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Modelling charging infrastructure in V2G scenario

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Abstract

Nowadays, electrification is largely acknowledged as a crucial strategy to mitigate climate change, especially for the transportation sector through the transition from conventional vehicles to electric vehicles (EVs). As the demand for EVs continues to rise, the development of a robust and widespread charging infrastructure has become a top priority for governments and decision-makers. In this context, innovative approaches to energy management and sustainability, such as Vehicle-to-Grid (V2G), are gradually being employed, leading to new challenges, like grid service integration, charge scheduling and public acceptance. For instance, the planned use scenario, the user's behavior, and the reachability of the geographical position influence the optimal energy management strategies both maintain user satisfaction and optimize grid impact. Firstly, this paper not only presents an extensive classification of charging infrastructure and possible planning activities related to different charging scenarios but also indicates the most feasible Point of Interest (POIs) for certain energy strategies and a user's behavior associated with POIs. Secondly, the article proposes a systematic procedure to analyze the potential location using accessible data from OpenStreetMap (OSM), considering different POIs categories and the classifications proposed above. Therefore, this methodology can support future practitioners both in the definition of the suitability of a charging geographical position for specified energy management strategies (e.g., V2G) and the best path planning for a defined charging location. Lastly, the proposed model is applied to a real case study, functional to the XL-Connect Horizon Europe project. The results proposed utilized open-source geographical data and can be obtained for other worldwide case studies.

Introduction

In the last decades, addressing the climate crisis through the decarbonization of the transportation sector has represented a necessary task for most of the countries. At the top of this challenge is the critical role played by the road vehicle transportation, which not only significantly contributes to greenhouse gas (GHG) emissions but also serves as a key factor in the overall chase of sustainable development [1]. In this context, the adoption of electric mobility is strongly accelerating, standing as a crucial step towards achieving low emission target imposed by the Paris Agreement [2]. According to the Global EV Outlook 2023 published by the International Energy Agency [3], globally over 10 million new cars were sold in the last year and, in Europe, the EVs car sales risen by over 15% in 2022, with a sales share of 20%. As well, national legislations are evolving rapidly including a range of strategies aimed at incentivizing EVs acceptance. The European Union has adopted the "Fit-for-55" package [4] that aims to facilitate the transition to sustainable mobility. This package includes a zero-emission target for new cars for 2035 and new regulation on alternative fuel infrastructure (e.g., minimum distance between charging points). The United States, through the adoption of the Inflation Reduction Act and the California's Advanced Clean Cars II [5], have stated the future goal of 50% EV market share by 2030. The United Kingdom have set the date to end the sale of ICEVs to 2030 [6]. Moreover, in various countries such as Italy, Spain, and Croatia, incentives and subsides have been introduced, focusing on replacing the older ICEVs [7]. In the coming years, consequently, the demand for EVs is expected to escalate, necessitating a corresponding growth in charging infrastructure development. In fact, the success of electric mobility is closely linked to the accessibility, reliability, and efficiency of charging infrastructures [8]: need to be evaluated not only its technological dimension but also the effects of users charging behaviors, and the interactions with the local grid and with the surrounding urban area. Thus, the geographical distribution of charging points (CPs) significantly influences the optimal use of the charging network, posing a considerable challenge that requires in-depth consideration [9]. For instance, understanding the relationship between the nearby point-of-interests (POIs), the planned utilization of the infrastructure and the user's charging demand, allows to indicate the ideal location to maximize the decarbonization efforts. Another aspect that needs to be considered is the increasing implementation of energy optimization strategies in charging points (CPs), ranging from unidirectional smart charging schemes (V1G) to bidirectional power flow in vehicle-to-grid (V2G). Those technologies are emerging as a solution to mitigate the expected peak of EVs energy demand, to provide ancillary services to the grid, and to maximize the integration of renewable energy sources [10]. Nevertheless, non-technical factors like users charging patterns, flexibility of charge sessions, and consumers' willingness to be involved can influence the scalability for widespread adoption [11]. It appears clear that the evaluation of the optimum location of the CPs through the analysis of the surrounding environment plays a crucial role for identifying possible opportunities for V1G/V2G implementation, at both micro and macro scales. Assessing the validity of specific energy management strategies for a particular urban area provides information not only to optimize the utilization of the CPs but also allow to categorize the infrastructures on the expected user's behavior and energy demand for a future network expansion. The article is structure as follows: *Research Background* provides the scientific literature for CPs technologies, charging strategies and Geographic Information System (GIS)-based analysis; *Research Methodology* describes the workflow used for the methodology; *Results and Discussion* presents the application to the real case study; finally, *Conclusion* summarizes the advantages of the methodology and the outlook.

Therefore, this work proposes to:

- Define a methodology to identify the best charging strategies for a specific location.
- Use open-source geographical data, applicable to other case study.
- Categorize and classify user behaviors, point-of-interests, and optimal charging planning activities.
- Apply this approach to a real case study, in the Italian context.
- Provide initial support for policy maker and practitioners while expanding the charging network.

Research Background

Charging Infrastructure

In the last years, a variety of charging point types has emerged to address diverse user needs, ranging from conventional residential charging to high-speed public charging networks. There are three levels of conductive charging systems, according to SAE J1772 [12]:

- Level 1 refers to AC charging system that commonly employ 110-120 V, characterized by EV on-board charger and suitable for long residential charging with standard household electrical outlets.
- Level 2 refers to AC charging system that commonly employ 220-240 V, characterized by EV on-board charger (OBC) and suitable for home and log-stop public charging.
- Level 3 refers to DC charring system that employ 480 V or higher, characterized by EV off-board charger suitable for rapid public charging.

