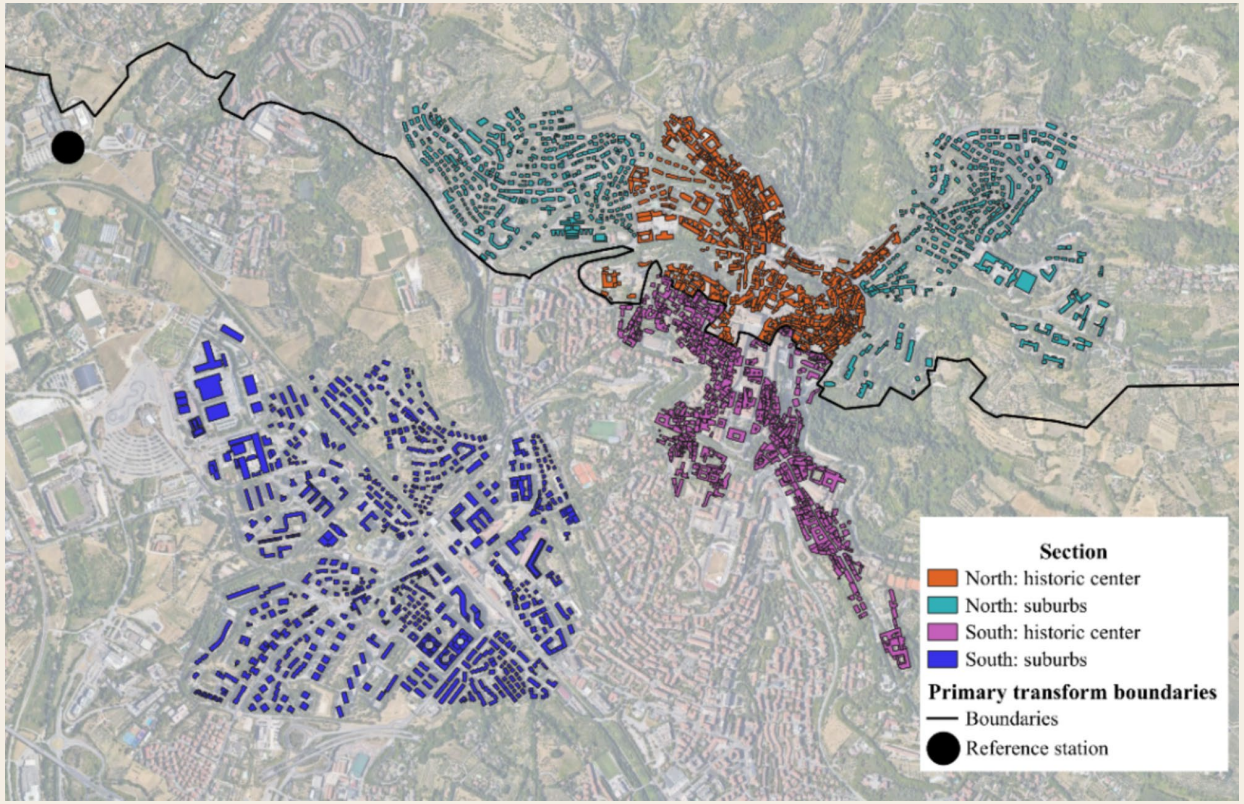
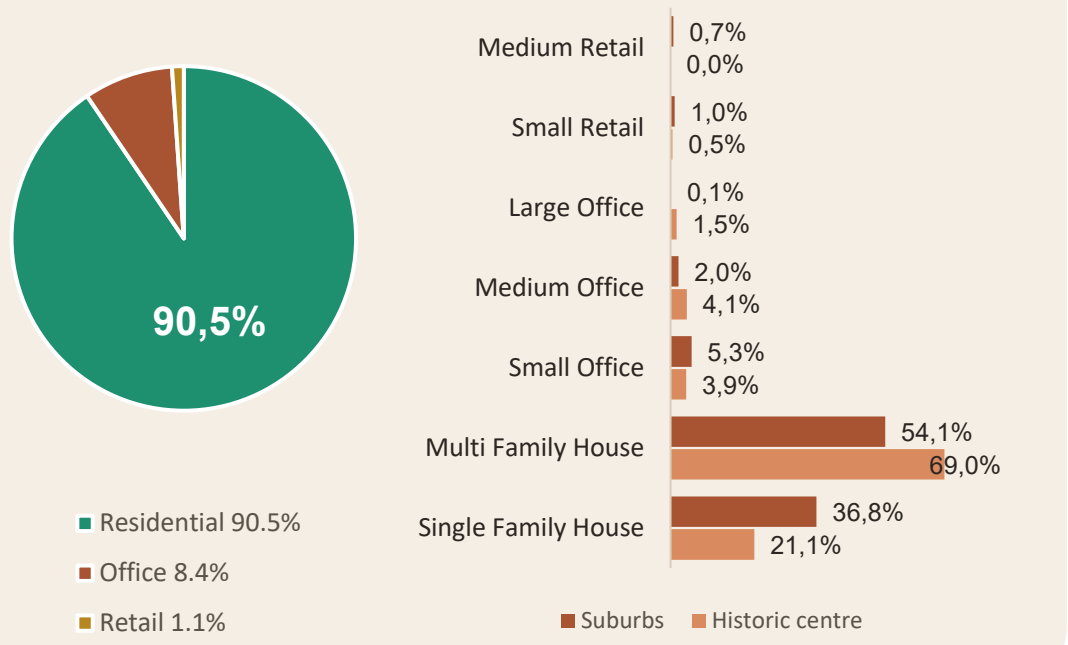



