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Forecasting the vehicle energy potential to support the needs of electricity grid: a floating car data-based methodology

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In a global context characterized by climate warming, the transport sector has found the use of electric vehicles to be one of the possible measures of decarbonization. Although the purchase rate of this type of vehicle is still low, there are many research fields related to both the development of the electric charging network and the improvement of batteries to ensure features that meet the expectations of users. Moreover, the increase of the use of electricity can cause issues in electrical network stability, especially during the peak hours. Therefore, this sector is facing new challenges, including the case of vehicle-to-grid (V2G), which is a solution that allows the use of vehicle batteries, not only as a source of energy for the vehicles, but also as stabilizers of the supply network when the vehicles are parked (i.e., no energy is needed for their activity). In the recent years, the researchers mainly focused on the energy infrastructure and technologies, neglecting problems related to the identification of the best locations for V2G services and the potential acceptance of the electric vehicles' owners, as well as on the potential energy that can be transferred to the grid according to the users' needs (e.g., to continue to use their vehicle for completing the daily activities). This paper proposes a methodology aimed at identifying potential areas for deploying V2G services by using floating car data (FCD) and at estimating the potential energy to be transferred to the grid without interfering with the daily activities. This methodology is finally applied to a case study of five provinces of the Veneto region, showing the significant results obtained.

KEYWORDS

V2G, vehicle-to-grid, charging location, floating car data, FCD, parking areas, trip detection, electric vehicle

1 Introduction

The strong push for decarbonization, particularly in the transport sector, with national and European policies that favor the transition to electric mobility, will contribute significantly to the growing demand for electricity (EC, 2019). The European Union (EU) is acting to regulate the transport sector, which is one of the main contributors to high CO_2 emissions with levels that are constantly increasing. An analysis on the rate of motorization in large Italian cities (ISFORT, 2023) confirms that a substantial part of the population uses a private vehicle to move, a phenomenon mainly linked to urban sprawl (Patella et al., 2019; Filippova and Buchou, 2020), to the different chains of movements carried out daily by individual users (Carrese et al., 2021), and to the perceived quality of public transport (Lunke et al., 2022; Nuzzolo et al., 2016). This figure results in a negative impact on road congestion and air pollution, since the highest CO, CO_2, and NH_3 emissions come from these vehicles (Cirianni and Leonardi, 2006; EEA, 2022; Guille and Gross, 2009). The goal pursued by the EU is complete decarbonization by 2050, with the elimination of internal combustion cars by 2035, with the aim of a reduction in emissions of about 55%. At the same time, this gradual abandonment of fossil fuels will contribute significantly to the growth of electricity demand. In this regard, according to the "Electricity 2024" report (International Energy Agency, 2024), global electricity demand is expected to grow by 34% in 2026. In particular, the report states that the increase in demand is expected to be met by record of electricity from renewable sources such as solar, wind, and hydroelectric. Furthermore, it is predicted that low-emission energy sources will account for almost half of the world electricity production by 2026. Within the identified scenario, the concept of the energy community takes a prominent position along with a different conception of the electric vehicle. It is found that electric vehicles, especially when used for systematic travel (e.g., home-work, home-school) within urban and metropolitan areas, store and keep unused significant amounts of electrical energy without necessity (e.g., electric vehicles parked for 6–8 continuous hours at workplace parking lots). In this context, research lines are being promoted; they focus on the possibility of considering electric vehicles not only as energy users but also as energy providers according to the needs of the entire electrical grid. Therefore, the idea of the vehicle to grid (V2G) is to connect electric vehicles to both domestic and public energy grids to exploit batteries as stabilizers, accumulating energy when produced in excess and releasing it during peak consumption times. In this way, vehicles, or rather batteries of electric vehicles, have great potential that goes beyond their main task of providing energy for mobility. In fact, the principle behind V2G is to have a technology that transforms electric cars from simple means of transport into energy providers capable of exchanging electricity with the grid (Shipmanet et al., 2021). Batteries can thus be connected to the public power grid to make it more stable and efficient (Philipet et al., 2021). This technology is based on the prediction of the available capacity to ensure that the vehicle can continue to perform its transport function. Therefore, it is appropriate to infer the use of vehicles to predict what is the current energy reserve that can eventually be given to the grid, considering the pre-attack state to the network and the residual energy necessary that it is appropriate to ensure for the vehicle after giving to the grid. From a technical point of view, this is possible due to a bidirectional power inverter connected to the vehicle battery and the grid. This device can draw energy from the grid to recharge the vehicle or return energy to the grid by drawing it directly from the vehicle battery. The flows are managed by a control unit that considers the vehicle charge state and energy demand.

To date, several studies have been carried out on the concept of V2G (Comi and Idone, 2024; Yang et al., 2024; Wan et al., 2024). However, the majority of these are focused on infrastructure, technology, and energy, without analyzing the topological aspects. A new methodology will be thus introduced in this paper to identify potential areas where V2G can be applied through the analysis of floating car data (FCD) which allow planners to infer on the current use of private vehicles (Comi et al., 2024; Nigro et al., 2024). This methodology will help optimize the placement and operation of V2G infrastructure, ensuring it meets the needs of users and the grid effectively.

The remainder of the paper is structured as follows. Section 2 introduces V2G operations, Section 3 presents the proposed methodology. Section 4 focuses on the case study, while Section 5 concludes and summarizes the obtained results, as well as draws the further perspectives of this research.

2 Vehicle-to-grid: a background

The operation of the charge-discharge process of electric vehicles (EVs) and the energy management analyses of the power grid play a central role for implementing the V2G services (Solanke et al., 2020). Below, first the working scheme of such a service is presented, then literature is reviewed pointing out the topics that need to be investigated and discussing how such a research contributes to solve literature lacks.

2.1 Working scheme of vehicle-to-service

Two key elements are involved in this process: the on-board charger and the charging infrastructure, both of which have to support bidirectional charging. In the case of alternating-current infrastructures, the on-board charger converts the direct current (DC) input from the grid into alternating current (AC) when the vehicle is charging. To perform the V2G function, the same device must be able to convert the direct current (DC) output of the battery into alternating current (AC) to return it to the grid. In this way, EVs highlight a potential that goes beyond their primary function of providing energy for movement (Jin et al., 2020).

The idea behind V2G is that when demand increases, EVs parked and connected to the infrastructure through appropriate charging stations can support the grid by transferring energy into it (Morency and Trépanier, 2008). Subsequently, during periods of low demand, the EV batteries can be recharged. A typical systematic daily travel of an electric vehicle that can be involved in V2G is illustrated in Figure 1:

- user leaves his/her house (i.e., from zone o) to make his/her daily activities with the battery fully loaded;
- user travels from his/her house to a usually parking place (i.e., zone d_k) where the V2G is available consuming a quantity of energy ($E_{consumed}$);
- during his/her daily activities, s/he leaves his/her car parked, and, if necessary, to the electricity grid, a rate of its energy stored in the batteries can be transferred to the grid (E_{to_grid}); the parking place in which s/he can do V2G will be determined by the parking time and type of the location of the area (e.g., office parking area);
- at the end of his/her activities at place k, during which his/her vehicle can contribute to the V2G activity, s/he continues his/her daily activities; then, the energy stored needs to assure the development of planned activities; therefore, vehicle needs to have enough energy to finish its remaining activities and coming back home (E_{to_keep}).

