Optimization Methods in Business Analytics – Academic Year 2024/25 – Brevi Viola, Capelletti Thomas, Pasina Claudio Pietro

POWERING BRESCIA

OPTIMIZING EV CHARGING STATION ALLOCATION

A Maximum Coverage Approach for Sustainable Urban Mobility

OBJECTIVE

The transition to **sustainable mobility** hinges on the availability of a robust **EV charging infrastructure**. This project aims to optimize the spatial allocation of electric vehicle charging stations across the **Province of Brescia**, projecting needs and deployment strategies through 2030 based on a comprehensive sensitivity analysis.
The study employs the **H3 hexagonal grid system**, enabling finer granularity than traditional municipal-level data. The core of the optimization process is framed by the **Maximum Coverage Problem (MCP)**, seeking to maximize demand coverage within the constraints of limited resources.

DATASET

Data was sourced from **ISTAT** and local authorities.

- **Civil status** and **altimetry data**.
- **Vehicle registration data** provided fuel-type breakdowns and partial EV counts.
- **OpenStreetMap** data was aggregated into H3 hexagons to assess infrastructure density.

Datasets were standardized via **municipality names** for consistency.

ESTIMATES

As of December 2023, the total number of charging-dependent vehicles is estimated at **~10,000** vehicles in Brescia, based on Motus-E trends and ISTAT ratios.
The are **1,623 charging points** distributed across **631 locations**, 97.4% of which are publicly accessible. These stations offer varying power levels, affecting charging speed. On average, there are approximately **10.4 EVs per charging point.**

With an average **daily consumption of 5.94 kWh/EV**, total demand is **~59,400 kWh/day**. Each point provides **~555.43 kWh/day (12-hour window)**. Brescia's **population** is currently **~1.26 million**, with 2030 projections of:

- **Conservative** (+0.5%) → 1,263,613
- **Optimistic** (+1.5%) → 1,276,186

INDEX ENGINEERING

Conservative EV Projections:

- **BEVs:** ~30,000–32,000
- **PHEVs:** ~9,000–10,000
- **Total:** ~40,000–42,000

Optimistic EV Projections:

- **BEVs:** ~39,000–42,000
- **PHEVs:** ~9,000–10,000
- **Total:** ~48,000–52,000

Estimated spatial EV charging demand across Brescia using a **weighted hexagonal grid (H3)** based on municipal data and spatial indicators. Demand is allocated to each hexagon using **normalized weights** derived from factors like population, altitude, and infrastructure density.

- **Current Scenario**: Includes building density; total demand: 34,500.45 kWh/day
- **2030 Conservative**: Excludes building density; total annual demand: 10,009,341.21 kWh
- **2030 Optimistic**: Excludes building density; total annual demand: 15,014,065.22 kWh

$$W_{\text{length}} = 0.5 \times \left(\frac{L_h}{L_{\text{avg}}} + \frac{L_h}{L_{\max}}\right)$$

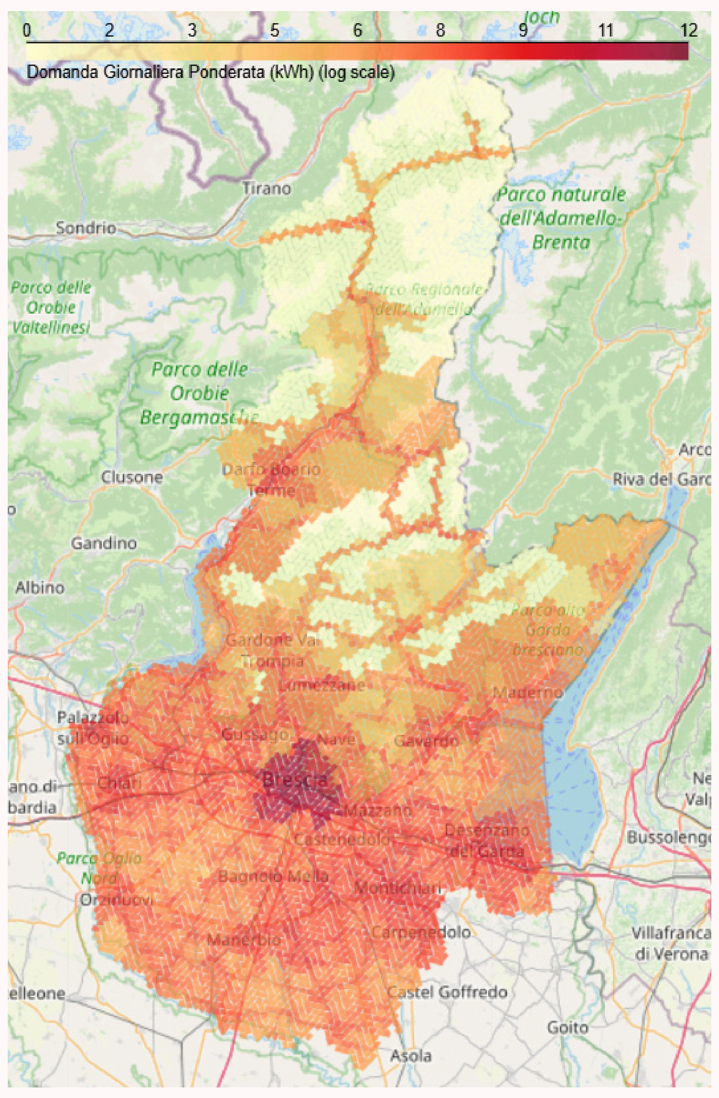
$$W_{\text{altitude}} = \max\left(0,\ 1 - 0.5 \times \left(\frac{A_h}{A_{\text{avg}}} + \frac{A_h}{A_{\max}}\right)\right)$$