*Fig. 4 — modelled urban context. Source: Tarpani et al. (2025), Energy & Buildings 338, 115709 — Fig. 4. CC BY-NC-ND 4.0.*

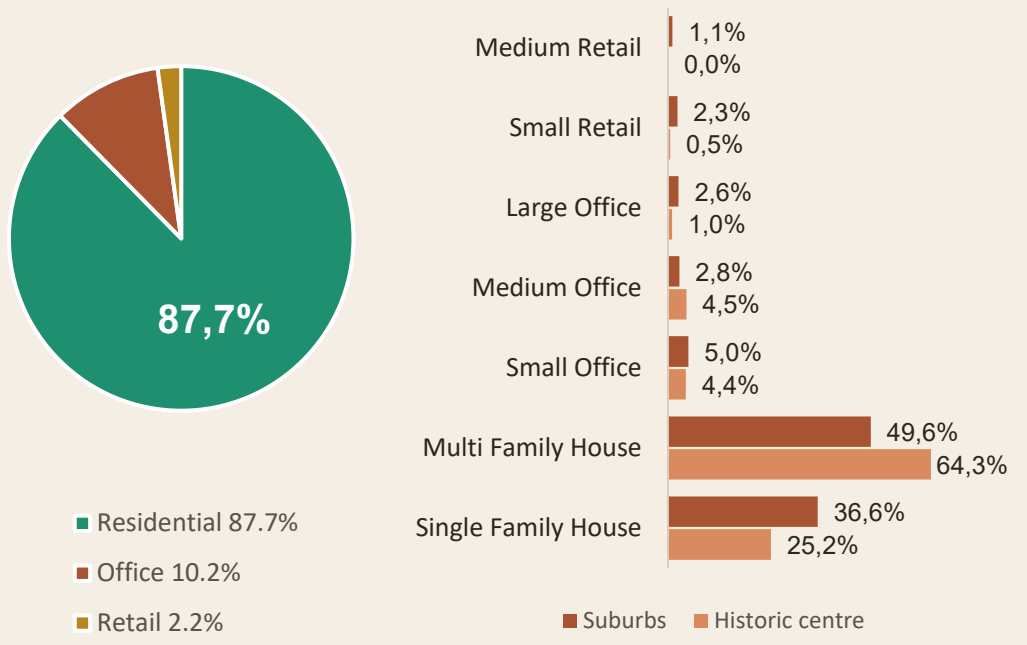
Orange / pink = historic-centre parcels (north / south); teal / blue = suburban parcels — the actual footprint dataset used to run CityBES, over real satellite imagery.

