PRINCIPAL ACADEMIC TUTOR
Michela Longo, Department of Energy, Politecnico di Milano

ACADEMIC TUTOR
Andrea Mazza, Department of Energy, Politecnico di Torino

EXTERNAL INSTITUTIONS
ATLANTE
EXTERNAL TUTOR
Paolo Ciliento, Francesca Mapelli, Marco De Donno

TEAM MEMBERS


Alessandro Amato,
Mechanical Engineering
@PoliMi


Filippo Cipriani,
Mathematical Engineering
@PoliMi


Gabriele Corbo,
Mathematical Engineering
@PoliMi


Michelangelo Giuffrida
Mechatronics Engineering
@PoliTo


Riccardo Rosi
Mechanical Engineering
@PoliMi


Paolo Timis
Mechatronics Engineering
@PoliTo


Aurelio Zizzo
Mathematical Engineering
@PoliTo

OASIS:

Optimal Allocation and Sizing of Infrastructure for charging electric vehicle basing on predictive Simulations.

Executive summary

The main issue addressed in the OASIS project is the environmental impact of road transportation due to air pollution and carbon emissions. The project's primary objective is to develop a decisional algorithm for optimizing the location and sizing of electric vehicle (EV) charging stations to promote the transition to clean energy sources. Atlante, a company focused on building an EV fast-charging network in Southern Europe, is the key stakeholder with requirements for an easy-to-use, automated, and revenue-maximizing solution.

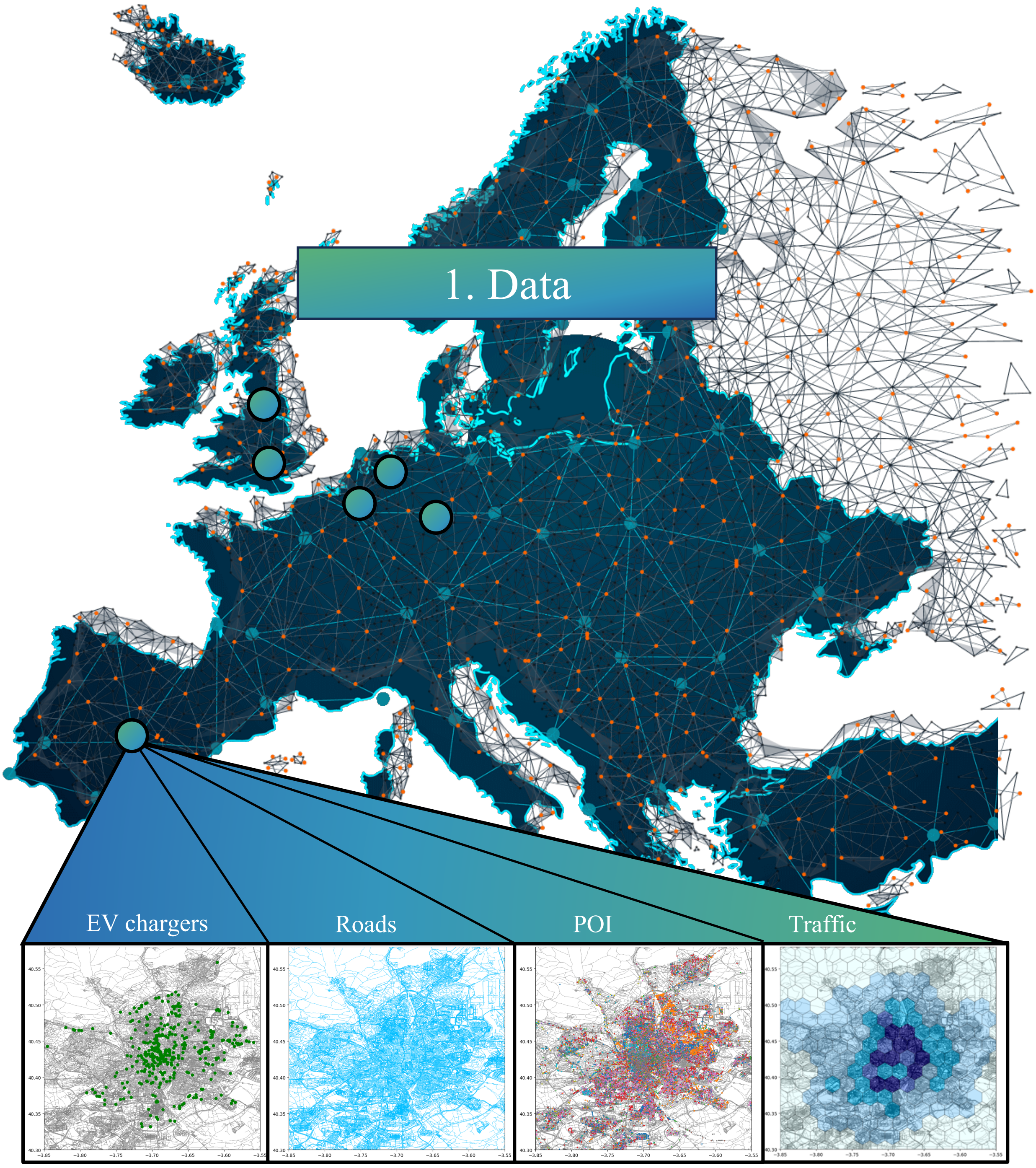
The project employs a Geographic Information System (GIS)-based approach, dividing the area into hexagonal cells and assigning suitability scores for charging station installation. Data collection includes traffic data, points of interest (POIs), costs, revenues, and information about existing EV charging stations.