$$W_{\text{building}} = \frac{B_h}{B_{\max}}$$

$$W_{\text{final}} = \frac{W_{\text{length}} + W_{\text{altitude}} + W_{\text{building}}}{3}$$

$$W_{\text{final}}^{2030} = \frac{W_{\text{length}} + W_{\text{altitude}}}{2}$$

DEMAND ESTIMATION



Example of the demand estimation: logarithmic map for the **optimistic scenario.**

OPTIMIZATION MODEL

Objective: $\max \sum_{h=1}^{n} y_h$

Subject to:

$\sum_{h=1}^{n} x_h \le p$ (Total stations constraint)

$y_h \le D_h \quad \forall h$ (Demand cannot be exceeded)

$y_h \le \text{cap} \cdot \left(x_h + \alpha \sum_{j \in \mathcal{N}(h)} x_j\right) \quad \forall h, \quad \alpha \in [0,1]$ (Capacity with optional attenuatio

$x_h \le 10 \quad \forall h$ (Max 10 stations per hexagon)

$x_h \in \mathbb{Z}_{\ge 0}, \quad y_h \in \mathbb{R}_{\ge 0}$

Where:

x_h = Stations in hexagon h

y_h = Daily demand covered in h

D_h = Estimated demand in h

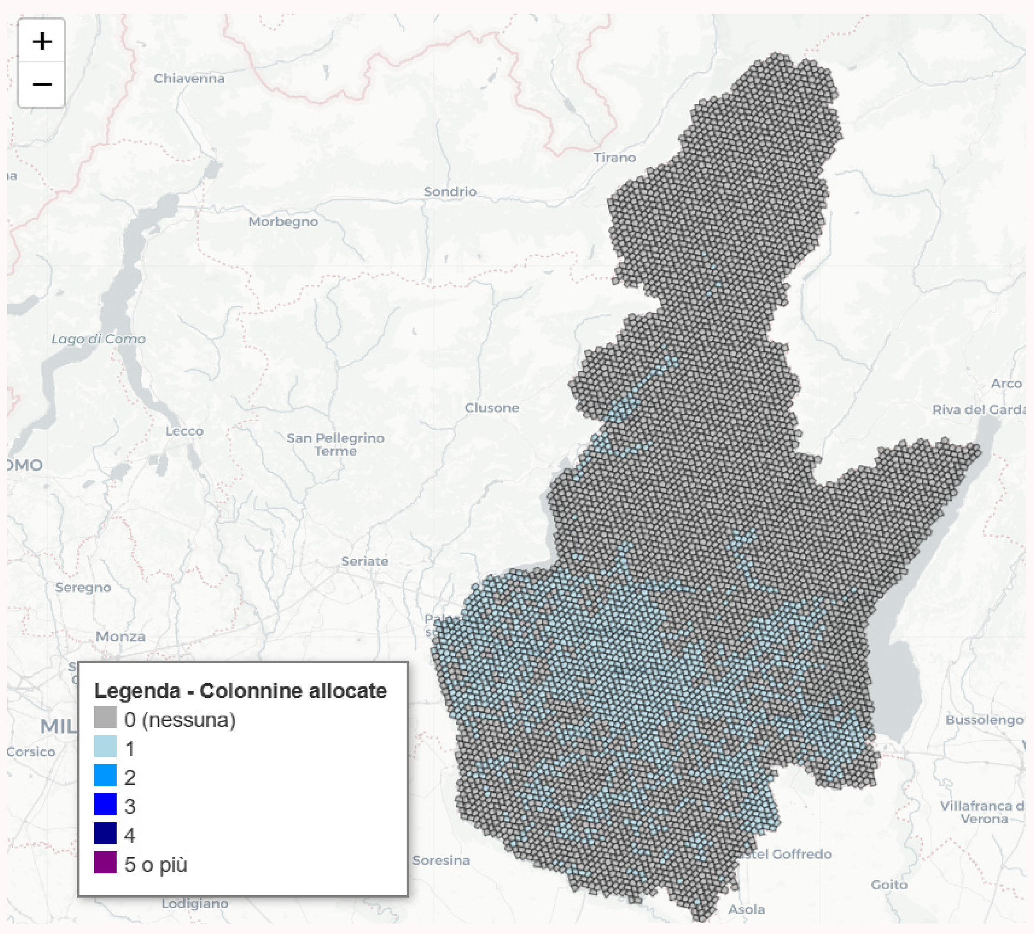
cap = Capacity of one station (e.g. 555.43 kWh)