# Building-stock composition, by zone

## Northern area — Fig. 5




## Southern area — Fig. 7

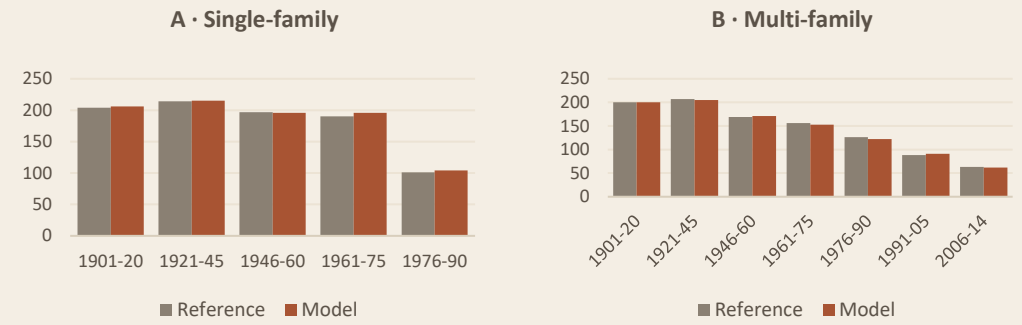



*Data drawn from Fig. 5 (north) and Fig. 7 (south). Source: Tarpani et al. (2025), Energy & Buildings 338, 115709 — Fig. 5 & 7. CC BY-NC-ND 4.0.*

**Historic centres are markedly older** — average construction year **1938** (N) / **1934** (S) vs. 1964 / 1971 in the suburbs — thicker, harder-to-retrofit masonry.

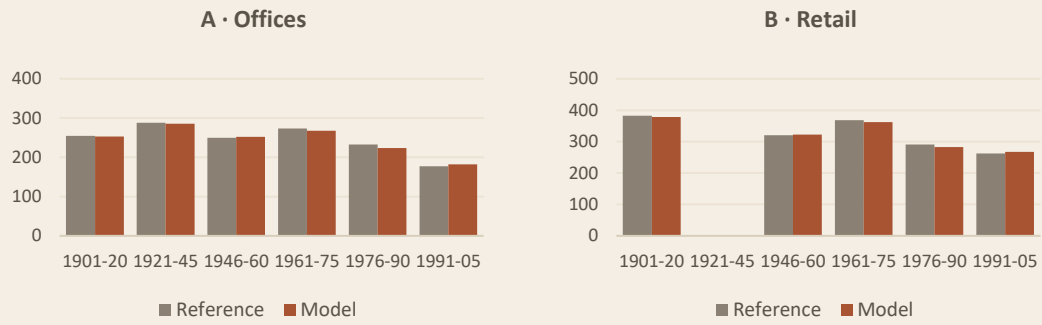
# Validating simulated demand against references

## Residential — Fig. 9 (vs. TABULA WebTool)




*Source: Tarpani et al. (2025), Energy & Buildings 338, 115709 — Fig. 9. CC BY-NC-ND 4.0.*