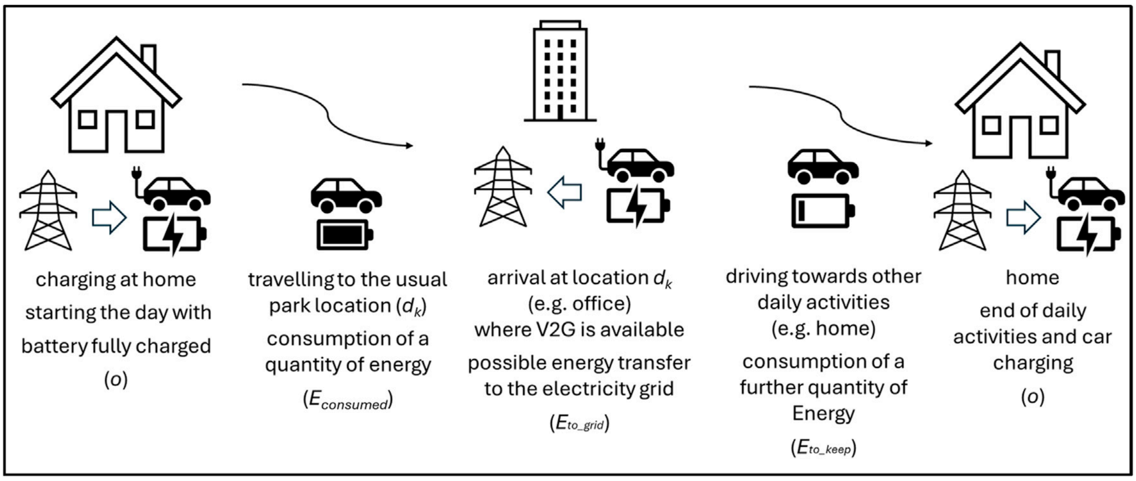

FIGURE 1
V2G working scheme.

In this way, V2G technology acts as a backup system for the distribution network. This system means that the potential impact of EVs on companies operating in the energy distribution sector can become significant as the number of these vehicles increases. Note that from the perspective of energy generation and distribution, the effect of V2G is limited, while the impact on the distribution system cannot be ignored. In fact, an in-depth analysis presented by Solanke et al. (2020) shows how charging EVs effects the current distribution network through its generation capacity, transformer aging due to overload, battery degradation, and power quality issues in the distribution system. This study also presents various methods to reduce these impacts, including multilevel hierarchical charge-discharge, centralized energy management, and direct control through intelligent charging algorithms.

2.2 Literature review

Currently, EVs constitute a rapidly growing market segment, although the infrastructure is inadequate for existing EV demand. In recent years, several aspects have been evaluated, such as the impact on the service network and the distribution network, power quality, and voltage regulation. From a technical point of view, the charge-discharge method essentially depends on the location of most parked EVs and energy demand (Comi and Idone, 2024).

Planning the amount of energy transferred from the system to EVs is necessary to study the impact on the distribution network and regulate EV charge-discharge control (Micari et al., 2017). In uncontrolled charging, electric vehicles are charged quickly when service is requested or after a user-specified delay. This delay is inserted to allow vehicle owners to charge their vehicles using off-peak rates. Once charging starts, it usually ends when the battery is fully charged or the vehicle is used, whichever occurs first. Unlike the just-presented method, the controlled charge-discharge procedure ensures more flexibility for users and greater efficiency for the power transmission network. This coordinated approach can be easily adopted and monitored by the operator who organizes the EV charge-discharge scheduling to avoid issues related to power quality and network overloads, while simultaneously meeting the driver's charging needs, business profits and sustainability goals. Furthermore, depending on the types of control parameters, the charge-discharge system can be incorporated into an indirectly intelligently and bidirectionally controlled approach (Solanke et al., 2020). The indirectly controlled approach is based on a strategy that does not directly operate on EV charging parameters, such as charging or discharging speed, the timing of battery charging or discharging. External parameters including real-time electricity price and real-time demand to adjust the EV charging parameter should be analyzed. Specifically, on the basis of market needs, battery charging speed will be regulated with a system-wide optimization perspective. Similarly, systems that analyze user movements, battery charge status, or downtime could be used to ensure greater efficiency in vehicle charging. Finally, the formulation presents stringent constraints regarding the maximum power available in battery charge and/or discharge, the vehicle battery capacity, the initial battery charge state, and driver travel practices to calibrate the charge/discharge system. Furthermore, the operation of a power supply system is constrained by the characteristics of generation units, the network structure, the efficiency of the transformer and the requirements for voltage and frequency. Regarding bidirectional charging, the main functions that can be used to extend the benefits of V2G in the long term are highlighted. Examples include the ability to easily connect and disconnect the vehicle from the infrastructure, the gradual start and stop of charging, automated charge and discharge operations, and regulating the speed of energy exchange with the grid. Through these tools, EV owners can benefit from reduced charging costs (Kiaee et al., 2015), greater uniformity and balance in charging, and voltage stabilization. Additionally, EV batteries act as an energy reserve, bridging the gap between demand and supply, both affected by significant randomness. Bidirectional V2G also supports the integration of renewable energies through smart grids, promoting a better utilization of energy from sustainable sources rather than traditional ones. Not surprisingly, such systems are often employed to reduce domestic energy consumption (Sørensen et al., 2024; Nagel et al., 2023).

The charging infrastructure is a central element for V2G applications and, more generally, to support the roll-out of electric vehicles. The primary function of these stations is to enable and facilitate charging of vehicle batteries. However, it must be stressed that they are essential for the functioning of V2G as they allow the connection between vehicles and the electricity grid, enabling reciprocal energy exchange operations. Therefore, it is necessary that the charging infrastructure is designed and calibrated to maximize and take advantage of all the benefits of V2G. In particular, a variety of aspects and regulations must be considered when designing the infrastructure. The first step is to choose the location of the charging stations, considering the available space and the flow of electric vehicles. The density of electric vehicles in each area will have a critical impact on the size of the charging stations; specifically, areas characterized by large flows of vehicles will require careful planning of transit areas. Especially in dense urban areas, adequate space must be considered to ensure optimal use of the service by all users. Taking into account the purely technical aspect, it is necessary to comply with the regulations in terms of the safety and efficiency of V2G charging systems.

The study of the use of electric vehicles is mainly based on a topological aspect, related to land use, on an energy aspect related to the energy consumption of vehicles and the demand for energy to be made available in the network, and on the study of new technologies for both infrastructure and production of vehicle batteries. For both the energy level and the topological level, it is necessary to refer to the travel and parking phases of each vehicle. This way, it is possible to predict the amount of energy needed to recharge vehicle batteries (Arias and Bae, 2016; Xydas et al., 2016). However, the possibility and need to recharge the vehicle is related to factors such as the number of journeys to be made, the distance to be covered, the energy consumption, and especially the location of the charging points. For this reason, the ability to identify and predict the demand for parking and energy is crucial. Usually, this activity can be performed through statistical surveys or through data collected, such as FCD data. Localization is usually carried out by means of information on travel destinations, charging points, and other sociodemographic points of interest (PoI).

Typical methods for modeling the activities of electric vehicles include origin-destination (O/D) analysis, generation of travel chains, and the Markov Chain model with reference to space - time vehicle localization. The energy demand for charging electric vehicles can be determined by knowing the energy consumption of electric vehicles. In this context, the fear of not having enough recharge from V2G services to complete own trip chain must also be considered (Zheng et al., 2022).