Additionally, charging protocols and connectors vary significantly worldwide: CCS have gained prominence in Europe while CHAdeMO and NACS connector in respectively Asia and North America [13,14]. However, it is feasible to encounter multiple connectors in a single location, as is evident with the widespread presence of CHAdeMO connectors throughout European countries. A list is provided in Table1. This diversity, while reflecting of innovation and evolving technologies, raises proper issues related to standardization and interoperability. EV drivers could face-off incompatible charging infrastructure during travels in country with different connectors adoption. Lately an uniformed international standard for communication between EVs and charging stations, the ISO 15118, was presented with the aim to obtain both world standardization and enable smart charging potential [15]. In fact, with the introduction of the above-mentioned standard, CHAdeMO is no longer the only standard that enables the V2G for both AC and DC charging. Charging connectors with those protocol allow not only bidirectional power flow functionalities but also permit advanced features like smart charging and demand response, and contribute to grid stability [16,17]. From the EV side, only few manufactures sell in the market V2G-ready vehicles for Level 3 charging systems, and for Level 1 and Level 2 charging infrastructure, no bidirectional on-board charger (OBC) is currently installed on commercial electric vehicles, resulting in the impossibility of purchasing a V2G-ready vehicles using AC charging, despite various experimental activities are running. [18]. The criticalities of traditional and smart charging infrastructures are highlighted below:

- Lack of standardized charging standard and collector valid worldwide.
- ISO 15118 standard proposes an international protocol for smart charging and V2G communications.
- Smart charging management (V1G) can be theoretically implemented in most of the charging infrastructure, but non-technical factors like user’s unawareness might discourage the consumer.
- Few bidirectional charging stations are currently available due to the high costs and limited available users.
- Few OEMs sell their vehicles ready for V2G charging station.

Table 1. Most used connectors and related standards [15].

Connector type	***Level***	***Max power***	***Location use***	***Standard***
Type 1 AC	1/2	19.2 kW	North America	SAE J1772-2017
Type 2 AC	2	22 kW	Europe	IEC 61851
CHAdeMO 2.0	2/3	400 kW	Japan	CHAdeMO (from 0.1 to 2.0)
GB/T (AC)	2	28 kW	China	IEC 61851
GB/T (DC)	3	250 kW	China	IEC 61851
ChaoJi	3	900 kW	China, Japan	CHAdeMO 3.0
CCS 1	2/3	350 kW	North America	SAE J1772/ IEC 61851
CCS 2	2/3	350 kW	Europe	IEC 61851
NACS	2/3	250 kW	North America	SAE J3400
MCS	3	3,75 MW	America, Europe	SAE J1772/ IEC 61851

V1G and V2G charging strategies

In this section, an insight of smart charging concept and applications is provided. In literature, with the definition of *vehicle-grid integration* (VGI) are grouped all the solutions through which EVs can be embedded into the power grid [19]. According to the Charging Interface Initiative e.V. (CharIN) [20] (a global non-profit organization that focuses on charging connectors and standards), VGI can be implemented at various levels that reflects the increasing grid support:

0. Passive management, the most prevalent form of charging today in which there is not communication between EV and charging infrastructure.
1. Unidirectional vehicle-to-grid (V1G) or smart charging, this technology allows variations in the time and the magnitude of the charging session controlled by EV users or CPs operator.
2. Coordinated unidirectional vehicle-to-grid (V1G), the single charging event is managed, by an aggregator, involving other CPs users target or other local infrastructure systems energy demand (e.g., buildings consumption profile).
3. Bidirectional local vehicle-to-X (V2X) includes a range of applications, such as vehicle-to-load (V2L), vehicle-to-vehicle (V2V), or vehicle-to-home (V2H); with those level of integration, it's possible to exchange energy between EVs battery and other local utilities (behind-end-meter - BTM - systems).
4. Aggregated bidirectional vehicle-to-grid (V2G) allows bidirectional power flows among EVs and the grid, matching frequency requirement demanded by the electric grid. The energy control logic is shifted from local systems' optimization to a front-of-the-meter (FTM) services management for which a high-level aggregator is necessary to ensure coordination across the parts.

Therefore, the main advantage of the VGI technologies lies in its capacity to enhance grid flexibility and reliability offering a series of services [21]. The main ones are listed below [22–25]:

- Regulating and Ancillary services, essential for maintaining the stability of the power grid. Those include:
    - Frequency and load regulation, preserving the grid's frequency and load in real time response.
    - Voltage and reactive power support, allowing VIG systems to actively participate in managing voltage levels and supplying reactive power as needed.
    - Spinning reserve, providing instantaneously reserve capacity already connected and synchronized with the utility grid.
    - Non-spinning reserve, offering additional power generation that is not in line and is activated after a brief delay.
    - Black start capability, supplying backup energy to facilities in case of power interruption.
- Arbitrage, enabling consumers and CP operators to earn revenue from selling energy at higher price or shifting (e.g., demand response market programs).
- Peak shaving and load leveling, reducing peak electricity demand, and balancing the local or grid loads by valley filling.
- Renewable energy integration, enhancing the penetration of renewable energy sources (RES) through the exploitation of EVs as dynamic energy storage systems.
- Other distribution services, that manage to provide stability and flexibility to the local systems or to the grid (e.g., transmission line congestion or local congestion in rural areas).

It is evident that not every level of Vehicle-Grid Integration (VGI) can provide all the mentioned services. For instance, ancillary services are feasible with only VGI levels 3 or 4. Additionally, achieving the benefits of a particular service can be obtained as side effects through the implementation of other services; for example, renewable energy integration can result from employing arbitrage trading strategies or load levelling algorithms. Currently, in literature various demonstration case studies where evaluated, focusing both on the technological challenges and on the economic and environmental benefits [26–30]. For instance, Menniti et al. (2022) [31] investigated the implementation of ancillary services in the Italian regulatory framework, highlighting the economic convenience of urban EV patterns compared to extra urban vehicles usage. As well, Gazioğlu et al. (2023) [32] assessed a real demonstrator in which mitigation of grid congestion was tested: through the evaluation of a smart charging tool, the study prove the operability of the demonstrator and suggest the possibility of scaling up to larger area. The potential environmental co-benefits were analysed by Wei et al. (2022), in which the integration of V2G technologies in the Chinese metropolitan were predicted through the simulation of stochastic adoption of electric vehicle (EV) fleets. To conclude, researchers have meticulously examined the technological feasibility of individual Vehicle-to-Grid (V2G) case study. Presently, the research focus is shifting from small-scale applications to addressing the broader technical, societal, and economic challenges of V2G mass deployment.