In the testing phase with data from cities like Madrid, Rotterdam, and London, the algorithm successfully balances parameters, identifying high-potential peripheral points and achieving excellent economic performance. Future improvements could include incorporating demographic data and refining the economics of the algorithm to account for price fluctuations in energy and installation costs.

Key Words

Charging station optimization, Electric vehicle (EV)
Geographic Information System (GIS)
Sustainability
Environmental impact

1. Data



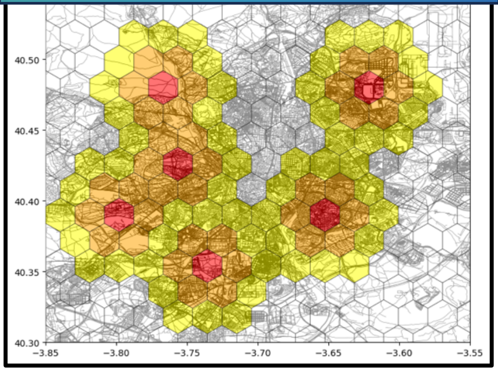
2. Model

$$\max \sum_{j=1}^{J} \left(dr_j \cdot c_j \cdot x_j\right)\left(1 - D_j\right)$$

$$dr_j = d_j - \sum_{z=1}^{Z} d_{jz}$$

$$D_j = \text{MinMaxScaler}\left(\sum_{l=1}^{L} dp_{jl} \cdot \lambda_l\right),$$

3. Solution



Team description by skill

The OASIS project assembles a dynamic team with a rich tapestry of skills and backgrounds. With their background in Mechanical Engineering and prior experience in electric vehicle prototyping, Riccardo and Alessandro contribute hands-on expertise in the automotive sector.

They are complemented by Michelangelo, whose Mechatronic Engineering knowledge adds insights into automation and industrial production. Paolo, driven by a fascination for the intersection of economics and engineering, provides a unique perspective on economic analysis and an openness to expanding his technical skills. Gabriele and Filippo's specialization in Statistical Learning equips the team with advanced data science and machine learning capabilities, while Aurelio, also a Statistical Learning expert, adds proficiency in optimization, implementation, and geospatial analysis.

With a collective passion for innovation and a willingness to bridge gaps in their knowledge, the team tackled the multidisciplinary challenges of optimizing the electric vehicle charging network in the OASIS project.

Goal

The OASIS project is dedicated to addressing the critical challenge of electric vehicle (EV) adoption by developing an advanced algorithm for the optimal allocation and sizing of EV charging infrastructure. This project is carried out in collaboration with Atlante, a company committed to building a fast-charging network powered by renewable energy and grid integration across southern European regions.

The primary outcome of the OASIS project is the development of a user-friendly algorithm that can identify the best locations for EV charging stations. The algorithm aims to maximize EV needs coverage, enhance customer experience, and create a viable business plan for Atlante. Additionally, the project promotes sustainable mobility and contributes to reducing greenhouse gas emissions.

The goal is to support Atlante's mission of creating a sustainable and efficient charging network for EV users. The team collaboratively conducted a comprehensive analysis of existing solutions, gathered essential data, and developed a sophisticated algorithm to determine the optimal locations for charging stations. The algorithm considers factors such as traffic data, grid capacity, proximity to key locations, and economic feasibility.