The brief overview introduced above shows that the idea of V2G has been the subject of several investigations to date. But most of them do not address the topological and land-use issues. Instead, they focus on infrastructure, technology, and energy. This research will provide a novel approach that uses FCD to infer on the current usage of cars, therefore, identifying prospective places where V2G may be implemented). Actually the use of FCD allows the identification of the car travels that are the most compatible with the V2G services and then to provide a first estimation of the potential energy that can be transferred to the energy grid. Besides, given that the telematics and the applications based on vehicle location systems (e.g., Global Position System, EGNOS) allow users to be traced continuously in time and space, the proposed approach exploits the opportunity given by floating car data (FCD) to identify the car trips that could be potentially interested in participating to V2G. Therefore, recalling Agenda 2030 by the United Nations (UN) and its 17 goals, this paper aims to contribute to the Sustainable Development Goal 11 (SDG 11), and in particular to target 11.2 (that relies with the sustainable transport systems). Using this method, the placement and operations of the V2G infrastructure can be optimized to better serve the demand of both the grid and the users.

3 Methodology

The proposed methodology (Figure 2) focuses on the possibility of identifying the areas that best perform the implementation of the V2G service using large amounts of FCD, which allow vehicles to be continuously followed in time and space, and limit the resources spent for obtaining the data on travel patterns. This methodology is based on the application of three closely related steps (Comi et al., 2024):

- the characterization of movements to/from the V2G parking points by vehicle type, by variables influencing parking demand, by distance travelled, and by vehicle type (*car trip detection*);
- the characterization of movements affecting the study area with spatial identification of the possible/potential points where V2G can be operated (*location of potential and actual areas*);
- the potential energy evaluations consisting of determining the variables useful for estimating the state of charge present at the time of parking (*energy residual*) and the minimum power necessary to ensure the functionality of the vehicle (*energy needed and energy to keep*) following a withdrawal from the grid (*energy evaluation*).

The correlation between energy supply and parking features is dictated by the fact that the identification of potential parking areas is closely linked to parking demand and, consequently, also to the characterization of the trip chain carried out by each individual vehicle. Once the location of the potential points where V2G can be operated has been determined. It is possible to determine the real applicability of V2G to the identified parking area based on the total energy that can be supplied to the system. These steps will be described in the following subsections.

3.1 Car trip detection

The use of FCD allows the reconstruction of the trip chains of each individual vehicle, making them well-suited for use in the proposed methodology. By identifying a trip chain for each individual vehicle *c*, characterized by a sequence of individual

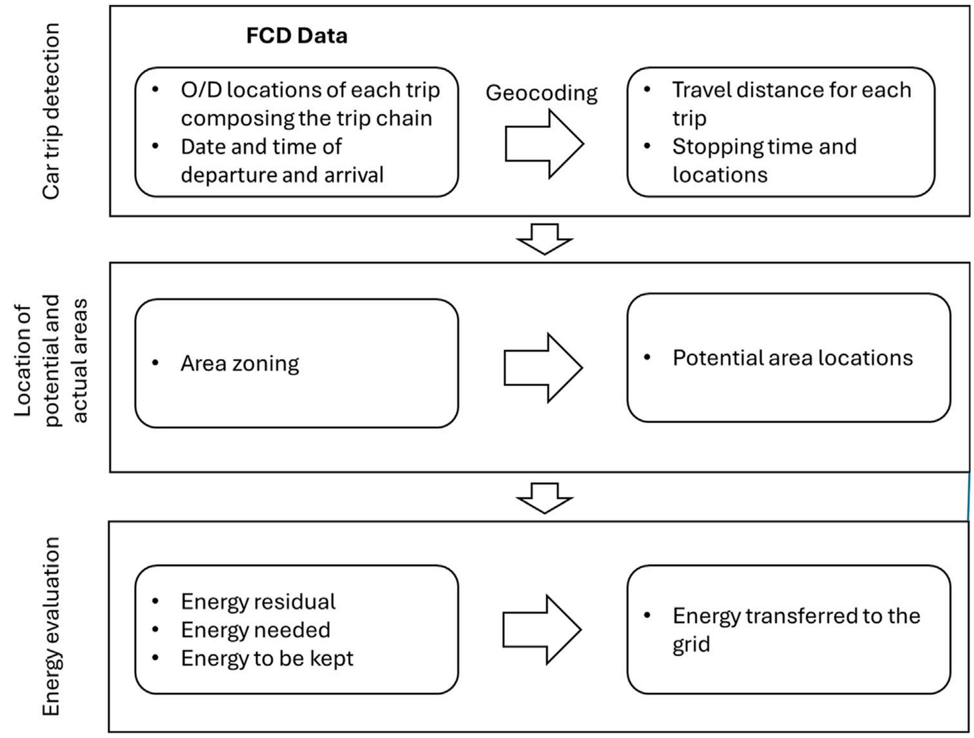

FIGURE 2
Methodology.

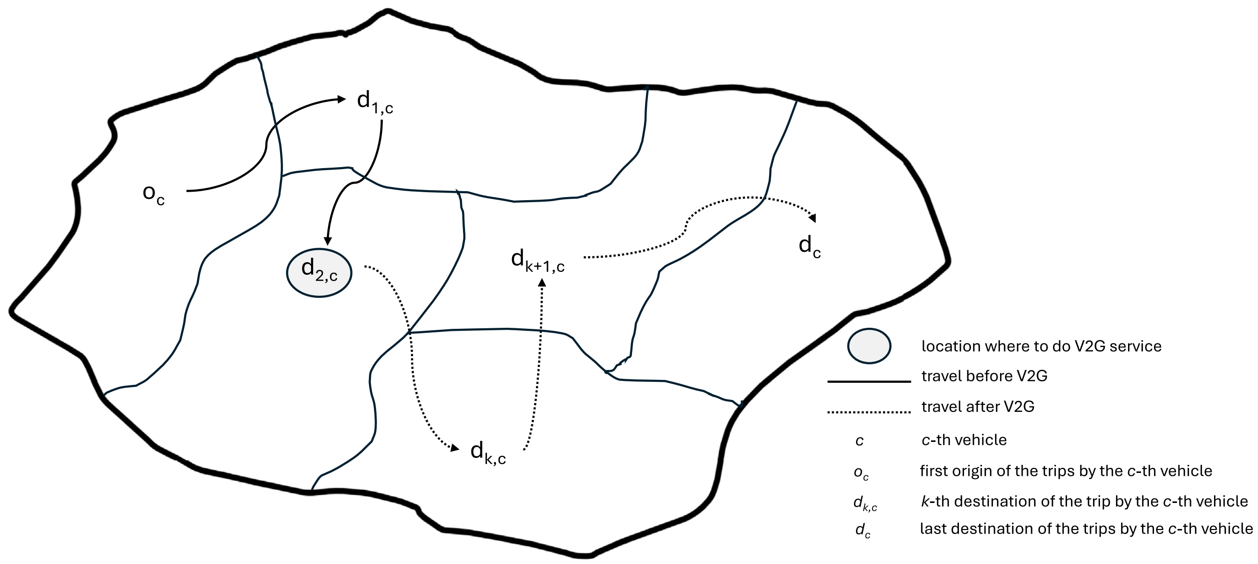

FIGURE 3
User trips.

O/D trips, where the origin of the next trip is the destination of the previous one, for each location zone d_k (Figure 3):

$$d_{k-1,c} \equiv d_{k,c}$$

with $d_{k\text{-}1,c}$ is the (*k-1*)-th zone reached by vehicle *c* during its daily travels.

The dataset to use should consist of *n* representative vehicles, each of them making *t* trips, at the end of which a stop of a given duration is made; this stop may or may not be a potential V2G point. To characterize the trips and identify likely V2G locations, secondary data can be used (e.g., land use as well as socio-economic ones).