Point-of-Interest and user's behavior

The potential large-scale implementation of VGI technologies in the existing infrastructures lies both in technical aspects -technological standardization, grid services integration and data management for charging strategies- and non-technical factors such as economic viability, users acceptance and VGI infrastructures deployment [33]. Among those challenges, the geographical distribution of CPs plays a crucial role in the scalability of real-world applications. Generally, identifying the best CPs location, in terms of attractiveness and accessibility, need to include features like:

- EVs adoption:
    - CPs demand by EV drivers, considering population density and EVs adoption in a certain area.
    - Type of EVs used, that influence the type of infrastructure more suitable for a certain area (e.g., Level 2 AC charging point or DC Level 3 charging point).
    - User behavior patterns, that include typical charging session characteristics, traffic patterns and flexibility.
- Infrastructures deployment:
    - Distribution, like the presence of other CPs in the surrounding area.
    - Level of charging infrastructure and VGI services proposed, define in the previous sections.
- Spatial data:
    - Point-of-Interests (POIs) in the adjacent area, a specific point or area nearby CPs that users could find interest.
    - Land-use attributes of the surrounding areas, such as industrial, residential, or rural.

In literature, the Geographic Information System (GIS) analysis can be used as a tool for integrate spatial data with decision-making processes associated with the future EVs adoption and infrastructure deployment. As a base for spatial data, volunteered geographic information projects have been developed with map information's content by volunteers [34]. Among them, OpenStreetMap (OSM) is one of most popular initiatives and is emerging as a promising free tool at global scale [35]. The spatial information registered by individual users are characterized by those features:

- Elements:
  - *Node* denotes a specific geographic point on the Earth's surface, identified by its latitude and longitude coordinates.
  - *Way* manifests as a sequence of interconnected nodes, creating polylines that serve to delineate various features.
  - *Relation* indicates the connection or association between diverse node, way, or other relationship.
- Geometries:
  - *Point*, that represents Node elements.
  - *Open polyline*, that represents way elements.
  - *Closed polyline* (polygon), that represents Way elements.
  - *Area* (filled polygon), that represents Way elements.
  - *Multipolygon*, complex areas with holes that represent Way or Relation elements.
- Tags:
  - *Key* defines a category or type of feature.
  - *Value* offers specific information regarding the feature specified by the key.
- Additional properties, like annotations, addresses or local names.

Table 2. Some of the most popular keys and values in OSM. A complete list can be found in [36].

Key	***Sub-classification***	***Example***	
		Value	***Elements***
Amenity	Sustenance	*"bar"*	*Node, Way*
	Education	*"school"*	*Node, Way*
	Transportation	*"charging_station"*	*Node*
	Financial	*"atm"*	*Node*
	Health	*"hospital"*	*Node, Way*
	Entertainment, Arts & Culture	*"cinema"*	*Node, Way*
	Public Service	*"post_office"*	*Node, Way*
Border	Border	*"forest"*	*Way, Relation*
Building	Accommodation	*"apartments"*	*Node, Way*
	Commercial	*"industrial"*	*Node, Way*
	Religious	*"church"*	*Node, Way*
	Civic	*"museum"*	*Node, Way*
	Sport	*"stadium"*	*Node, Way*
Highway	Roads	*"motorway"*	*Way*
	Cycleway	*"cycleway"*	*Way*
Landuse	Developed land	*"residential"*	*Node, Way*
	Rural and agricultural land	*"farmland"*	*Way*
Leisure	Leisure	*"sports_centre"*	*Node, Way*
Office	Office	*"company"*	*Node, Way*
Public transport	Public transport	*"station"*	*Node, Way*
Shop	Food, beverages	*"bakery"*	*Node, Way*
	General store	*"supermarket"*	*Node, Way*
	Clothing	*"clothes"*	*Node, Way*
Sport	Sport	*"tennis"*	*Node, Way*
Tourism	Tourism	*"hotel"*	*Node, Way*

POIs are not always reported as nodes, but also ways and even relationship, as long as those geo data represent relevant destination for the mapping users. Additionally, OSM tagging system allows to tag the same spatial information with different tags, depending on the features that are highlighted [37]. For instance, an area that describes a church can be tagged as building = *"church"* for indicate a building constructed for religious purpose, as amenity = *"place_of_worship"* for indicate the current worshipping use of the area, landuse = *"religious"* for describing the usage of all the complex surrounding area as religious intentions. So, a tag combination and a subsequent data filtering and validation are necessary to better understand the complexity of a certain geographic attributes. When examining charging infrastructures, potential POIs represent possible destination for CPs users influencing EV drivers' behaviors like session duration, charging flexibility and hourly distribution of energy demand, and therefore impacting on the successful implementation of different charging strategies or VGI integration. Generally, flexible and long charging sessions, associated with residential, or workplace areas, are the most suitable for VGI services like renewable energy integration or load levelling [33]. On the other hand, short charging sessions, related to shop or amenity places, can be best exploited with frequency regulation services or even with uncontrolled high power strategies [38]. In the next part of the paper will be presented an evaluation of the relation between spatial data, charging patterns and energy management strategies.

Research Gap

Several studies investigated the charging location problem using a Geographic Information System (GIS) analysis. Different types of algorithms, such as genetic algorithms [39] or multi-objective optimizations [40], were implemented to identify the best geographic target, considering different factors like traffic patterns, grid distribution and urbanization. Some of the works used open data from OSM. Niederle et al. [41] analyzed the influence of CPs surrounding area in Germany, focusing on the OSM land usage and on the influence to the grid distribution planning. Kłos at al. [42] individuated the most suitable CPs location taking into account pedestrian reachability of CPs in an iterative analysis for a Poland real case study. Falchetta and Noussan [43] examined the accessibility of the CPs in possible future scenarios, considering both the development of V2G services, the future adoption of EV and using geographic information from OSM. To date, few studies has assessed the suitability of a charging location's geographical position characterizing the surrounding area attractiveness from a VGI integration point of view. Specifically, no study has investigated the Italian scenario exploring the relationship between VGI and CP location. Overall, this work aims to close those research gaps, proposing an open-source model and applying it to an Italian real case study.