p = Total number of stations available

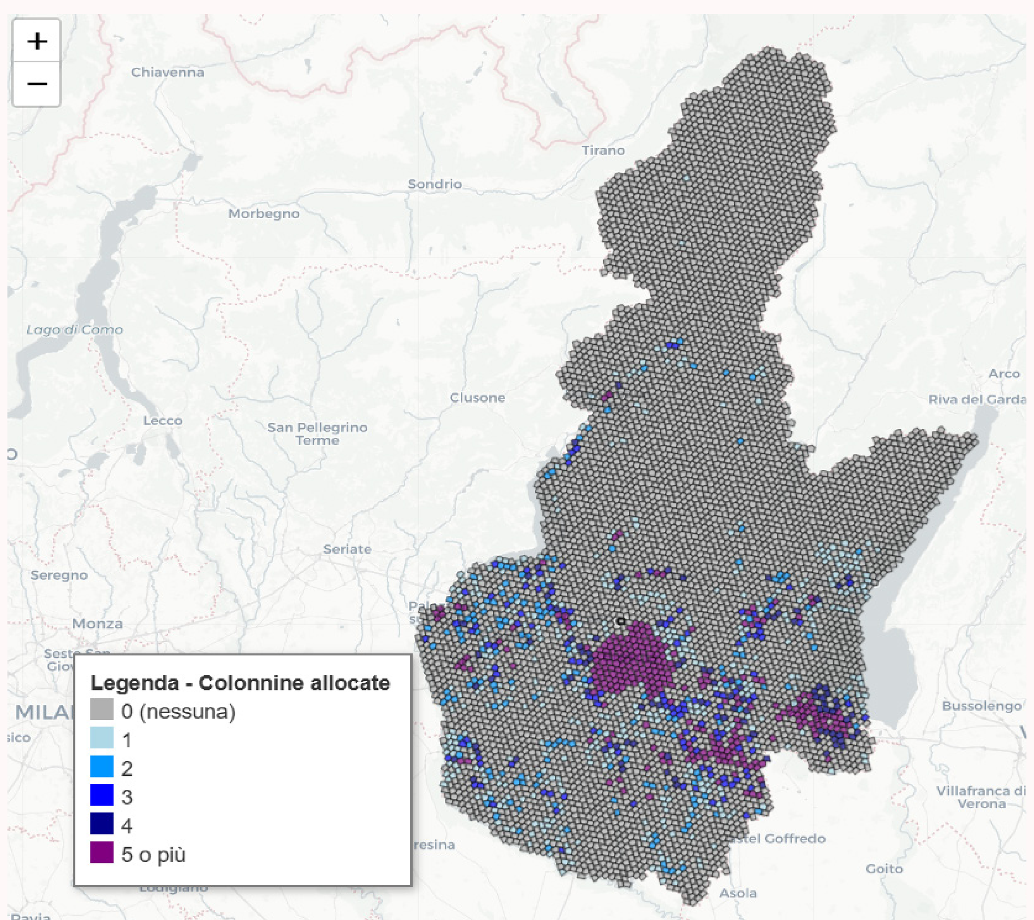
$\alpha \in [0,1]$ = Attenuation factor (set to 1 if ignored)

The Maximum Coverage Problem (MCP) was selected to optimize the placement of EV charging stations, aiming to maximize total demand coverage under a fixed station budget. The final model includes a tunable attenuation factor that reduces the contribution of neighboring stations based on their proximity, reflecting limited accessibility across hexagons.
Additional features such as partial coverage, demand weighting, and capacity constraints ensure a **balance between spatial equity, efficiency, and computational feasibility**. Two simpler models were also tested: a **local-only coverage model** (evaluated on current demand) and a **neighbor-aggregated model without attenuation**, both used to benchmark performance under present and 2030 demand scenarios.