## Offices & retail — Fig. 10 (vs. Luddeni et al.; Fabrizio et al.)

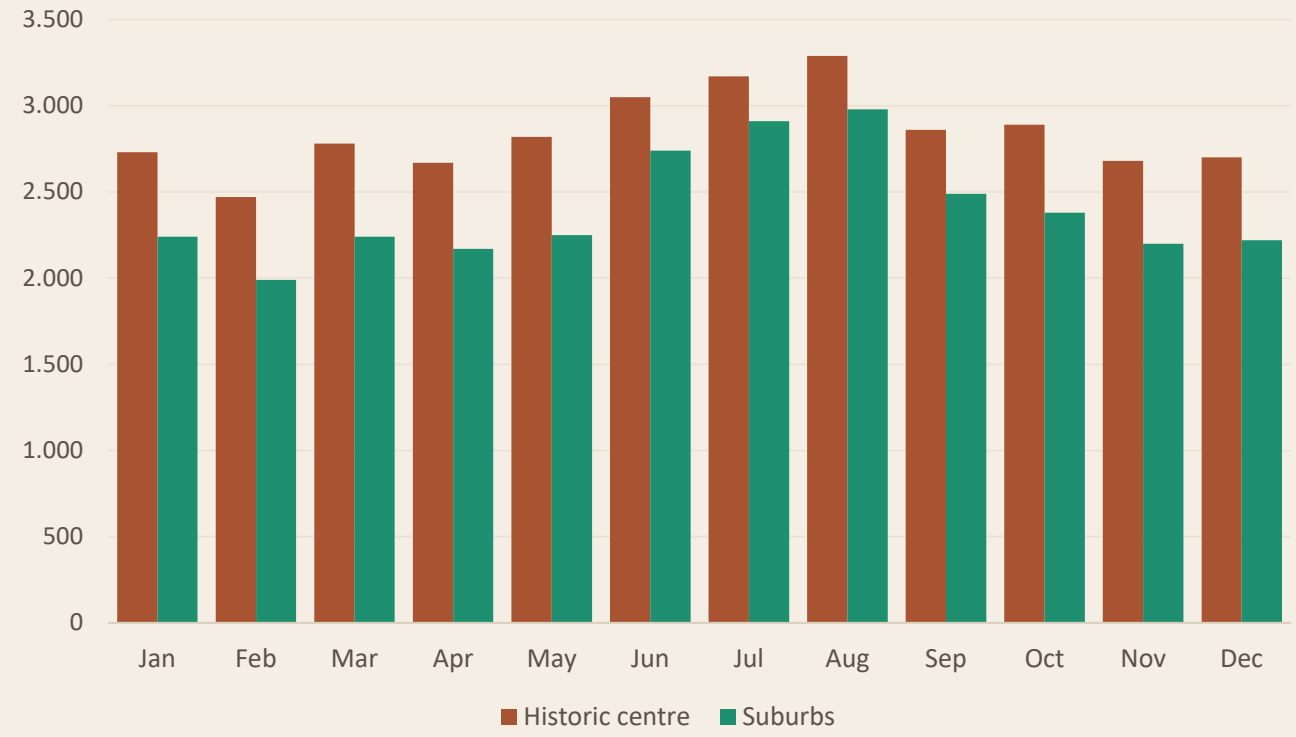



*Source: Tarpani et al. (2025), Energy & Buildings 338, 115709 — Fig. 10. CC BY-NC-ND 4.0.*

Close agreement across every typology — gaps of just 1–8 kWh/(m²·yr), negligible against total demand: a dependable basis for the PV and REC analysis that follows.

# Electricity demand: a summer-peaking pattern

**Northern area — total monthly electricity demand**




*Bar totals read from Fig. 11 (panels A, C). Source: Tarpani et al. (2025), Energy & Buildings 338, 115709 — Fig. 11. CC BY-NC-ND 4.0.*

**Multi-family housing dominates volume** in both zones — it is ~90% of the building stock.

**Per-user, large & medium offices drive** the highest individual monthly demand (Fig. 11, panels B/D).

**Demand peaks June–August in both zones**: cooling loads (HVAC) in offices and mid-size retail.

*Southern area follows the same shape (Fig. 12), with slightly lower absolute demand in the suburbs.*

# Suburban rooftops: generation vs. demand, hour by hour

*PV on suburban residential roofs only (south-facing, 30° tilt, crystalline-silicon modules) — 30% vs. 70% roof-coverage scenarios.*

## 30% coverage
*conservative estimate*

single-family peak surplus (N, spring)