Research Methodology

This section presents the methodology procedure, implemented in python version 3.7.1 [44]. The overall workflow is shown in Figure 1 and the main steps are discussed below.

Target definition

The input data are collected, defining the coordinates of the potential or existing charging point, called *target location*. Also, the ranges within which collect spatial data are determined, named *target distances*, for POIs analysis, land usage evaluation and CPs proximity. This algorithm neglects the practical restrictions and the connection requirements imposed by the distribution network operator, due to the electric network configuration. Through this hypothesis, any potential location can be assessed whatever the country is chosen. In fact, the characteristics required to implement VGI in CPs by local distribution network operators and by national grid electricity transmissions can vary significantly from one country to another, reflecting the complexity of geographical, technological, and regulatory factors. Obviously, further evaluations are needed to analyze the feasibility of each case study, including installation works (e.g., cabling works, foundation works), restrictions and requirements for V2G implementation (e.g., specific power quality, specific meter cabinet enabled for V2G or special municipality approval).

Data extraction

Through an algorithm, spatial data from OSM are extracted starting from the *target location* and within the *target distances*, focusing on three main aspects:

- *CPs proximity*, using amenity = *"charging_station"* plus man_made = *"charge_point"* tag queries.
- *Land usage*, whereby the tag landuse –characterizes the usage of an area of territory- and all related values are chosen.
- *POIs*, for which key tags are defined:
    - amenity, includes valuable and essential amenities for the nearby population.
    - building, classifies node or way as a man-made construction with a roof.
    - leisure, covers places in which users go in the free time.
    - office, maps places that offer services.
    - public_transport, denotes transport stops like bus stop or train station.
    - shop, marks places that selling commercial goods.
    - sport, identifies areas in which spots can be practiced.
    - tourism, involves places that are attractive from point of view of tourists.

The tag queries are retrieved through dedicated python package (e.g., OSMx [45]) and saved in GEOJSON format. Then, the population density and the electric vehicle fleet for a specific area are extracted from dedicated repositories and combined with the geo data. For the Italian context, the population density and the electric vehicles officially registered are obtained from Italian National Institute of Statistics (ISTAT) and from Automobile Club Italia (ACI) reports [46,47]. Next, this database is visualized and categorized.

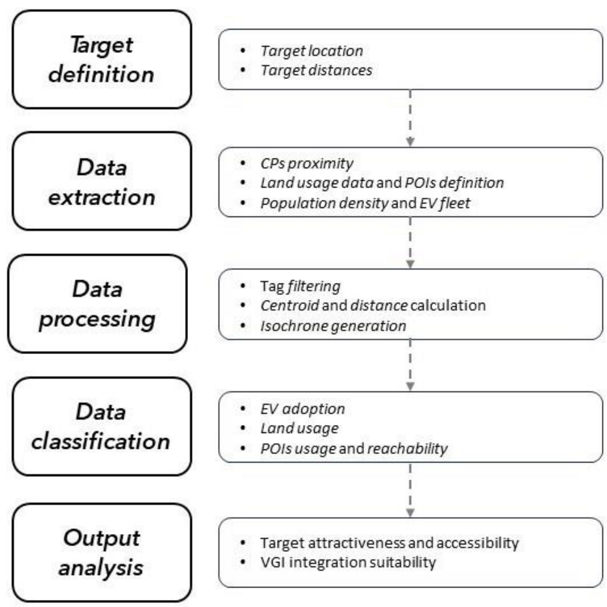

Figure 1. Methodology workflow carried out in this paper.

Data processing

Firstly, unspecified geo data types are excluded to increase the accuracy and interpretability of the database. For instance, building tag is mostly composed of "yes" tag value that identify building area for which OSM users are unable to provide more specifical information [48]. Additionally, those tag combinations are discarded: amenity = *"yes"*, building = *"unspecified"*, leisure = *"yes"*, tourism= *"yes"*, landuse= *"yes"*, amenity = *"office"*, amenity = *"shop"*. Next, the centroid coordinates are identified for each polygon/multipolygon footprints, referring to *Way* and *Relation* elements. The distance between the *target location* (latitude φ_1, longitude λ_1) and each centroid or node (latitude φ_2, longitude λ_2) is calculated, through the haversine formula (1), and added to the dataset [49].

$$d = 2r\sin^{-1}\sqrt{\sin^2\left(\frac{\varphi_2-\varphi_1}{2}\right)+\cos(\varphi_1)\cos(\varphi_2)\sin^2\left(\frac{\lambda_2-\lambda_1}{2}\right)} \quad (1)$$

Lastly, OpenRouteService (ORS) - an open server application that employees OSM frontend data [50]- with specific python package (e.g., ORS) and Application Programming Interface (API), is used, to calculate *target location* accessibility thought isochrones generation. Imposing the walking time interval, the produced polygon includes all the POIs reachable from the *target location*, considering walkable routes such as foot paths and not only a point buffer evaluation [51]. A pedestrian velocity of 5 km/h is set.

Data classification

In this step, the spatial data processed are classified and the degree of reachability is determined. Four qualitative classification metrics are proposed whereby characterized the target location:

- *EV adoption*, indicating the spread of electric mobility in the municipality with both the EV fleet population and the population density.
- *Land usage*, considering the predominant exploiting of the nearby area (e.g., residential, industrial, farmland, see OSM guideline for the complete list of value) and the total extension for each landuse key tag.
- *POIs usage*, aggregating the extracted POIs into duration-based and hourly distribution-based categories.
- *POIs reachability*, determining which POIs is reachable from the *target location*.