Therefore, the usable dataset should allow the identification of the following vehicle activities:

- the use of vehicle *before to stop* for a time feasible for V2G (i.e., to forecast the energy available from the vehicle once V2G place is reached);
- the parking, which allows analyst to forecast the possibility to participate in V2G subject to minimum parking time and to energy available to transfer;
- the trips to undertake after the parking to assess the required energy for completing the daily activity; this stage is relevant to stimulate a high level of participation because the involvement in V2G should not have significant impact on daily user's scheduled activities.

Then, the vehicle dataset should ensure the possibility of tracing the given vehicle (i.e., anonymized *vehicle_ID*) to reveal the date, time, and coordinates of the origin and destination of each trip, as well as the engine status (on/off).

The *vehicle_ID* allows for the assignment of a set of one or more O/D trips to the same vehicle, each composed of the previously defined sequence of trips. If the same vehicle makes the same O/D route, identified by the origin and destination coordinates of the trips, on different days, it can be considered systematic and a potential candidate for V2G technology. A systematic user, consistently repeating the same trip chain, will be more likely to repeatedly supply energy to the system, ensuring a stable minimum amount over time. However, as said, this requires meeting additional conditions related to the characterization of the trips that make up the vehicle trip chain, as the feasibility of energy transfer depends on the energy consumed in trips before the stop ($E_{consumed}$), on the energy needed up to the end of the day (E_{needed}), and the desired residual charge at the time of V2G application (E_{to_keep}).

Then, the parking time of the vehicle c in the zone d_k ($TP_{d_k,c}$) can be determined as follows:

$$TP_{d_k,c} = \tau_{d_k,c} - \upsilon_{d_k,c} \tag{1}$$

where.

- $TP_{d_k,c}$ is the parking time of vehicle c in a parking zone d_k,
- $\tau_{d_k,c}$ is the departure time of vehicle c from parking zone d_k,
- $\upsilon_{d_k,c}$ is the arrival time of vehicle c in the parking zone d_k.

After identifying the zones where stops occur and reconstructing the actual route followed by users for each individual trip within the trip chain (Comi et al., 2021), the next step is to calculate the energy consumed from the beginning of the trip chain to the parking zone d_k.

Let.

- i_c be the route followed by vehicle c from zone d_k to zone d_{k+1},
- $dist_{i_c}$ be the length of the route i_c,
- ce_c be the average energy consumption per kilometer related to vehicle c,

the energy consumed ($E_{consumed,d_k,c}$) by the vehicle c from the origin of the trip chain (zone o) to the parking zone d_k can be calculated as follows:

$$E_{consumed,d_k,c} = ce_c \cdot dist_{i_c} \tag{2}$$

3.2 Location of potential and actual areas

As foreseen in the proposed methodology (Figure 2), in order to look for a V2G location, given that vehicles cannot participate individually, it is necessary to identify the best location(s) that can guarantee a significant number of potential participants to be present simultaneously and to have a significant rate of energy to transfer to the electricity grid. Therefore, after having investigated the different possible locations where the vehicles stop, the next step is to select the best zones where to perform V2G. It should ensure reaching a minimum threshold of energy transferability to the system, which has been identified from the literature (Çiçek and Erdinç, 2021).

Therefore, having highlighted the endpoints of the individual trips that make up the trip chain (car trip detection phase), potential V2G locations can be identified by considering the total number of vehicles that stop there in a day for a minimum stopping time consistent with V2G. According to Li et al. (2023) 30 min have been selected.

Given that the pre-selection of the location for V2G depends also on the distribution of activities and services in the area, a preliminary phase to develop consists of the identification of potential V2G locations. For example, the potential location could be: modal nodes (e.g., railway stations), commercial, industrial, sports, educational, and health activities areas. Equally important is the urban structure of the area. In fact, cities with central pedestrian or restricted access areas will have parking spaces adjacent to the borders, where many vehicles stop for enough time, creating potential locations for V2G.

However, not all identified parking places can be considered as potential V2G areas: all locations where vehicles are stopped at the end of the day (e.g., residential areas) should not be considered. In fact, the vehicles usually stop during off-peak hours of energy demand and the energy transfer takes place unidirectionally from the network to the vehicles (i.e., vehicle charging). In addition, it should be noted that evening and night are off-peak temporal periods and there is no need for more energy to stabilize the power of the electricity grid. Commercial, industrial or high-density office and service parking areas are characterized by the long-term stopping of several vehicles simultaneously during hours of low traffic and high energy demand. Therefore, they are best suited for the V2G application. To identify the potential areas where V2G operation will take place, it could be of interest for planners to have a first estimate of the potential energy available from parked vehicles. This type of analysis is developed in the third stage of the proposed methodology. Subsequently, the choice of the best places where to implement V2G services is on the best identified places that also assure a resonable rate of energy that can be transferred to the energy grid.

3.3 Energy evaluation

Given the vehicle registration number from the FCD data, it is possible to identify the installed battery pack. This value represents the energy capacity of the battery of vehicle c, i.e., the maximum energy available in the vehicle (C_c).

The energy that vehicles parked simultaneously in zone d_k can potentially provide to V2G depends on the energy that vehicles have when they reach zone d_k and the minimum level of charge that each user wants to ensure when s/he returns to use the vehicle. Then, for each vehicle reaching zone d_k the energy residual can be calculated according to the energy consumed (Equation 2) as follows:

$$E_{residual,d_k,c} = C_c - E_{consumed,d_k,c} \quad (3)$$

where $E_{residual,d_k,c}$ is the residual energy remaining available to the electric vehicle before it is connected to a V2G.

The proposed methodology assumed that the users, after the connection to V2G, can continue to conclude his/her daily activities as planned. Therefore, it is relevant to calculate the energy that each vehicle needs to conclude its daily activities.

Let $E_{to\_keep,d_k,c}$ be the energy that the vehicle c, parked in zone d_k, needs to complete the planned daily activities, the potential energy that can be transferred to the grid ($E_{sub\_grid,dk,c}$) can be calculated according to the Equation 3 as follows:

$$E_{sub\_grid,d_k,c} = E_{residual,d_k,c} - E_{to\_keep,d_k,c} \quad (4)$$

However, this energy (Equation 4) represents only the potential amount that could be transferred by vehicle c parked in zone d_k. The effective amount of energy transferred by the vehicle c ($EF_{sub\_grid,d_k,c}$) depends on the vehicle parking duration and the rate of energy transfer to the grid ($s_{tr,c}$). Assuming that the vehicle begins to transfer energy as soon as it starts its parking period. Such an energy $EF_{sub\_grid,d_k,c}$ can be determined, according to the parking time calculated through the Equation 1 and subject to the constraint given by the Equation 4, as follows:

$$EF_{sub\_grid,d_k,c} = s_{tr,c} \cdot TP_{d_k,c} \leq E_{sub\_grid,d_k,c} \quad (5)$$

Finally, the total energy that can be transferred to the grid by all vehicles parked in zone d_k can be calculated by summing up the contributions (Equation 5), that is:

$$ET_{sub\_grid,d_k} = \sum_{c \in VE_{d_k}} EF_{sub\_grid,d_k,c}$$

where VE_{d_k} is the set of vehicles participating in V2G, which are parked in zone d_k.

