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A methodology based on floating car data for forecasting the available capacity for vehicle-to-grid services

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Abstract

The paper investigates the exploitation of the current availability of large amounts of floating car data (FCD) based on individual mobility for characterising car trips for forecasting the potential electric capacity of cars to be used in vehicle-to-grid services. A methodology is proposed which aims to: analyse the current car trips and to infer on the electric ones; characterise the vehicle movements; define the attributes (variables) necessary to develop models for predicting the aggregate capacity supplied by electric vehicles (EVs) to support the needs of the electricity grid. The preliminary results of its implementation in the city of Trani, a town in the Southern Italy, are presented.

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Keywords: vehicle-to-grid, V2G, vehcile charging, vehicle recharging, electric vehicles, floating car data, car trips.

1. Introduction

As the world continues to grow and develop, urbanisation depends on successful management and planning. According to the United Nations (UN, 2019): "In 1950, 30% of the world's population lived in urban areas, and by 2050, 68% of the world's population is expected to live in urban areas", therefore many of people's activities are concentrated in cities. The population growth trend is making cities the focus of attention. Moreover, the 30 countries with the most active urbanisation predicted from 2018 to 2050 have been identified, and Italy is one of them. In particular, Italy is the first country in the European Union on the list, as it has the highest percentage of relative change in the rural population over the period described, 41.5%.

In the context of urban development through the concentration of citizens (Gao and Zhu, 2022), transportation plays a crucial role in urban planning. It provides and guarantees the movement of users to their desired destinations, as well as the goods they need. However, a large percentage of citizens use private cars for travelling. According to statistics,

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the highest rates of CO, CO_2, NH_3 come from such vehicles among all modes of transport (EEA, 2022). Therefore, the European Commission has pointed out the need to promote more sustainable development through the Sustainable Development Goals (SDGs), one of which is related to cities (e.g., SDG 11). Researchers, planners and local authorities have been urged to develop new strategies and policies to address urban issues, from the more restrictive ones (e.g., allowing access to cities only to environmentally friendly vehicles) to encouraging users to adopt more sustainable transport behaviour (e.g., using public transport, sharing journeys). For example, the European Union's "Fit for 55 in 2030" project promotes the complete decarbonisation of the transport sector by 2050 and the phasing out of internal combustion vehicles by 2035, with an expected reduction in pollutant emissions of around 55%.

In recent years, the increase in energy efficiency and the promotion of renewable energy sources have promoted a strong change in the electricity sector. In a basic pre-COVID and pre-war scenario in Ukraine, an increase of the energy demand of +0.4% by 2026 (Terna, 2016) was forecasted. Furthermore, the strong incentive towards decarbonisation, particularly in the transport sector, with European policies in favour of the transition to electric mobility, will contribute significantly to this growth in electricity demand. The concept of energy community is one of the distinctive and innovative elements pursued within the national regulatory framework, which includes pilot activities such as the UVAM (Mixed Aggregate Virtual Units, Italy).

In the decarbonisation scenario, the introduction of electric vehicles (EVs) will play an increasingly important role, posing a growing challenge to the energy supply in the appropriate area. The vision of EVs as only consumers of energy is almost limiting. In fact, it does not consider the possibility of using the vehicle batteries as devices for accumulating and releasing electricity to the grid on demand, according to the vehicle-to-grid (V2G) paradigm. In this context, it is found that EVs, especially when they are used for systematic daily short round trips (e.g. home-work, home-school) within urban areas, they store and keep unused significant quantities of electricity (e.g., parking for 6-8 continuous hours in a parking close to the workplaces).