The *POIs usage* classification aims to associate a possible user charging scenario to the nearby POIs and a suitable energy strategy or VGI implementation to the *target location*. The typical used scenario proposed are the following [52]:

- Duration-based:
    - Non-flexible short stops, that last less than 1 hour and for which users don't declare arrival and departure time.
    - Non-flexible medium stops, that last from 1 to 6 hours and for which users don't declare arrival and departure time.
    - Flexible medium stops, that last from 1 to 6 hours and for which users declare arrival and departure time.
    - Flexible long stop, that last more than 6 hours and for which users declare arrival and departure time.
- Hourly distribution-based:
    - Daytime charge.
    - Nighttime charge.
    - Mixed charge.

Also, the categorization is combined with the distance between POIs and location target, for a more complete evaluation. Through the aggregation in categories, the possible opportunities for charging strategies or VGI implementation are pointed out. For example, renewable energy integration or peak leveling are more suitable for flexible long or medium stops in the daytime, instead flexible short or medium stops are more appropriate for ancillary service implementation (e.g., frequency control). Lastly, to assess *POIs reachability*, an object-based matching algorithm is utilized: employing the centroid method [53] allows to determine if a geographical point lies within a polygon. In the proposed procedure, the matching condition is evaluated between isochrone polygon and POIs centroid, or node and a list of reachable POIs is created. However, centroids derived from the footprints of POIs may not accurately depict pedestrian access points. Thereby this representative error requires evaluation, particularly for larger entities [51].

Output analysis

Ultimately, in the last phase all the major findings are discussed, identifying the qualitative peculiarities of the target location. Through the attractiveness of the area and the reachability of the nearby POIs, the suitability of the vehicle-grid integration is discovered and the best V2G services are highlighted. Furthermore, not only an overview of the current possible usage of the CPs is provided but are presented suggestions for support practitioners in future V2G strategies implementation.

Results and Discussion

XL-Connect case study application

The XL-Connect project [54] is a European Union initiative dedicated to enhancing on-demand charging solutions for electric vehicles, focusing on VGI technologies. The primary objective is to develop a charging network that takes into consideration various factors such as human behavior and technical requirements throughout the entire charging process. This advanced infrastructure will be piloted and exhibited in four diverse European countries (Italy, Belgium, Germany, Portugal) as part of the project's demonstration phase. In this context, the University of Florence (UNIFI) aim to install, by the end of 2024, a public CPs demonstrator in a university campus (municipality of Calenzano, Italy) with VGI technologies. The location of the demonstrator was initially chosen to support the electric mobility on the proximity of a university campus, known to attract a significant number of commuters, including workers, students, and companies. Integrating this case study was one of the objectives outlined in the demonstration activities proposed by the XL-Connect project. Moreover, this location met the specifications imposed by the municipality and the local distribution network operator, such as proximity to a substation and adherence to regulations regarding public road excavation and traversing third-party land. The systematic procedure is therefore applied to this real case study. In the Table 3 and Figure 2 are shown the input data.

Table 3. XL-Connect case study target definition.

Target Location coordinates	43°51'41.6"N / 11°09'49.9"E
Distance POIs analysis	500 m
Distance land usage	1000 m

Distance CPs proximity	1000 m

Next, the spatial data are extracted and processed according to the previous workflow. The population density of the municipality of Calenzano is 235 inhabitants per square kilometer and the 2022 electric vehicle fleet is about 35 units, 10610 units for the entire province of Florence. This data shows that the potential EV drivers will potentially use the target location during commuting or pleasure travel, and less likely for overnight charges typical of residential users.

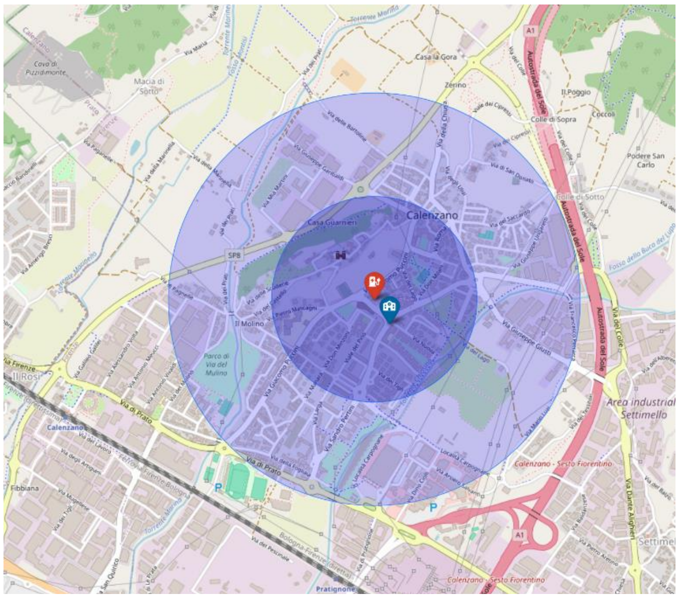

Figure 2. Illustration of the target location: the markers represent respectively the target location (red) and the university campus (blue). The blue circles indicate the POIs analysis distance (dark blue) and the land usage and CPs proximity distances (light blue). Background map is provided by OSM.

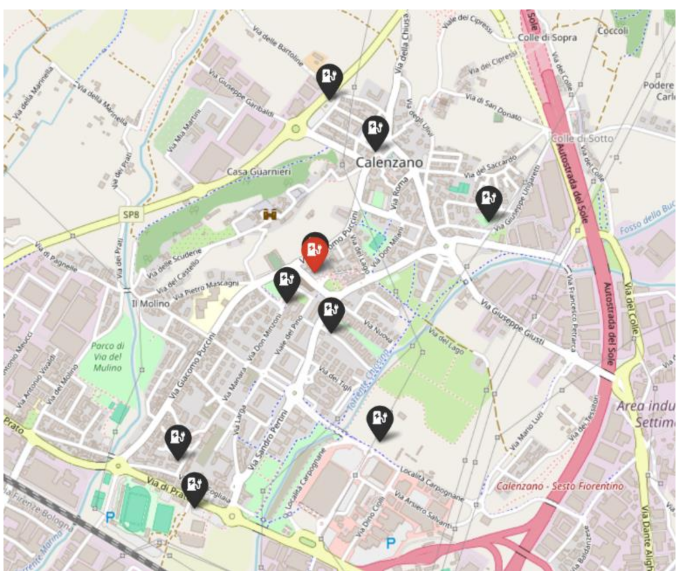

Figure 3. CPs proximity map. The black and red markers indicate respectively the nearby CPs and the *target location*. Background map is provided by OSM.