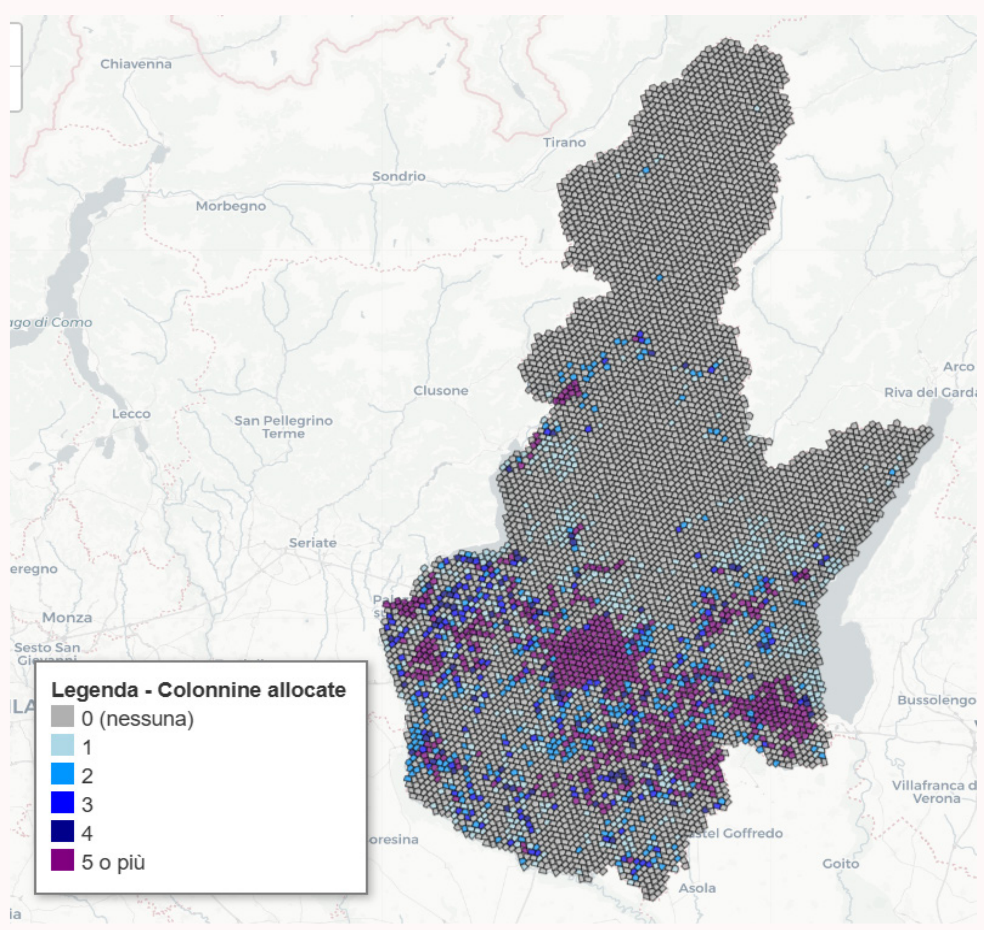
RESULTS AND CONCLUSIONS



Current scenario: The model covers 28,010.36 kWh/day, meeting **81.2% of provincial demand**. Full coverage is unachievable under current constraints.



Conservative scenario: The model placed 4,039 stations, covering 2,243,381.77 kWh/day—just **22.4% of projected demand**, underscoring the challenge of future infrastructure scaling.



Optimistic scenario: With 7,435 stations, the model covers 4,129,622.05 kWh/day—only **27.5% of projected demand,** showing full coverage is still out of reach

The study shows that even under optimistic scenarios, **Brescia's charging infrastructure will not fully meet 2030 demand**. Both conservative and advanced models reveal a persistent gap, highlighting the challenge of **expanding infrastructure fast enough to match EV adoption**. The proposed model effectively identifies these gaps and aids planning. Future research should incorporate dynamic demand and leverage advanced optimization methods for more realistic, scalable solutions to support sustainable EV charging network growth.

- *International Energy Agency, Global EV Outlook 2023 (2023).*
- *Church & ReVelle, "Maximal covering location problem," Papers in Regional Science (1974).*
- *Daskin, Network and Discrete Location (1995).*
- *He, Venkatesh & Guan, "Optimal public charging deployment," IEEE Transactions on Smart Grid (2013).*