Therefore, the new research trend is to explore the opportunity to utilize such unused energy and to investigate its potential. Thus, this paper focuses on the possibility of considering EVs not only as energy accumulators but also as energy suppliers according to the needs of the entire electricity grid. From a technical point of view, V2G systems use a bi-directional power inverter connected to the car battery and to the grid. This device can therefore draw energy from the grid to recharge the vehicle, or return energy to the grid by drawing energy from the car battery itself. The flows are managed by a control unit that takes into account the state of charge of the vehicle and the energy demand as required. Two key elements are involved in this process: the on-board charger and the charging infrastructure, both of which must support bi-directional charging. In the case of AC infrastructures, the on-board charger converts the AC power from the grid into DC power when the vehicle is charging. In order to fulfil the V2G function, the same device must be able to convert the DC current from the battery back to AC in order to feed it back into the grid. Therefore, we have been investigating EVs connected to the grid, both private (and public), to use batteries as stabilisers, accumulating energy when it is produced in excess and transferring it during peak consumption periods, V2G (Kester et al., 2019; Meelen et al., 2021; Wolkswagen, 2021). In this way, EVs, or rather their batteries (Jin et al., 2020), have a great potential that goes beyond their main task of providing energy for movement. Batteries can therefore be connected to the public electricity grid to make it more stable and efficient (Philip et al., 2023). In fact, the underlying principle of V2G is a technology that allows EVs to be transformed from simple means of transport to energy vectors capable of exchanging electricity with the grid (Shipman et al., 2021).

The remaining of the paper is organised as follows. Section 2 overviews the current state-of-the-art pointing out the temporal usage, the spatial usage as well as the energy usage of EVs. Section 3 presents the proposed methodology, while Section 4 reports the preliminary results of the investigation of Floating Car Data (FCD) to forecast the potential capacity to transfer to the grid. Finally, conclusions and the road ahead are drawn in Section 5.

2. Literature review

The promotion and use of EVs is considered one of the main solutions to reduce greenhouse gas and pollutant emissions. Several countries have implemented incentives and technological advancements in supporting EV penetration. More than 17 countries around the world have defined their future strategy towards 100% zero-emission vehicles by 2050 (Zheng et al., 2023). The global market for electric vehicles is growing rapidly, accelerating the technological development of electric vehicles for the transport of people and goods (Andaloro et al., 2015; Chang et al., 2023; Napoli et al., 2021). EVs are generally equipped with relatively large capacity batteries with respect to their usual use in an urban area. The average trips by cars are less than 5 km (Filippova et al., 2020). In addition, statistics show that cars spend more time parked than driving. In America, only 5% of cars are on the road, while more than 90% of private cars are parked (U. S. Department of Transportation, 2017). It has been demonstrated that unmanaged charging of massive EVs would trigger an extreme increase in electricity demand during peak hours, thus threatening the economic and secure operation of grids (Lebrouhi et al., 2021; Zheng et al., 2023). In this context, in 1997 the proposition of vehicle-to-grid was proposed (Solanke et al., 2020; Staudt et al., 2018). As mentioned above, the aim is to return the energy stored in the EV batteries to the electricity grid. Therefore, the EVs can serve as the distributed energy storage devices to provide a range of ancillary services for the power grid, e.g., frequency regulation and spinning reserve. On the other hand, the EV owners can earn a reward based on the provision of grid services, although these can be used to cover additional costs related to the grid-connection time, residual energy for further uses as well as for battery degradation. The success of such a service cannot neglect the EV users' patterns, which are based on key parameters such as travel/charging time, charging location, and required charging energy. Besides, such characteristics need to be detailed in terms of temporal, spatial, and energy usage/consumption.

According to Li et al. (2023), EV usage behaviour mainly includes travelling, parking and charging activities, and modelling EV behaviour is key to predicting charging demand and charging scheduling (Arias and Bae, 2016; Xydas et al., 2016). The charging demand of an EVs can be largely determined by the number of trips, trip distance, and energy consumption, and the availability of charging infrastructure is characterised by the parking location, permitted charging power, and the intended parking time. Therefore, predicting the location, time, frequency, and required energy of charging activities is critical for accurate charging demand prediction. EV charging behaviour can be identified from charging profiles or inferred from travelling and parking activities. All these activities indicate certain usage patterns that can be described in terms of time, location, and energy.