In the Figure 3 and Figure 4 the CPs proximity and the land usage are mapped. Within CPs proximity distance, are installed 9 CPs from different providers: in the same parking lot as the *target location* is already placed a CP (level 2 charging and Type 2/Type 1 AC connector) and within 300 m two AC CPs are installed; the nearest level 3 (DC) charging infrastructure is about 600 m away. As regard land utilization, the area in which is located the *target location*, is tagged as predominantly residential, whereas the adjacent zones are mostly indicate as industrial and commercial usage. Only about 5,7% of the tagged areas are related to rural and agricultural land, such as allotments, farmland, or forest.

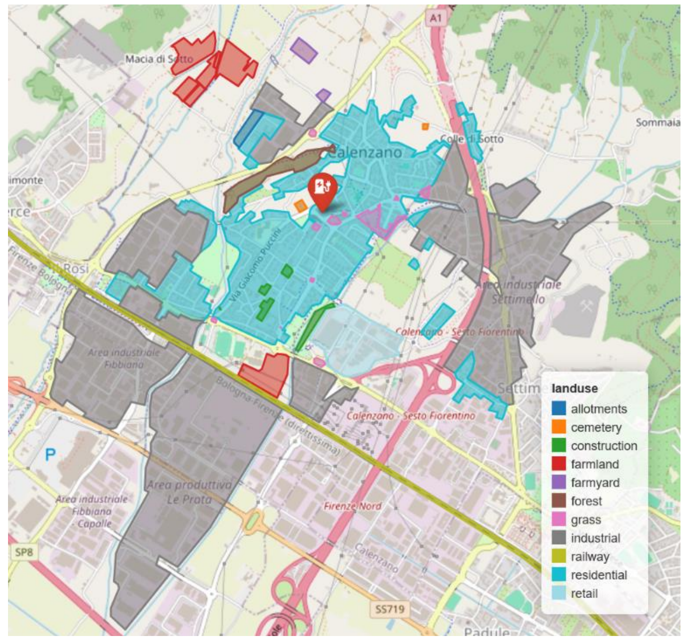

Figure 4. Land usage of the nearby area. The red marker maps the *target location*. Background map is provided by OSM.

The complete database of POIs and land usage are not reported due to data length, anyway an overview of element typology is proposed in Table 4: most of the elements extracted belong to amenity and building POIs among which Way element are the most common.

Table 4. Numbers of element include for each POIs key tags subdivided by type. The last column shows the numbers of element discarded in the processing phase.

POIs	***Elements Node***	***Elements Way***	***Discarded elements***
amenity	8	34	4
building	5	68	349
leisure	0	9	1
office	1	1	0
sport	0	1	0
public transport	39	0	0

shop	3	0	0
tourism	4	0	0

To obtain a dataset composed by 173 elements, almost 350 are discarded, mostly with the tag combination building = *"yes"* excluding several footprint representations from the POIs map. The area extension and centroid-location target distance are calculated using lambert cylindrical equal-area projection and the haversine formula [51]. The POIs extracted and classified by key tags are plotted in Figure 5; the main characteristics are:

- amenity, 41 elements that group those macro-categories:
  - sustenance facilities, with *"bar"* (1 element), *"café"* (1 element).
  - education facilities, with *"school"* (4 elements), *"university"* (2 elements), *"library"* (2 elements), *"music_school"* (1 element), *"childcare"* (1 element).
  - financial facilities, with *"bank"* (2 elements).
  - entertainment facilities, with *"arts_centre"* (1 element), *"theatre"* (2 elements).
  - public service facilities, with *"police"* (3 elements), *"townhall"* (1 element).
  - transport facilities, with *"parking"* (15 elements), "*fuel*" (1 element).
  - other facilities, with *"place_of_worship"* (3 elements), *"drinking_water"* (2 elements).
- building, several node and way elements distributed on the map from a minimum distance of 41 m to a maximum of 746 m:
  - accommodation buildings, with *"residential"* (28 elements), *"apartments"* (19 elements), *"house"* (10 elements).
  - religious buildings, with *"church"* (3 elements).
  - civic buildings, with *"school"* (3 elements), *"public"* (4 elements)
  - commercial buildings, with *"commercial"* (2 elements).
  - other buildings, with *"roof"* (4 elements).
- leisure, way elements that indicate "*park*", "*pitch*", and "*garden*" with a minimum distance of 205 m and maximum of 595 m.
- office, two elements that represent administration offices at about 525 m.
- shop, three node elements that are mapped at respective distance of 115, 362 and 690 m.
- sport, only a way element ("*soccer*") that is included in bigger leisure area at the distance of 346 m.
- public transport, spread node elements that represent public transport stop and the respective area in which where passengers are waiting for the public transport vehicles.
- tourism, four node elements ("*museum*" and "*viewpoint*") that are collocated at an average distance of 352 m.