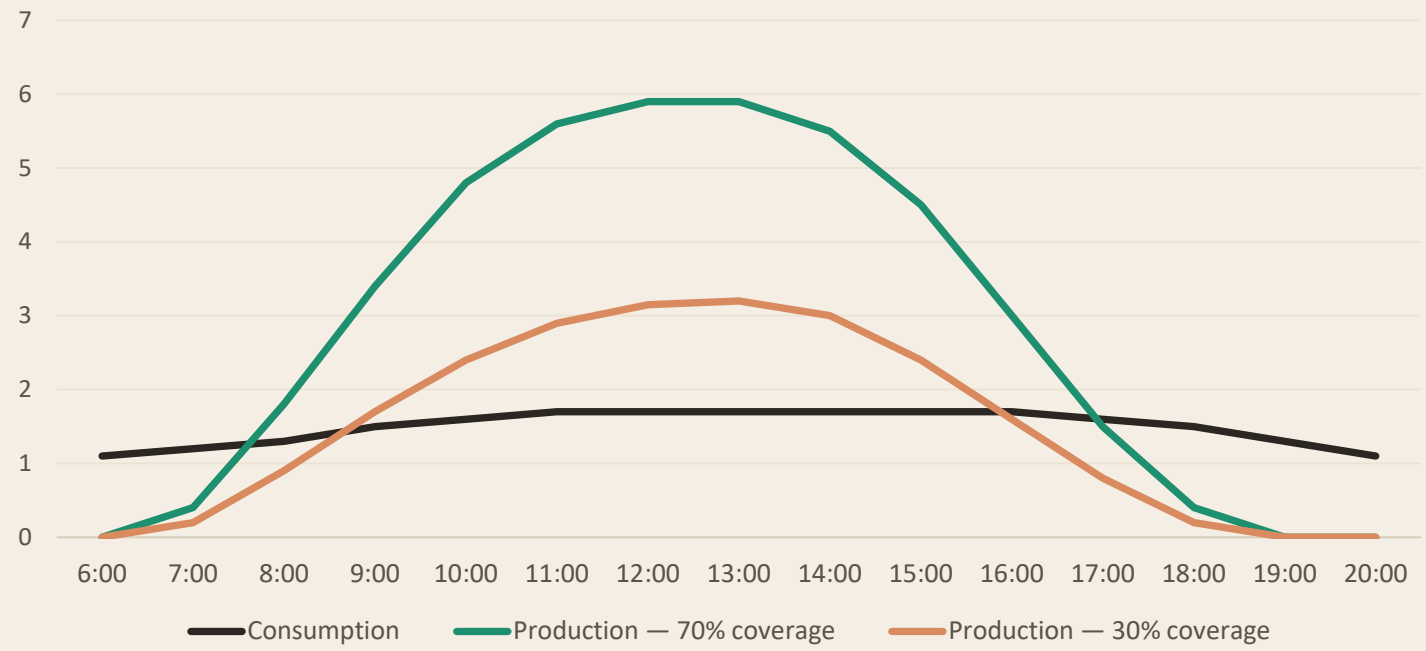
**+1.5 kWh**

## 70% coverage
*ambitious estimate*

single-family peak surplus (N, spring)

**+4 kWh**

### A reference spring day, single-family houses (northern area)




*Schematic curve calibrated to the peak surplus values reported in Fig. 13 (Tarpani et al., 2025).*

***Self-sufficiency window widens** from ~8am–1pm (summer, 30%) to ~7am–5pm, all year round (70%); multi-family peak surplus reaches +8 kWh (30%) / +20 kWh (70%).*

# A multi-objective optimization problem

## Two competing objectives

### Maximize self-sufficiency (SS)

minimize (1 − SS) = share of consumption not met by shared + self-produced renewable energy

### Minimize unshared grid surplus

minimize PV generation − total consumption, for energy produced but not consumed by any REC member