The OASIS project has far-reaching implications for the electric mobility sector. It supports the transition to EVs, reduces range anxiety for users, and helps integrate renewable energy sources into the transportation sector, recognizing the increasing global interest in EV adoption as a powerful mean to combat climate change.

Understanding the problem

In our comprehensive analysis, we delved into the intricacies of electric vehicle charger allocation. Within the realm of optimization models, our research sought to unearth existing solutions and emerging trends.

We addressed four pivotal research questions: exploring existing solutions for optimal EV charger allocation, research trends over recent years, primary inputs used in charger allocation strategies, and the emergence of projects and research groups in the field.

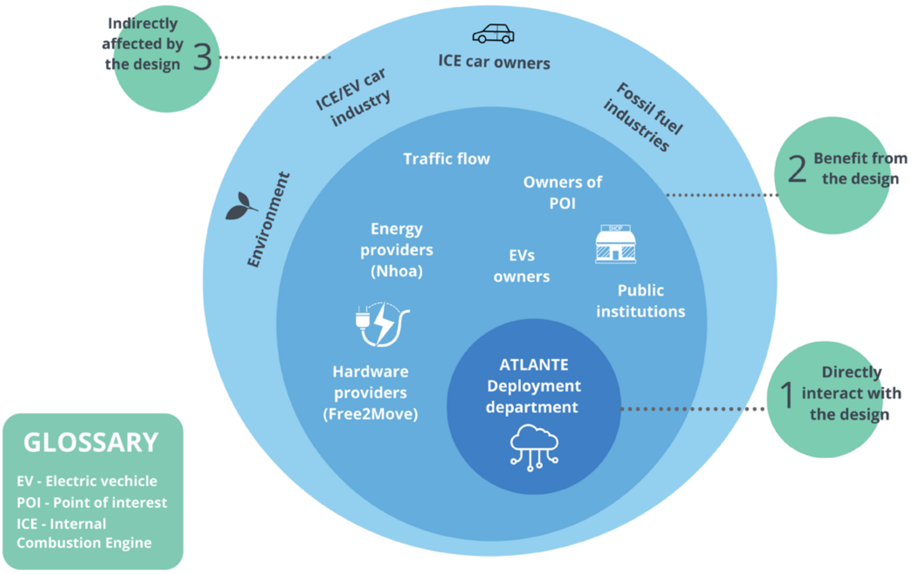
Geographic Information System (GIS)-based approaches are commonly used for optimal charger allocation. These methods involve creating grids and integrating various data layers, such as population density, infrastructure, and points of interest, to identify optimal charger locations. Additionally, other methods like graph-based approaches, genetic algorithms, and geospatial models using Kriging prediction and clustering are also employed. The research direction in the field of EV charger allocation remains diverse, with no dominant approach.

While both graph-based and grid-based approaches are prevalent, the choice depends on the specific problem constraints and input parameters.

Input parameters for optimization models are categorized into three primary groups: users' data (demographics, geo-location data), destinations' data (Points of Interest, charging stations), and routes data (infrastructure costs, usage probabilities, charging capacity). These parameters play a crucial role in shaping allocation strategies to balance user needs, destination dynamics, and route intricacies effectively.

Limited information on companies or group projects specializing in EV charger allocation research is available. However, we identified one notable project by Tesla, that aims to strategically place charging stations across the U.S. to maximize long-distance trip completion using battery electric vehicles. The project uses mixed integer programming and a modified flow-refueling location model to find solutions, emphasizing the importance of expanding fast-charging infrastructure.

It was also essential to evaluate the impact of EV charging on the European electrical grid and underscore the importance of seamlessly integrating EVs with the existing infrastructure. We found that intelligent charging systems and Vehicle-to-Grid (V2G) technology are pivotal components for success. There were also notable differences in grid organization, distinguishing between rural and urban grids with varying power limits and distribution characteristics, influenced by factors like power density, distribution networks, and peak power demand patterns. A diverse landscape of EV charging technologies was also explored, including wired and non-wired solutions, with a shift towards Direct Current (DC) charging, notably in leading European countries. Our investigation delved into the grid impact of different charging strategies, ranging from slow/medium to fast/ultra-fast charging, revealing common challenges such as increased power demands and the necessity for new substations. Finally, we shed light on the technical and regulatory barriers impeding V2G adoption across Europe, including tax implications, coordination issues with Distribution System Operators (DSOs), and the need for more incentivized schemes. In summary, our findings collectively paint a complex picture of the EV charging infrastructure landscape, with V2G technology poised to revolutionize grid management and sustainability.