Temporal usage refers to the beginning and the end of the use of the vehicles at different events, e.g., parking, driving, charging with parking. Usually statistical-descriptive models are used for such a scope, and the models developed use data from direct surveys or from operational data, such as FCD.

Spatial usage modelling is important for investigating the potential involvement of EVs in V2G services. Spatial investigation refers to obtaining information on destinations, charging locations, and other socio-demographic points of interests (POIs). Typical methods for modelling the spatial activities of EVs include the origin-destination (OD) analysis, trip chain generation and extended time Markov Chain model with temporal-spatial vehicle states.

Energy usage modelling is for the prediction of EV charging demand. Without knowing the energy consumption of EVs, it is not possible to obtain accurate charging demand profiles using only temporal and spatial usage models.

The fear of battery degradation due to V2G services is one of the dominant barriers to large-scale V2G application (Zheng et al., 2022). In the V2G system, in order to satisfy the rising and falling power demands, EVs need to be charged/discharged frequently, which signifies the potential capacity fade of EV batteries (Lee et al., 2020). Hence, the economic concerns of EV users in the provision of V2G services should be pointed out in depth in order to attract the "full responsiveness" of all users (Wang et al., 2020). Other concerns, namely the privacy and security of V2G services, would also limit the widespread adoption of V2G among EV users (Bibak and Tekiner-Moğulkoç, 2021). Due to the fact that EV users are requested to report the EV information to EV aggregators for optimal scheduling, they suffer from the privacy risks of all the V2G-related data (including, but not limited to charging location, plugging/unplugging time, vehicle state and EV battery state of charge).

3. Methodology

As said, the V2G services use a set of EVs batteries to provide the aggregate capacity required by the energy grid (Terna, 2016; Wang et al., 2021; Shipman et al., 2019). This participation is based on the prediction of the available capacity to ensure that the EVs can continue to perform their daily transport function after V2G activity. Therefore, it is appropriate to infer the use of EVs to predict the current energy reserve that can eventually be transferred to the grid. Consequently, we take into account the necessary residual energy which should be left in the EVs after transfer and the pre-attack state of the grid. Therefore, the V2G system represents a new frontier that, with the increase in the number of EVs, could have a direct impact on the electricity distribution network. Thus, EVs become distributed energy storage assets and, together with other storage solutions, can contribute to grid management by providing additional capacity when necessary.

The proposed methodology, which uses the information coming from car usage activity (e.g., monitors through GPS devices), consists of the following steps (Figure 1):

- *Car trip* detection, i.e., according to some predefined rules, this stage aims to detect the activity stops performed by each sampled vehicle travelling in the study area, in particular, for the full electric vehicles; therefore, the individual trips (with OD) undertaken by resident and non-resident vehicle can be obtained. Furthermore, for each surveyed trips, the following characteristics are of interest, i.e., starting and ending time of all trips, OD locations, level of battery at each destination point, and further travels to be performed by each stop;
- *Land-use analysis* i.e., according to the study area data, the zoning is performed and the potential locations where to implement vehicle-to-grid services are identified, e.g., parking close to cinema or shopping centres, parking at workplaces;
- *V2G activity* i.e., in this step, the participation in V2G services is pointed out taking into due consideration the minimum level of battery charge that each sample vehicle needs to maintain after energy transfer to the grid; subsequently, the sample results are expanded to the network. It is useful to keep in mind that the connection of a vehicle to a V2G infrastructure can also include traditional energy transfers to the vehicle.