4 Application to a real test case

This section reports the application of the methodology used to estimate the potential energy to be transferred to the electricity grid in the Veneto region (northern Italy), which is the third region in Italy for registered EVs. The application has been carried out to ascertain to what extent the objective of using FCD data to estimate vehicle activities for the V2G assessment could be realistic. The investigation has been performed by analyzing a large dataset of private cars driving in the following main cities of the Region: Padua, Rovigo, Treviso, Verona and Vicenza. The city of Belluno and Venice, as explained below, has been excluded for its land characteristics that do not allow to be considered feasible for such a scope.

Furthermore, these cities have been selected because a large FCD dataset has been available and for the good results that were obtained in previous studies to determine the O/D car flows (Comi et al., 2021). In addition to this, it is also the third most populous region in Italy (ISTAT, 2023).

The study area, which covers these five urban regions, has a total surface of 18,391 km^2 and a population of 4,905,037 (2011 census data; ISTAT, 2023). Table 1 shows the main characteristics of the Veneto region. As shown, all the provinces are roughly equivalent in terms of population, except for Belluno and Rovigo, which have about four times less inhabitants. Therefore, while the province of Rovigo has been considered as of interest for the V2G study due to its urban analysis, the provinces of Belluno and Venice have been excluded. Belluno, for its low number of vehicles, due to the particular alpine-environment territory, and Venice, due to the exclusive geographical-urban configuration.

Focusing on the level of motorization, it has been possible to determine the variation in this parameter by province, ranging between 552 and 674 cars per 1,000 inhabitants and consequently the relative number of cars per capita, which has been found to be quite similar throughout the region.

Below, the results of the application are described pointing out each stage of the proposed methodology: car trip detection, location of potential and actual areas, and energy evaluation.

4.1 Car trip detection

For the vehicle trip detection phase, as stated in Section 3, FCD data have been used. They allowed essential information about vehicle movements to be obtained, including driving conditions, speed, location, and other relevant variables.

The collected data consist of information on car journeys within the Veneto region (that is, at least one survey data within the region on the day of the survey) from the first to the last trip made during the whole day. The data have been analysed to identify travel patterns, thus obtaining indications on the trips performed. The available database consists of five working-day observations, spread over the autumn months (i.e., October–November 2018) on different working days. The information form includes basic vehicle data for each sampled vehicle, including vehicle class, brand, year, type, fuel type, and gross weight. The vehicle identifier, date (the day the record is logged), timestamp (the time the record is logged), coordinates (the geographic location: latitude and longitude), instantaneous speed, type of road (urban, extra-urban, freeway), and direction angle are all included in the daily car operation logs, which list all trips the surveyed vehicle made in chronological order. There is no information available regarding the nature of the activity performed or the trip purpose (e.g., work or study) of the surveyed cars. These data have been of fundamental importance, as they constituted the basis for applying the methodology described in Section 3 that made it possible to identify the origin and destination of each individual trip. Therefore, the analysis of the identified parking areas constitutes the input in determining the V2G service areas (*location of potential and actual areas*).

After a thorough cleaning and removal of observations containing incomplete data, the remaining data were processed to look at trip patterns and duration. A whole of 29,158 private cars has been examined, which complete about 70,000 trip chains in 5 days. Then, in order to transfer the sample results to the vehicle population driving in the Veneto region a further analysis has been performed (i.e., *expansion to the universe*), following the methodology proposed by Comi et al. (2021).

TABLE 1 Veneto region statistical data.

Province	Area [km^2]	Inhabitants	Number of cars	Average number of vehicles per inhabitant
Belluno	3,678	204,900	135,261	0.660
Padua	2,141	936,740	603,290	0.644
Rovigo	1,789	236,400	159,231	0.674
Treviso	2,477	887,420	588,052	0.663
Venice	2,463	853,552	471,324	0.552
Verona	3,121	922,821	614,838	0.666
Vicenza	2,722	863,204	577,339	0.669
Total	**18,391**	**4,905,037**	**3,149,335**	**0.642**

TABLE 2 Trips characterization.

Province	Survey days					Average number of trips	Total trips	Number of urban trips	Number of out-of-town trips	Number of vehicles
	15.10	*22.10*	*07.11*	*15.11*	*23.11*					
Padua	4,883	4,957	5,054	5,272	5,392	5,112	25,558	9,833	15,725	3,407
Rovigo	427	448	458	443	480	452	2,256	1,124	1,132	308
Treviso	2,681	2,737	2,832	2,855	3,061	2,834	14,166	4,862	9,304	1,907
Verona	6,407	6,460	6,755	6,940	7,218	6,757	33,780	22,754	11,026	2,550
Vicenza	3,760	3,731	3,992	4,193	4,427	4,021	20,103	8,536	11,567	2,303
Total	**18,158**	**18,333**	**19,091**	**19,703**	**20,578**	-	**95,863**	**47,109**	**48,754**	**10,475**

Reference has been made to the days of 15.10 (Monday), 22.10 (Monday), 7.11 (Wednesday), 15.11 (Thursday), and 23.11 (Friday). In this way, the possibility of daily variations in the journeys has been taken into account. It should be noted that the examined vehicle has been studied for 24 consecutive hours with the possibility of extending the recording to the following day in case the last journey had not been completed or to include the previous day if the vehicle journey started on such day and ended on the day of the survey. The characteristics of the database in terms of cardinality and survey day are summarized in Table 2.

TABLE 3 Socio-economical data of the provinces investigated.

Province	Number of employees	Number of zones
Padua	93,219	56
Rovigo	15,455	28
Treviso	27,606	30
Verona	111,761	81
Vicenza	49,331	112
Total	**297,372**	**307**

4.2 Location of potential and actual areas

To identify potential areas where V2G could be implemented, each province covered by the study, consisting of the provincial capital and its neighboring municipalities, has been divided into traffic zones with a different level of aggregation, i.e., the zone size decreases moving from neighbors to the city center (Table 3). To do this, information from the latest ISTAT (Italian national institute of statistics) census, pertaining to the year 2011, has been used. In particular, the zoning has been performed by taking into due consideration the following factors:

- territorial homogeneity (i.e., population density assessment, service providers, employees),
- relevant physical references (such as the presence of rivers, railway and/or road routes),
- membership of different municipalities,
- presence of places of interest and/or of affluence,
- transport homogeneity (i.e., census sections served by the same basic element of the transport system, such as a metro station.),
- topological homogeneity.

Once the zoning of the study area for each province has been determined, the evaluation of the V2G technology at points of interest has been carried out based on the travel information obtained from the FCD. By georeferencing the individual trips belonging to each trip chain, it has been possible to calculate the distance traveled, the time taken, and the average speed maintained for each trip. Through