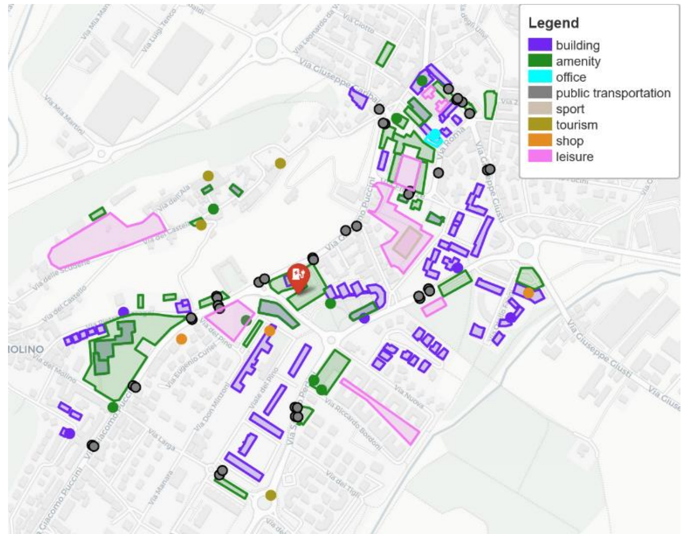

Figure 5. POIs extracted within the distance POIs analysis. The different colors represent different OSM key tags (see the legend). The circle areas map the Node elements, and the polygon areas indicate Way and Relation elements. Background map is provided by OSM.

As we can notice, the location of a few centroids exceeds the distance POIs analysis: to include part of the polygon in the data extraction, it is necessary that even just a perimetral part falls within the target distance.

As last step in data processing, the isochrone polygons are generated, see Figure 6. The features imposed are foot-walking profile and five range of time – from 60 to 300 seconds.

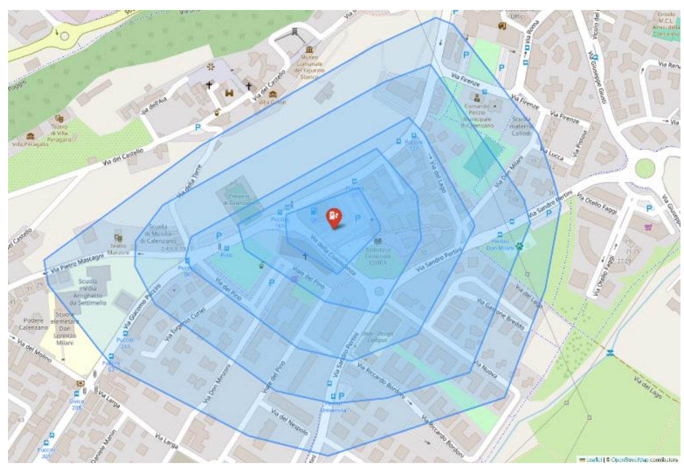

Figure 6. Five isochrone polygons: each represent the maximum distance that can be reached through foot paths in the range time imposed - 60, 120, 180, 240 and 300 seconds. Background map is provided by OSM.

Moving to *data classification*, it is possible to make the following observations. For *EV adoption*, the population density evaluation and the number of EV registered in the municipality define an early-stage EV adoption scenario. In fact, we expect that the target location will be used currently during commuting and in the next years will be utilized by resident as the adoption of electric cars increases. On the other hand, the *Land usage* analysis highlights the exploiting of the

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nearby area as predominantly urban-residential zone (29% of the total area and minim distance centroid-*target location* of only 84 m). As concern the industrial usage areas, the share increase to 53%, but with a minim distance centroid-*target location* of almost 700 m, away from user areas of interest. Next, the POIs identified within the target distance are classified showing that:

- Excluding "*parking*", the other amenities are related mainly to daytime usage and to medium/long flexible stop, mainly referring to workplace like university/school, public service facilities or leisure places.
- Building elements refer mainly to mixed usage and flexible long stop, including mainly accommodation buildings.
- Leisure, sport, shop, tourist elements are classified as flexible medium stop in the daytime since they comprehend parks, museums, and supermarket.
- Office POIs are classified as daytime charges and non-flexible short stop due to the typology of public service facilities.
- *"church"*, *"place_of_worship"*, and *"bank"* are classified as non-flexible short/medium shop in the daytime.
- *"theatre"* and *"arts_centre"* refer to short/medium stop and to mixed hourly-distribution usage.
- Special to emphasize is the public transport category that includes exclusively bus stop used by students and workers to reach specific places. Due to the presence of the university and the extension of the public transport network in the municipality, it is likely that those bus stops are used as arrival stop to commuting place and that the nearby parking are not used as park and ride facilities.

The POIs can therefore be subdivided as: 57 elements as flexible long stop in both daytime and nighttime, 41 elements as flexible medium/long stop in the daytime, 2 elements as flexible short/medium stop in both daytime and nighttime and 13 elements as non-flexible short stop in the daytime. All public transportation values, *"roof"*, *"drinking_water"*, *"parking"* are not linked to any of *POIs usage* categories but are indicative of the attractiveness of the area. For the *POIs reachability*, the geo data available within the isochrone polygons are determined. A list of POIs reachable within 60, 120 and 180 seconds of walking time are reported in the Table 5 and the map of isochrone polygons and POIs is shown in Figure 7. Undoubtedly, the main POIs are church, library, university campus, supermarket, and bar; all of that are classified as daily usage. Therefore, considering the reachability, the focus shift from as flexible long stop, throughout the entire day, previously emerged to a flexible medium/long stop in the daytime due to the proximity of the university campus, the relative library/bar, the park, and the supermarket. The nearby church could appeal EV drivers for short/medium stop mainly in the daytime. It's become clear that VGI integration is suitable due to the expected POIs usage and the daytime services like renewable energy integration, load levelling or arbitrage are the most appropriate for taking full advantage of the flexible long stop. Possible target energy strategies in the nighttime could be promoted for the adjacent residents, even if it's expected a lower user attendance due to the current EV fleet in the municipality.