## Setup

- **Decision variables**: number of prosumers (suburban residential) and consumers (historic centre + remaining building types)
- Genetic algorithm, up to 500 configurations
- **Bounds**: 25–1,500 kWh surplus to the grid; 0.1–0.8 for (1−SS)
- **Three archetypes compared**: residential-only, commercial-only, mixed

# Selected optimal configuration per REC type

| Area | REC type | Monthly production (kWh) | Shared energy (kWh) | Self-sufficiency | Grid surplus (kWh) |
|---|---|---|---|---|---|
| Northern | Residential-only | 18.2 | 16.3 | 0.87 | 29.6 |
| | Commercial-only | 36.2 | 27.0 | 0.83 | 70.7 |
| | Mixed | 45.1 | 32.4 | 0.86 | 150.6 |
| Southern | Residential-only | 39.7 | 32.0 | 0.89 | 31.5 |
| | Commercial-only | 69.8 | 56.4 | 0.88 | 47.7 |
| | Mixed | 87.2 | 61.5 | 0.88 | 126.8 |

*Highlighted metric: self-sufficiency (SS) — the fraction of demand met from within the REC.*

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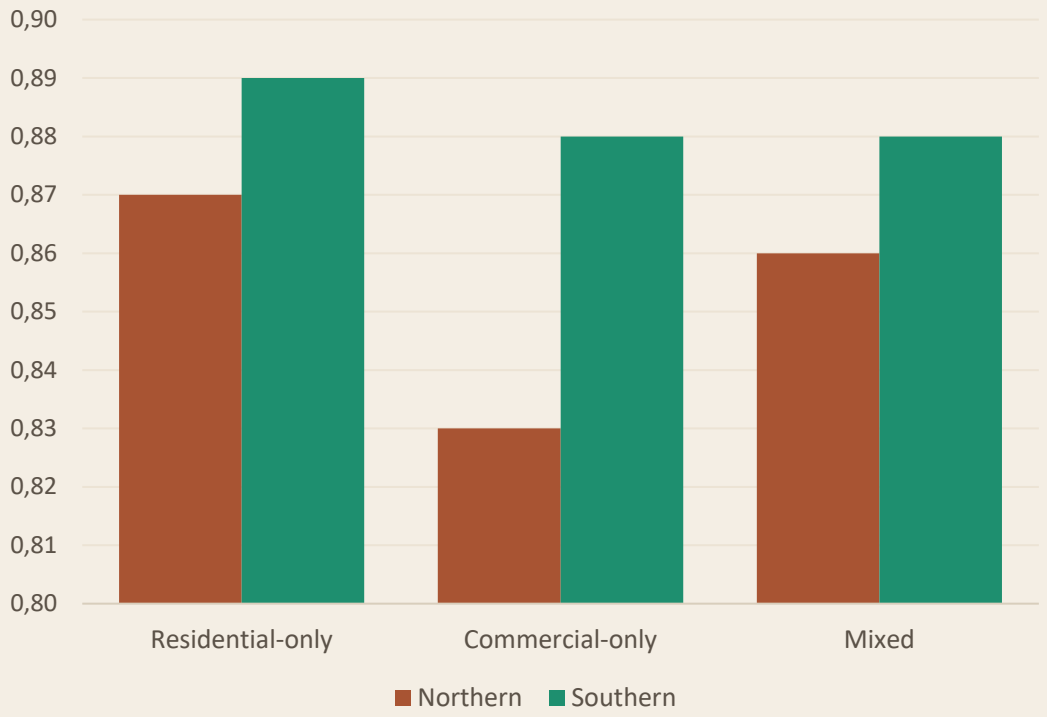
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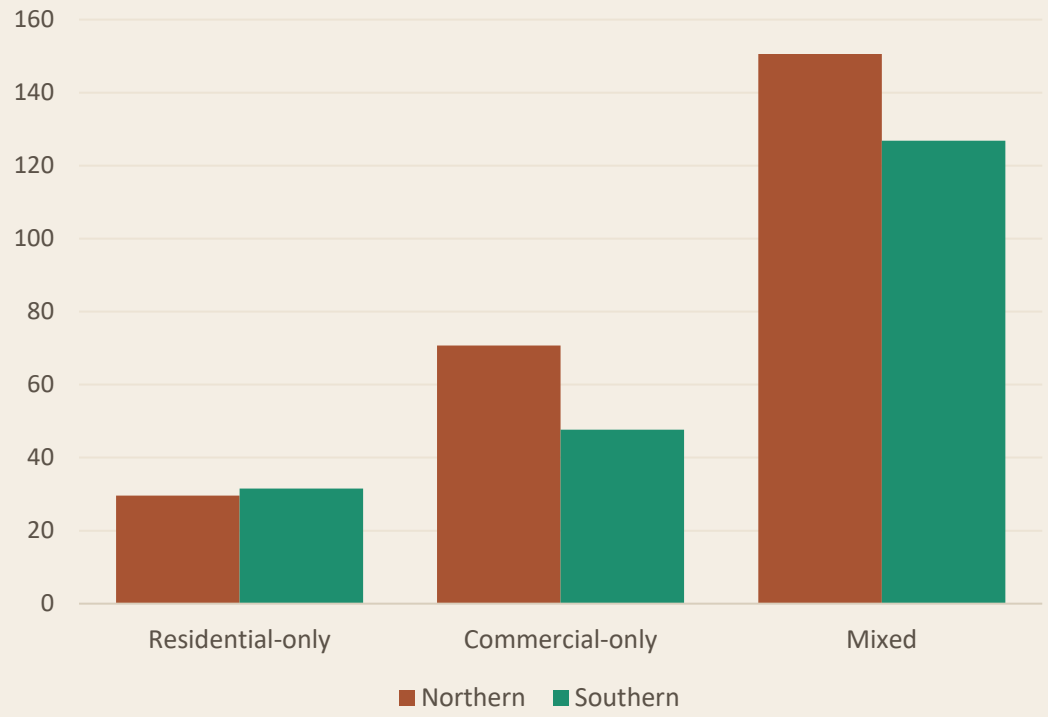
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# Self-sufficiency vs. grid surplus, by REC type