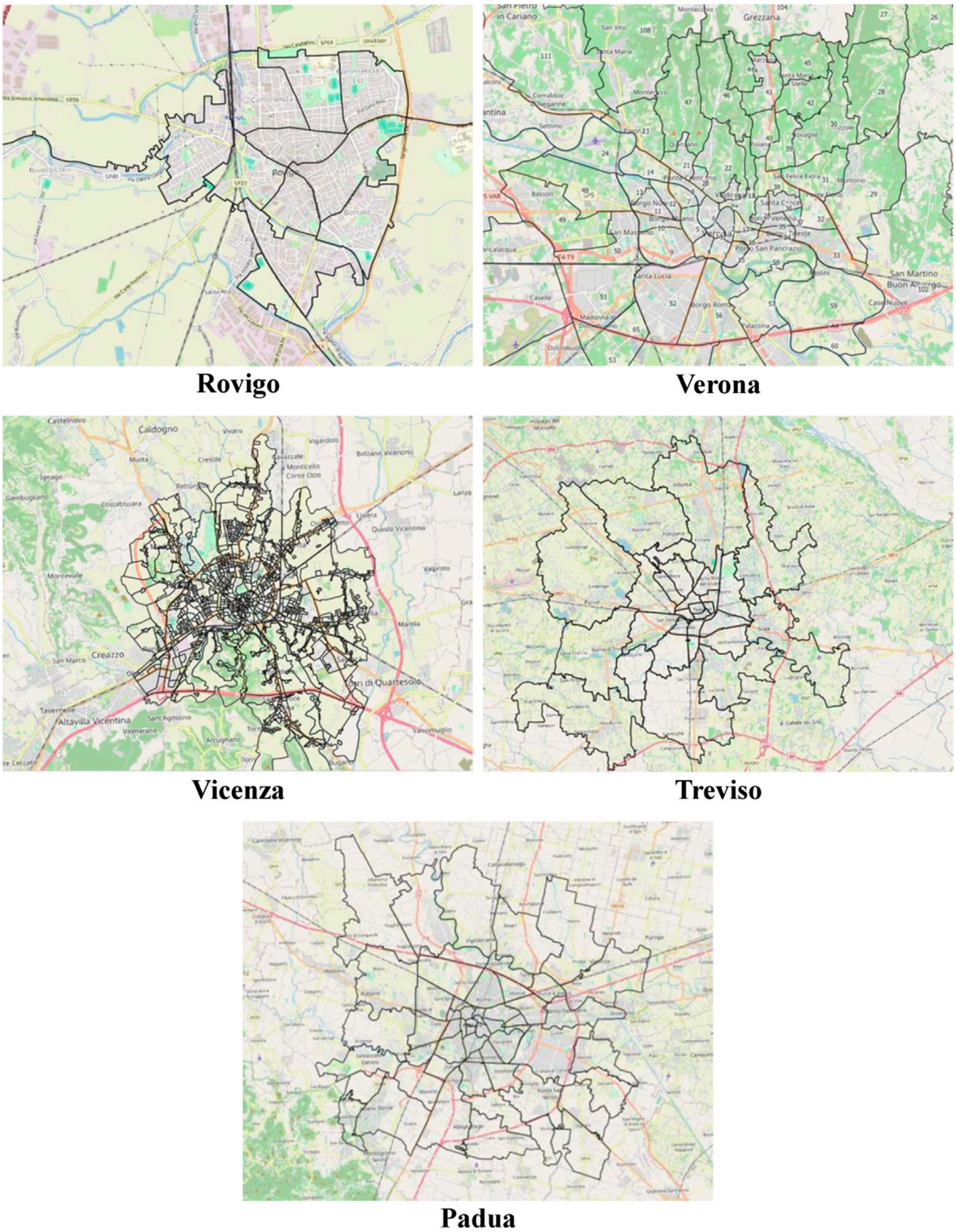

FIGURE 4
Area zoning.

georeferencing the zoning of the area (Figure 4) and the destination points of the previous trip, it has been possible to identify the location of the most frequently used parking zones.

In this regard, Figure 5 shows the identified parking locations in Rovigo. The identified locations are highlighted in red near the commercial area of Viale Porta Po (South of the city), near the railway station, the hospital (East of the city) and the University (North of the city).

A similar parking pattern can also be observed in the other examined cities. In Treviso, for example, urban planning aspects play a crucial role in identifying potential V2G application areas. The presence of an LTZ (Limited Traffic Zone) in the historic center has led to the creation of a series of parking areas in the surrounding zones, where a high number of vehicles park throughout the day (highlighted in red in Figure 6).

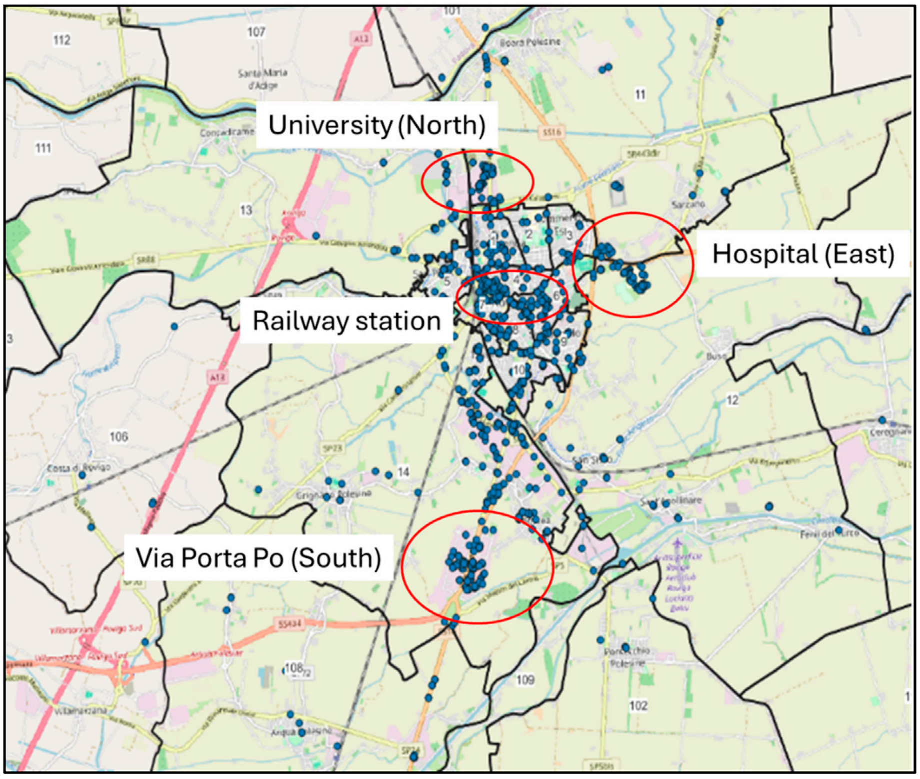

FIGURE 5
Inner area of Rovigo: main stop areas.

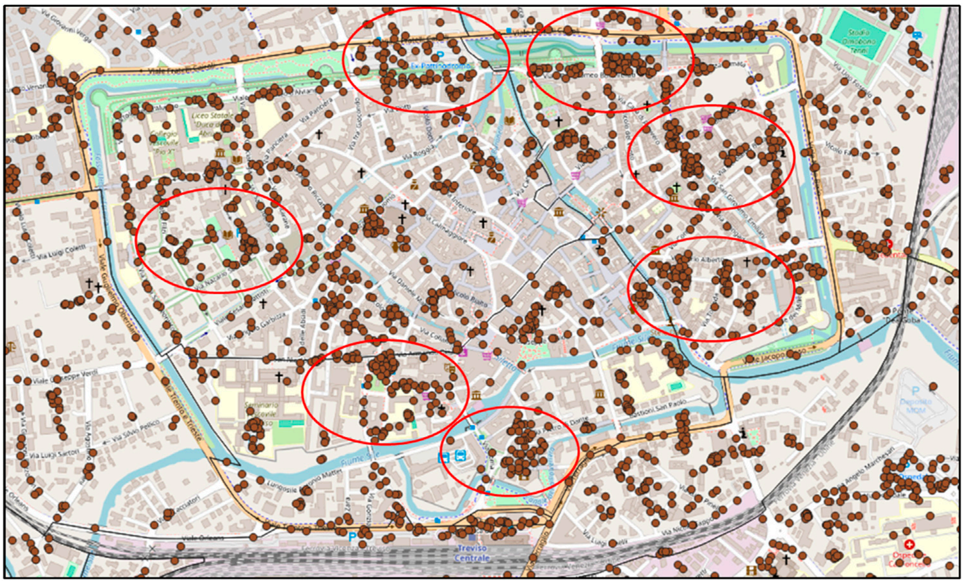

FIGURE 6
Inner area of Treviso: main stop areas.