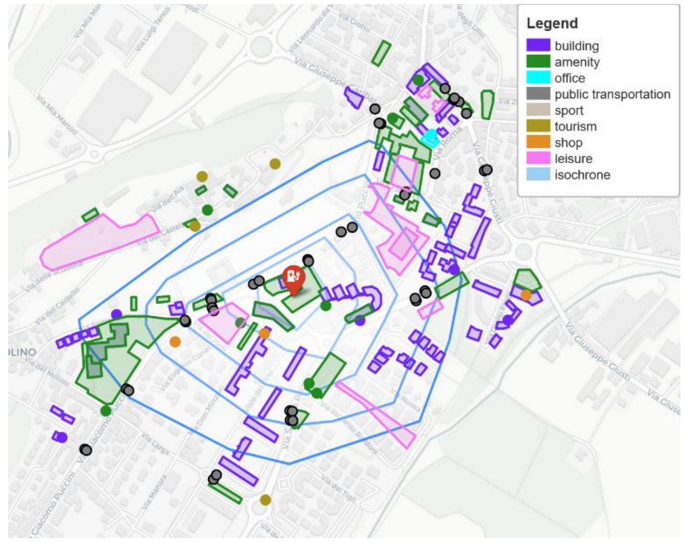

Figure 7. Isochrone polygons and POIs maps. Background map is provided by OSM.

Table 5. POIs included in the 60, 120 and 180 seconds isochrones.

POIs key	***POIs value***	***Dist. (m)***	***Isochrone match***
amenity	*"parking"*	34	60 seconds
amenity	*"parking"*	158	180 seconds
amenity	*"library"*	99	120 seconds
amenity	*"place_of_worship"*	74	60 seconds
amenity	*"fuel"*	48	60 seconds
amenity	*"bar"*	187	180 seconds
amenity	*"university"*	191	180 seconds
amenity	*"university"*	198	180 seconds
amenity	*"parking"*	159	180 seconds
building	*"residential"*	96	60 seconds
building	*"residential"*	137	120 seconds
building	*"residential"*	177	120 seconds
building	*"residential"*	198	180 seconds
building	*"residential"*	190	120 seconds
building	*"apartment"*	141	180 seconds
building	*"church"*	74	60 seconds
building	*"roof"*	122	120 seconds
building	*"roof"*	162	180 seconds

building	*"roof"*	47	60 seconds
shop	*"commercial"*	115	120 seconds
public transport	*"stop_position"*	89	120 seconds
public transport	*"platform"*	87	120 seconds
public transport	*"platform"*	106	120 seconds
public transport	*"platform"*	120	120 seconds
public transport	*"platform"*	237	180 seconds
public transport	*"stop_position"*	258	180 seconds
public transport	*"platform"*	259	180 seconds
public transport	*"stop_position"*	240	180 seconds
public transport	*"platform"*	197	180 seconds
public transport	*"platform"*	245	180 seconds
leisure	*"park"*	205	180 seconds

So, in summary, the XL-CONNECT case study is characterized by:

- Early-stage adoption of electric vehicles in the Calenzano municipality that identifies the currently expected CP customer as commuter user.
- Other 3 CPs are installed within 200 m all with AC Level 1 charger, pointing out the lack of DC Level 3 chargers in the zone.
- The adjacent areas are predominantly urban-residential zones, even if the more distant neighborhoods are mostly for industrial usage. This indicates a possible increase of overnight charging sessions typical of residential users in the next years.
- High attractiveness of the area evaluated, with several POIs individuated such as several education structures, commercial stores, public transportation stop, car parks and public service facilities. Therefore, the correct promotion of the future service implemented will be crucial for the correct success of the infrastructure.
- The reachability analysis underlines the walkability of the university campus, the related bar and library, a church, and a big commercial store.
- Both the POIs usage classification and reachability allow to identify the flexible medium/long stop in the daytime as the currently possible user charging scenario. So, daytime service like renewable energy integration, load levelling or arbitrage will take full advantage of the flexible long/medium stop.
- In the next few years, with the potential mass adoption of electric vehicles, the area appears to be suitable for nighttime energy strategies for residents nearby.

Conclusion

The paper presented a systematic methodology for analyzing potential locations and identifying the potential VGI strategies using open-source geographical data from OpenStreetMap (OSM). Firstly, an extensive review of the charging infrastructures and V1G/V2G strategies were performed, defining charging power and VGI integration levels and assessing the technological, economic, and social challenges of VGI mass deployment. Next, the Geographic Information System (GIS) analysis and the related scientific publications were evaluated, showing the main feature of OSM, and highlighting the current gaps of the literature. In the *Research Methodology* section, all the steps of the workflow were presented. The work suggested a data extraction and processing procedure with an OSM tag filtering, distances calculation and an isochrone generation. The characterization of the potential location was made through four qualitative classification metrics and the level of accessibility was determined using the centroid method. Lastly the methodology was applied to a real case study as part of the European project XL-CONNECT, assessing the potential location of a VGI integrated CPs. The XL-CONNECT case study revealed an early adoption of electric vehicles in the municipality, primarily by commuters. Surrounding areas consisted mostly of urban-residential zones, with potential for increased overnight charging by residents. Also, the area's attractiveness was notable, with various points of interest; reachability analysis emphasized the walkability of key locations like the university campus, church, and commercial store. Both the classification of points of interest and their reachability suggested flexible medium/long stop charging during the day, emphasizing the opportunities of a V2G integration with services like renewable energy integration, load leveling and arbitrage. Looking ahead, with the collective acceptance of electric vehicles in the coming years, the area will be ready for nighttime energy strategies targeting nearby residents. The following outlook need to be implemented in the next research:

- Includes more sophisticated data processing algorithms like deep learning models.
- Improves *POIs usage* classification with CPs and user behavior real data acquisition.
- Extends the application of the methodology to an existing CPs to identify the most suitable energy strategy to use.
- Includes the possible electric network constraints imposed by local distribution network operator.
- Compares the proposed methodology and its outcomes to those employed by energy provider company and vehicle OEMs.

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Definitions/Abbreviations

EVs	Electric vehicles
ICEVs	Internal combustion engine vehicles
GHG	Greenhouse gas
V1G	Vehicle-one-Grid
V2G	Vehicle-to-Grid
V2X	Vehicle-to-X
CP	Charging point
POI	Point-of-Interest
GIS	Geographic Information System
OSM	OpenStreetMap
AC	Alternating Current
DC	Direct Current
VGI	Vehicle-Grid integration
BTM	Behind-end-meter
FTM	Front-of-the-meter
RES	Renewable energy source
ORS	OpenRouteService
API	Application Programming Interface