OASIS Project’s Stakeholder Analysis

Generating a solution

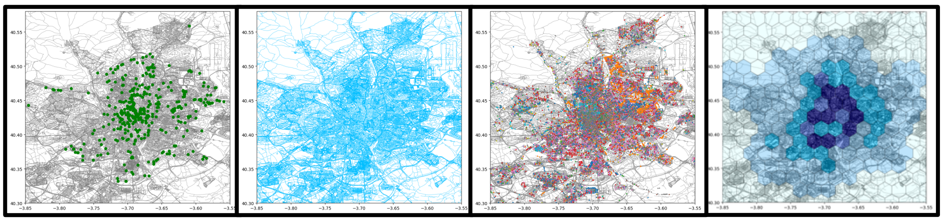
We embarked on the development of a comprehensive GIS-based approach, focusing our efforts on Madrid as a complex case study.

Our project began with the meticulous gathering of diverse datasets, ranging from maps and satellite imagery to demographic and infrastructure data. Despite the challenges in procuring traffic data, our perseverance paid off as we aggregated and processed this information.

Ultimately, we managed to establish a data pipeline for every city to be analyzed, gathering 4 main data sources: daily traffic point averages in the cities' streets, existing EV charging stations, road network and Points of Interest (restaurants, hospitals, schools etc.).

To visualize traffic distributions within the city, we devised a grid system. The EV charging station locations were gathered from OpenChargeMap, gaining valuable insights into their operational specifics. OpenStreetMap provided us with crucial data on Points of Interest (POIs) and street configurations, enabling us to create clusters and assign weighted values to POIs for prioritization. Additionally, we compiled cost and revenue data, encompassing factors such as acquisition costs, energy management expenses, and power fees.

To analyze Madrid's unique features, we adopted a hexagonal grid aligned with the H8 framework. This is a common choice in literature, due to the absence of 90-degree angles that allow to more accurately resemble the road morphology.



From left to right: Existing EV chargers, Road network, POIs and Traffic distribution.
The traffic distribution is already shown in the H8 Hexagonal Grid.

The optimization model we have developed focuses on the selection of hexagons (or cells) for charging stations within a specific area. There needs to be manual intervention after the selection to identify the specific spot to place the charger in the hexagon.

Our goal is to maximize the objective function, i.e., that for every chosen cell a charging station in the selected hexagon can meet the remaining demand for charging in its area while minimizing the distance from points of interest (POIs). The objective function is the sum of these contributions over every hexagon.

$$\max \sum_{j=1}^{J} (dr_j \cdot x_j)\,(1 - D_j)$$

The objective function of the model

In this model, we utilize various symbols and constraints. Notably, we have the binary variable **x**, representing whether a charging station is selected for hexagon j, where j denotes the number of grid cells.

Another factor is **dr**, which represents the remaining demand for charging in the hexagon: this is calculated using the traffic value – the higher the traffic, the higher the demand - and considering demand already satisfied by existing EV chargers.

Lastly, **(1-D)** represents the cumulative distance between the hexagon and all the other POIs. Constraints are also applied to control the selection process: for example, two charging spots can't be too close to each other, and there is a maximum number of EV chargers that can be placed.

Overall, our optimization model strives to determine the optimal combination of areas for charging stations, considering both the charging demand and proximity to POIs. This approach aids in efficiently meeting the charging needs of EVs while minimizing the impact on surrounding areas.