Once potential areas are identified, it is possible to determine the duration of parking of a vehicle between trips to assess whether this parking period meets the minimum time requirement for the implementation of V2G, as introduced in Section 3.2.

4.3 Energy evaluation

Once potential parking areas have been identified for the five municipalities of interest, energy assessments have been carried

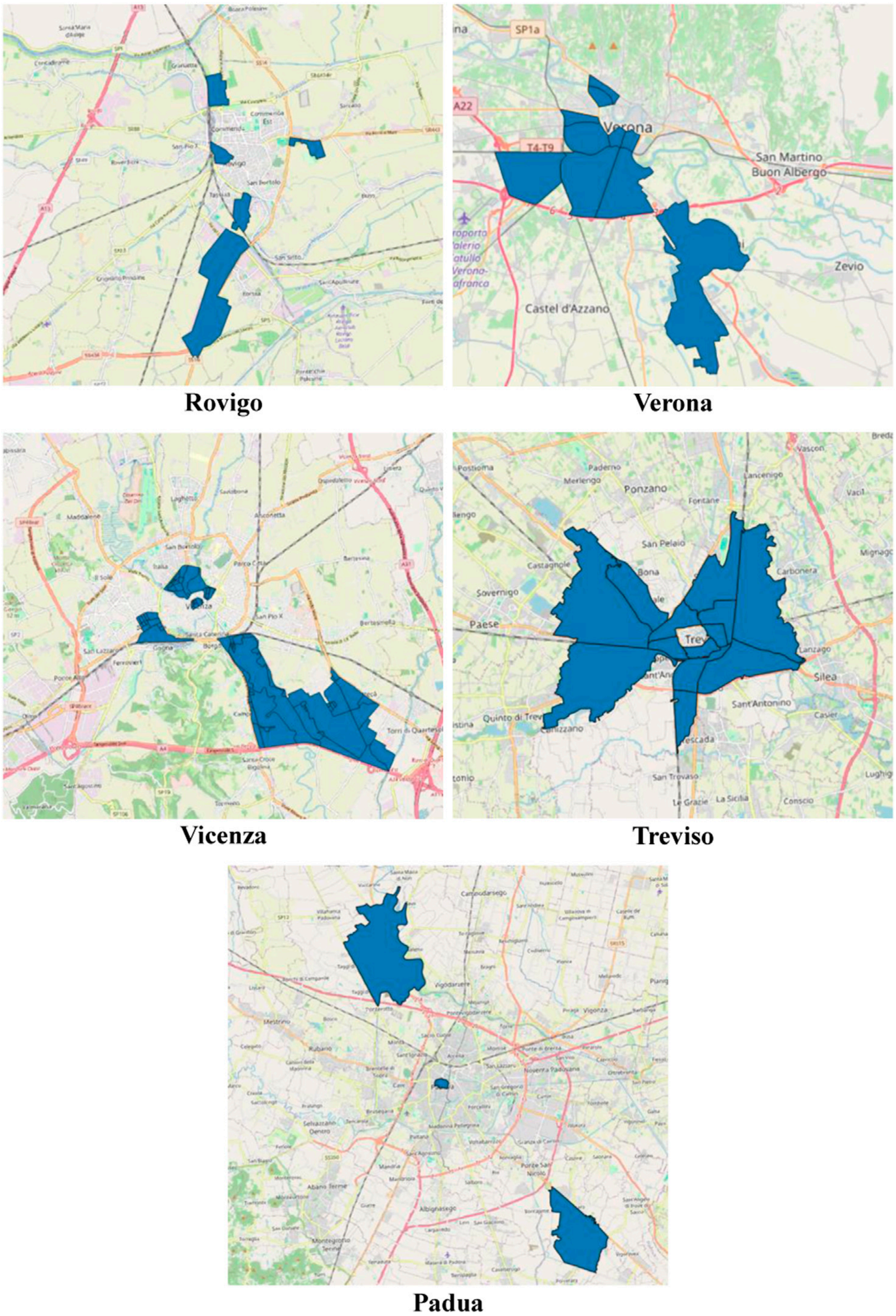

FIGURE 7
V2G parking areas.

out to identify whether V2G could be used in that parking area. To this end, the energy consumed, the energy needed, and the energy to be kept for each parked vehicle have been determined. In this way, the energy potentially transferred to the grid has been calculated according to parking time and transfer speed of each vehicle. Finally, for each parking place and for each day in the dataset, the effective energy submitted to the grid has been calculated as a sum of the energy submitted to the grid by each vehicle. Results in Tables 4–8 show where the average energy for each parking area has been determined. As said, the sample results have been expansed to the universe of investigation using the methodology proposed by Comi et al. (2021). The identified effective areas chosen are plotted in Figure 7.

The results of the methodology applied to the study area are revealing. In particular, as reported in Tables 4–8, the application

TABLE 4 Energy submitted to the grid: Padua.

Parking zone	1	55	56	Total
Average energy transferred to the grid, E_{to_keep} = 40% [kW/day]	150,603	302,078	484,422	**937,104**
Average energy transferred to the grid, E_{to_keep} = 60% [kW/day]	121,265	243,382	389,018	**753,665**
Average energy transferred to the grid, E_{to_keep} = 80% [kW/day]	91,927	184,686	293,614	**570,227**

TABLE 5 Energy submitted to the grid: Rovigo.

Parking zone	1	2	3	4	5	Total
Average energy transferred to the grid, E_{to_keep} = 40% [kW/day]	47,013	123,601	100,349	66,636	172,418	**510,017**
Average energy transferred to the grid, E_{to_keep} = 60% [kW/day]	30,756	77,607	62,356	41,686	108,203	**320,607**
Average energy transferred to the grid, E_{to_keep} = 80% [kW/day]	15,303	32,324	24,999	18,071	44,424	**135,121**

TABLE 6 Energy submitted to the grid: Treviso.

Parking zone	78	79	80	81	82	84	86
Average energy transferred to the grid, E_{to_keep} = 40% [kW/day]	9,470	62,187	58,255	56,455	40,134	61,167	13,292
Average energy transferred to the grid, E_{to_keep} = 60% [kW/day]	6,097	38,358	35,769	36,784	24,632	38,547	9,154
Average energy transferred to the grid, E_{to_keep} = 80% [kW/day]	2,417	13,539	12,590	14,824	8,693	13,142	3,392
Parking zone	87	88	90	91	94	96	97
Average energy transferred to the grid, E_{to_keep} = 40% [kWday]	109,153	38,969	49,480	42,422	61,924	81,851	44,881
Average energy transferred to the grid, E_{to_keep} = 60% [kW/day]	65,686	23,392	29,480	27,949	38,835	48,761	26,549
Average energy transferred to the grid, E_{to_keep} = 80% [kW/day]	22,840	7,764	11,121	10,326	13,514	16,381	8,832
Total [kW/day] - 40%: 729,642		**Total [kW/day] - 60%: 449,991**			**Total [kW/day] - 60%: 159,374**	

TABLE 7 Energy submitted to the grid: Verona.