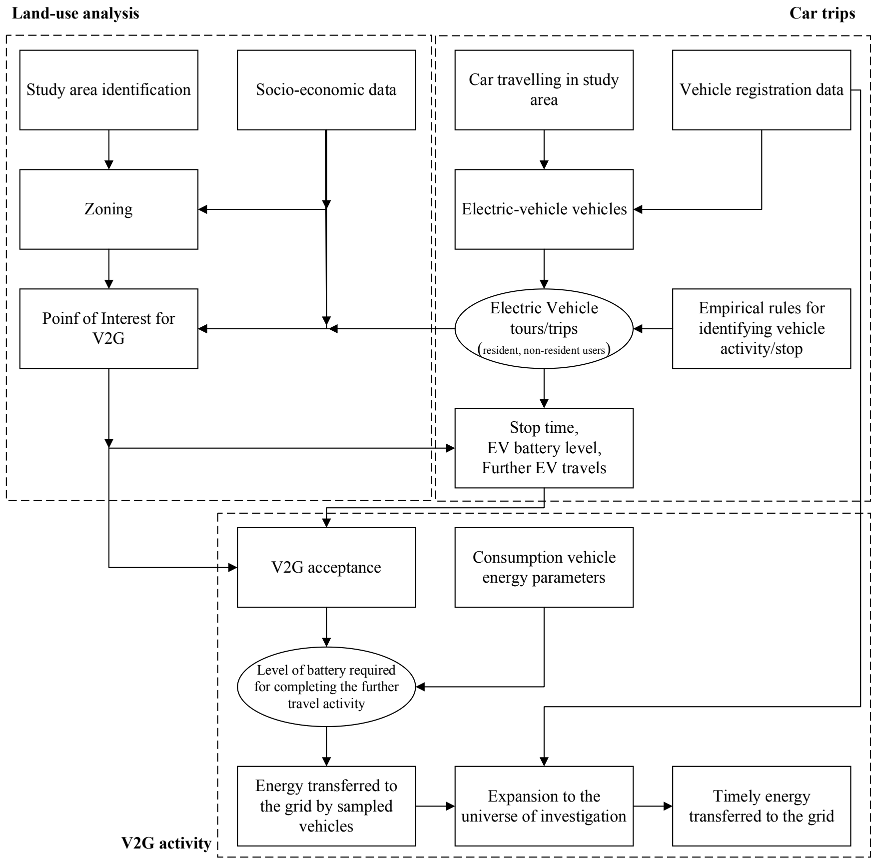


Figure 1. The proposed methodology

Moreover, it should be noted that, although the methodology is detailed for electric vehicles, due to the current penetration of such a type of vehicle, it could be of interest to use data from traditional vehicles and then implement a vehicle choice model for forecasting the transition towards electric ones. However, referring to the EVs, the Figure 2 focusses on the vehicles' movements, identifying *pre-parking*, *parking* and *post-parking* activities. For each of the three identified activities, the methodology foresees the data summarised in Figure 2, which needs to be collected in a central platform (system) for their real usage. The information flow is from the EVs to the system, while the narrows show the physical and information flow. The decision is a notification consisting of instructions for the station point (and the driver). For example, the driver can be informed on the reserve charge and the closest recharge station, or start/end charging, detected error, etc. The EVs have to share different types of information that the system needs.

According to the three EV trip stages plotted in Figure 2, five activities can be pointed out (Table 1). It presents the kind of information that could be used in the system for monitoring the vehicle activity and for obtaining data to forecast the capacity that can be transferred to the grip during parking. Such data collection can be based, for example, on information from real historical data obtained through GPS devices (e.g., FCD) about movement of the EVs.

Table 1. Example of data to be collected at each EV trip stage.

Steps	pre-parking	pre-parking to parking	parking	parking to post-parking	post-parking
Protocol №	Trip ID				
Battery level	Lvl1	Lvl1-2= Lvl1-Lvl2	Lvl2(start); Lvl2(end)	Lvl2-3= Lvl2-Lvl3	Lvl3
GPS position (longitude/latitude)	GPS	GPS	GPS	GPS	GPS
Date and time of acquisition of the step	date, time	date, the duration	date, the duration	date, the duration	date, time
Speed (km/h)		speed		speed	
Address (state-region-province-municipality-address)	address	route	address	route	address
Type of road (urban, suburban, motorway, unknown)		+		+	
Driving style (dangerous curve, braking, acceleration, exceeding speed limits)		+		+	