An innovative approach

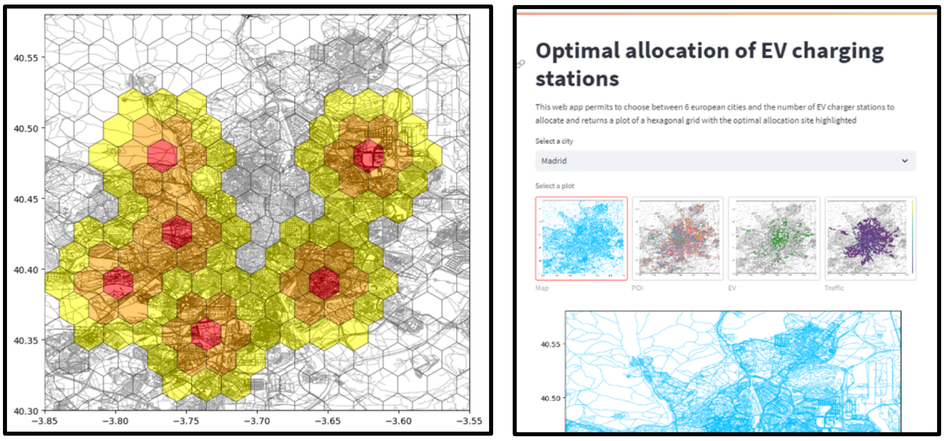
Following the initial model implementation, discussions with Atlante highlighted certain limitations, primarily associated with the nature of the collected data. We considered viewing traffic as a flux, distinguishing between inward and outward fluxes at high-traffic locations. We devised a numerical index, called “congestion index”, calculated using Google Maps API, using travel delay time between hexagons as a proxy for raw traffic flux data. This index quantifies the additional traffic flow due to congestion, providing insights into traffic patterns. It simplifies complex traffic dynamics into a single value for each hexagon, representing inbound traffic relative to outbound traffic: the higher the index, the higher the demand. The index can be normalized and integrated into the model's objective function as a multiplicative coefficient.

Results

The optimal allocation of six EV charging stations in Madrid, as determined by the algorithm, is shown below. Notably, these charging stations are distributed beyond the city center, and this distribution can be attributed to various factors. Firstly, constraints prevent stations from being too close to each other. Additionally, the layout of the hexagonal zones is influenced by factors like current demand satisfaction and the congestion index. Some of these zones encompass major highways and boulevards, which, while not having high punctual traffic density, experience frequent congestion episodes, making them suitable charging station locations.

Lastly, the near-fulfillment of demand in the city center justifies placing stations away from it. This approach ensures resource allocation is not overly concentrated in areas with already met demand.

It's important to note that the algorithm operates semi-automatically and requires manual intervention to determine precise charging station locations, considering factors like viability, accessibility, and dimensions of the roads. The same procedure was applied to other European cities, obtaining similar results: London, Manchester, Utrecht, Rotterdam, and Hamburg.



Optimal allocation of EV charging stations

This web app permits to choose between 6 european cities and the number of EV charger stations to allocate and returns a plot of a hexagonal grid with the optimal allocation site highlighted

Select a city

Madrid

Select a plot

Left: optimal areas for EV Charger placement identified in Madrid.
Right: the web app developed for end users of the algorithm

The subsequent step involves an economic analysis phase that addresses station sizing based on projected traffic volume. This approach balances spatial and economic considerations to ensure optimal charging station placement.

The economic analysis consists of two different parts: a preliminary analysis, based on a Python script, focuses on capital expenditures and operating expenses without cash flow actualization, calculating the breakeven point and expected return of investment, both critical parameters for assessing area profitability.

Then, an Excel-based phase, aimed at developing a Techno-Economic Analysis (TEA) using Life Cycle Cost Analysis (LCCA). LCCA dissects acquisition, operation, maintenance costs, and revenue streams considering the time value of money through discounting, resulting in a comprehensive financial perspective for informed decision-making. These metrics help assess project viability and profitability. This comprehensive approach ensures that Atlante can make informed decisions about charging station placement while considering both spatial and economic factors.

Main bibliographic references

Dimitrios Gkatzoflias et al., 2016. Optimal allocation of electric vehicle charging infrastructure in cities and regions. In*: technical research report of the Joint Research Centre of the European Commission, the European Commission's in-house science service*.

Mehmet Erbas et al., 2018. Optimal siting of electric vehicle charging stations: A GIS-based fuzzy Multi-Criteria Decision Analysis'. In: *Energy 163*, pp. 1017–1031.

Ali Khalife, Tu-Anh Fay and Dietmar Gohlich., 2022. Optimizing Public Charging: An Integrated Approach Based on GIS and Multi-Criteria Decision Analysis. In: *World Electric Vehicle Journal* 13.8 p. 131.

ENTSO-E., 2021. Electric Vehicle Integration into Power Grids.

ArcGIS Pro 3.1., 2022. Why hexagons? *url:* *https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-statistics/h-whyhexagons.htm*.

Zeming Jiang et al., 2016. Statistical analysis of Electric Vehicles charging, station usage and impact on the grid. In: *IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT).* pp. 1–5.