Parking zone	3	4	7	8	9
Average energy transferred to the grid, E_{to_keep} = 40% [kW/day]	66,284	34,665	29,571	39,975	79,184
Average energy transferred to the grid, E_{to_keep} = 60% [kW/day]	41,868	22,038	18,992	25,418	50,313
Average energy transferred to the grid, E_{to_keep} = 80% [kW/day]	17,422	9,333	8,413	10,768	21,419
Parking zone	10	51	52	56	101
Average energy transferred to the grid, E_{to_keep} = 40% [kW/day]	55,972	44,021	236,094	331,361	34,404
Average energy transferred to the grid, E_{to_keep} = 60% [kW/day]	35,684	27,528	149,416	210,562	21,623
Average energy transferred to the grid, E_{to_keep} = 80% [kW/day]	15,365	11,034	62,644	89,662	8,818
Total [kW/day] - 40%: 951,531		**Total [kW/day] - 60%: 603,441**		**Total [kW/day] - 60%: 254,877**	

TABLE 8 Energy submitted to the grid: Vicenza.

Parking zone	5	6	24	39	47	48	60	Total
Average energy transferred to the grid, E_{to_keep} = 40% [kW/day]	38,911	20,162	8,182	15,215	15,702	19,597	5,810	**123,579**
Average energy transferred to the grid, E_{to_keep} = 60% [kW/day]	24,696	12,644	5,069	9,577	9,808	12,284	3,600	**77,678**
Average energy transferred to the grid, E_{to_keep} = 80% [kW/day]	10,754	5,299	2,029	4,172	4,056	5,134	1,485	**32,929**

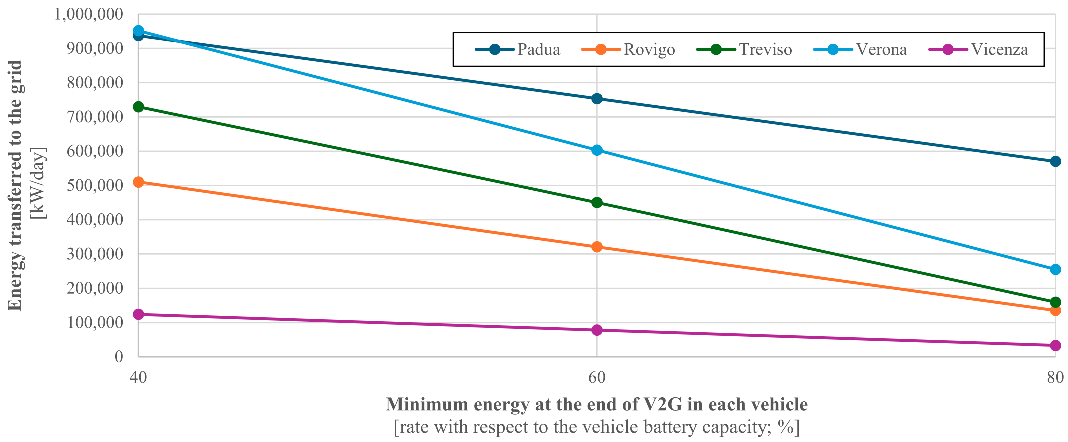

FIGURE 8
Energy transferred to the grid.

findings shows that in all three levels of minimum energy stored in the vehicles after the participation to V2G (remaining satisfied with the constraint that each vehicle has to continue to perform the usual daily activities, i.e., without penalty due to having participated in V2G), the energy to be used could be significant. In particular, this potential energy is strictly related to the travel patterns that are specific to each city. It is more evident if the results are plotted as shown in Figure 8. For example, although Padua and Verona show the same level of energy available when the energy to the vehicle is assumed greater than 40% of the vehicle energy capacity, the difference at 80% is significantly different in the two cities, given that usually the average of travel time passes from 15 min to more than 21 min, respectively, in Padua and Verona. The other cities show a similar slope in the plotted lines. Therefore, one of the most notable findings is that vehicles consume limited energy for their daily activities and a large amount of energy remains stored and not used while asking electricity providers to increase their production during peak hours, although the energy in the whole system could contain such an extra effort with benefits for the environment and sustainability.

However, although such good preliminary results confirm the goodness of the proposed methodology, further development germinates. To further analyze the role of the control of the energy storage of the EV cluster and research the impact of V2G on the grid load, it is also necessary to fully consider user behavior and combine the energy storage characteristics and the traffic characteristics of electric vehicles in order to achieve a more accurate description of the V2G model. Most of the research currently available only considers traffic and trip data; they do not developed a comprehensive analysis of a range of factors, such as user behavior, willingness preferences, charging and discharging techniques, and the impact of charging on the grid (Comi and Idone, 2024). In particular, it is difficult to identify user acceptance due to the low familiarity users have with electric vehicles. Then, recalling a preliminary survey carried out in Italy where about 300 users have been interviewed, a maximum of 74% of those surveyed expressed interest in taking part in V2G, and half of them (50.4%) said they would like to keep the battery at least 60% residual at the end of the day. In the end, only 74.8% of respondents were willing to accept payment that was equal to or greater than the energy cost they had to pay for charging; but 2.9% of respondents - motivated by their concern for the environment - were willing to accept less. The others wished not to provide an assessment. In this regard, a precautionary level of minimum rate of energy of 40% has been used in such study.

5 Conclusion

The proposed methodology aims to show how the localization of the main areas for implementing V2G can be achieved through the study of FCD, as well as providing a first estimation of the energy that could potentially be transferred to the grid contributing to optimizing the energy use. These data, in addition to the zoning of the territory based on socioeconomic data, allow planner to capture the individual trips that make up the daily trip chain of each user, and thus identify the locations of parking places, which then become potential V2G points. For these points to serve as optimal V2G locations, it is important to perform an energy evaluation to determine the amount of energy that can be efficiently supplied to the system. This amount depends on the trips of individual users, the energy required to complete their entire daily trip chain, and the amount of energy the user wishes to keep in the vehicle at the end of the parking period.

However, this study is a first step in identifying the possible areas to be used for V2G as it assumes that participation is related to parking in specific locations and having enough energy at the end to not penalize the other daily activities. However, the advancement of such a research is addressed to take into due consideration the willingness of users to participate in V2G services and under what conditions (economic reimbursement and energy desired). For this reason, in this specific case the desired energy threshold has been cautiously assumed using some precautionary rates, significantly reducing the potential energy contribution that can be transferred from vehicles to the grid. Furthermore, technical restrictions on charging station location and energy available, as well as the cost of energy, have not been considered. Among the further development of such a research, there is thus the integration of a model for simulating the rate of participation to V2G, the time distribution, and the methodology for forecasting short and medium demand. Therefore, moving to a decarbonized transportation system is considered more difficult than in other areas of the economy. Decarbonizing urban mobility can be achieved through a variety of technological and regulatory approaches. But a decarbonized urban transportation system cannot be achieved by technical advancements alone. They have to be supplemented with actions that target travel patterns and cause a change in people's everyday mobility behaviors. Then, increased acceptance and use of smart and bidirectional electric vehicle recharging in order to support locally powered, zero-emission mobility in cities across electric mobility modes, including public transportation, and to reduce the need to invest in distribution grid extension as a result of the rise in the number of electric vehicles used in cities should be a good lever. Finally, the assessment process should explore how new business schemes incorporate the requirements and demand characteristics of users, thereby addressing V2G providers' concerns and developing supporting regulatory frameworks. Business plans should actually address operational and commercial concerns, such as the needs of EV owners, in addition to relying on improvements in technology and transportation services.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

AC: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing–original draft, Writing–review and editing. UC: Supervision, Visualization, Writing–review and editing. SS: Formal Analysis, Investigation, Software, Validation, Writing–original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

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