3.1. Car trip detection

According to the purpose of the methodology proposed and, given that V2G services are based on the spatial characterisation of trips made by grouping them by place (zone) of destination, the first stage is to identify such places. In this context, a trip is defined as the act of moving from one place to another (OD) in order to carry out one or more activities. Due to penetration of telematics, the traditional methods for revealing car trips can be replaced by FCD, which allow vehicles to be traced continuously in time and spaces (Comi et al., 2021). Referring to the prober vehicle datum, the vehicle location (GPS coordinates and time) and its status (stopping or travelling) can be revealed. With two consecutive data from a given vehicle, significant changes in vehicle position can be detected according to the relevant status, and the origin and destination of a trip can be identified. A sequence of trips, following each other in such a way that the destination of one trip coincides with the origin of the next, is referred to as a journey or trip chain (Cascetta, 2009). Therefore, from the fine-grained FCD, the activity stops need to be identified, and referring to the EVs, the level of battery and the further usual activities performed after each stop can be forecasted.

The procedure proposed is based on the speed and engine status of a vehicle measured minutely. The procedure (Figure 1) evaluates these measures to determine whether the vehicle has completely stopped or is moving at a very low speed. The most significant source of errors in classifying stopping events from vehicle data are observations wherein the vehicle has stopped at a bottleneck, but when evaluating its speed, it appears to be parked. By evaluating both speed during the previous time interval, as well as the GPS data and engine status, the procedure ensures that only activity stops (e.g., longer than a pre-fixed threshold and far from while-travel intermediate/service sites, such as petrol stations) are classified as such in the result.

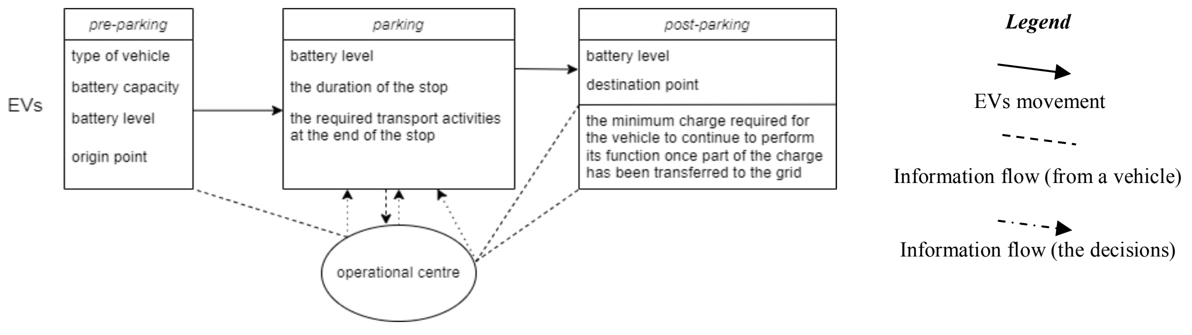


Figure 2. The EV trip stages.

3.2. Land use analysis

Once the trips belonging to a trip chain have been identified, the next step is the spatial characterisation of trips made by grouping them by place (transport zone) of origin and destination. Linking the land use data with the stopping place of vehicles, the potential point of interest for V2G services can be identified. This information (demand flows) can be arranged in vector as destination flows, whose entries correspond to the different zones (or better, Point of Interest – PoI) where the vehicle stopped for performing an activity longer than a given threshold (e.g., 20 minutes).

Besides, the PoI flows obtained can be characterised for time slice *h* (selecting only trips belonging to a given time slice *h*), vehicle type (selecting only trips belonging undertaken by a given vehicle type), stop time and so on.