## Self-sufficiency (SS)




## Unshared grid surplus (kWh/month)

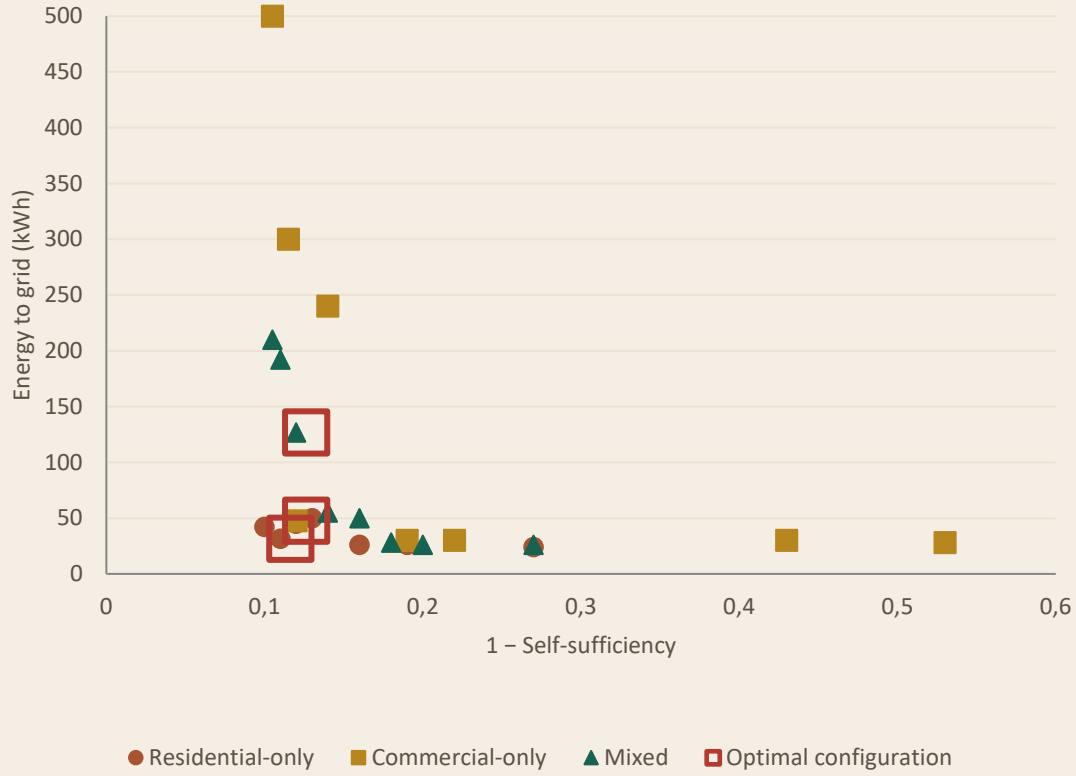


# Pareto front: self-sufficiency vs. grid surplus

## Northern area




## Southern area




*Optimal points = Table 3; surrounding cloud is an illustrative reconstruction of the genetic-algorithm search space, adapted from Fig. 15. Source: Tarpani et al. (2025), Energy & Buildings 338*

*Residential-only clusters bottom-left (high SS, low surplus); commercial and mixed spread across both axes.*

# REC composition is a design lever



## Residential-only

**Highest self-sufficiency** (SS ≈ 0.87–0.89) and lowest surplus — but small, so **total production stays modest**.



## Mixed

**Highest total production** and shared energy — but also the **largest unshared surplus**, a risk for local grid stability.

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### Commercial-only

Balances high self-sufficiency with efficient use and low surplus — the study's "potentially optimal" archetype.

**Best balance**

CONCLUSIONS

# What the Perugia model shows

**A city-scale**, not neighbourhood-scale, **REC design method** — for the first time linking historic centres to their suburbs

Technically feasible: suburban **PV at 70% roof coverage** can meaningfully offset historic-centre demand

Scalable & replicable: an open, Python-based procedure, adjustable to other cities, climates and user mixes

**REC composition** (residential / commercial / mixed) **is itself a lever** on the self-sufficiency vs. grid-surplus trade-off

# What's next

## Boundary conditions to keep in mind

- **Results reflect the Italian regulatory frame** (2019–2021 transposition) — provisions on plant caps and REC boundaries continue to evolve
- **Heritage-site renewable constraints may ease over time** as technology (e.g. building-integrated PV) advances
- **Reference year (2020) climate data** — a changing climate will shift heating/cooling balances

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## Planned developments

- Future/projected climate scenarios in place of historical TMY data
- Real-time pricing and dynamic consumption patterns
- Detailed cost-benefit analysis of REC + PV investment
- Resilience value during grid outages and extreme events
- Replication in other historic cities with different climates and heritage rules

OUTLOOK

# From Perugia to the Mediterranean

*The same challenge — **heritage preservation vs. renewable deployment** — is exactly what SHAREN is tackling across its pilot sites.*

**Altea**
Spain

**Byblos & Anjar**
Lebanon

**Madaba**
Jordan

**Monterotondo**
Italy

**Uşak**
Türkiye

## A transferable blueprint

**City-scale, data-driven REC design — pairing where energy CAN be produced** with **where it is needed** — offers a **template that each Mediterranean pilot can adapt** to its own climate, regulation and governance model.

# Thank you

*Questions & discussion welcome*

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Tarpani, E., Hong, T., Pigliautile, I., Zhang, W., Sun, K., Pioppi, B., Pisello, A.L. (2025).
On renewable energy community implementation in historic cities: A city-scale validated model.
Energy & Buildings, 338, 115709. https://doi.org/10.1016/j.enbuild.2025.115709

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