3.3. V2G activity

Once the sample PoI flows for different survey days or times are determined, current PoI flows can be estimated starting from these results. Knowledge of sampling units (vehicles) and the method for enumerating the population universe (e.g., lists of registered vehicles in a traffic zone or counts of passing vehicles) are then required. This represents one of the main issues in adopting such FCD data for travel demand forecasting (Cascetta, 2009; Comi et al., 2021). Indeed, the issue of estimating trip flows depends on the sampling strategies used, and it is also important to investigate sample representativeness both in terms of trip production and attraction. For more details on the procedures, the pros and cons in performing such an operations, the readers can refer to Cascetta (2009), Ortúzar S. and Willumsen (2011) and Comi et al. (2021).

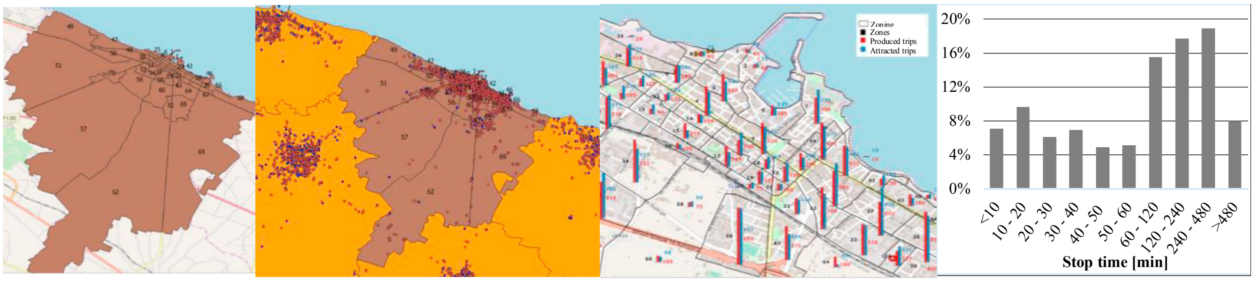
4. Application to a real test case

In particular, the preliminary applications of the proposed methodology in Trani, a town in the Apulia Region (southern Italy) refer to the first stage of the proposed methodology. Trani is a city of about 55,000 inhabitants located on the Adriatic coast and is constituted by three main areas (Figure 3a): the ancient core (9 zones), the medieval area (18 zones), and the modern area (33 zones). Due to non-high rate of penetration of EVs, the FCD relative to a sample of (both electric and traditional) vehicles was used. The data refer to four full days and monitored the fully activities performed by a sample of vehicles driving, at least, in one road network link of the study.

The collected data provide information on car trips in the study area from the first to the last trip of the whole day (i.e., at least one point inside the study area on the survey days). The available data relies with the trips of private cars (e.g., without considering taxi and other service vehicles) and they were analysed to identify the trip patterns (Figure 2). Four working-day FCD (collected in November 2018) for a total of 5,255 sampled trips were available. Each entry in the database contains the vehicle identifier (an ID), the date (the date when the record has been gathered), the timestamp (the time when the record has been gathered), the geographical location (latitude and longitude), the speed, the type of road (e.g., urban, extra-urban, highway), the direction angle (the angle with respect to the north). Besides, the registration data related to each sampled vehicle were extracted by national vehicle registration dataset: vehicle class (e.g., small, sport utility vehicle), brand, vehicle registration year, fuel type (e.g., electric/petrol/ diesel).

As shown in the Figure 1, it is of interest to identify the trips performed by residents, given that the use of V2G services could refer mainly to systematic trips. Such a category of users is identified considering the registration of vehicle's owner as well as if daily user starts and ends his/her trip from the same location. Having consolidated the procedure for identifying the residential area, the next step was the characterisation of travel into round trips and trip chain. In fact, it becomes significant for identifying the further activity performed by vehicles after stopping. A round trip is a sequence, made up of two movements, which starts and ends in the residential area. A trip-chain, on the other hand, is a sequence of more than two trips. It also starts and ends in the resident area. It was obtained that the 60.4% are round trips, while 39.6% are trip chains.

Both for round trips and trip-chain, it was possible to characterise the activity performed. For example, the 87.6% of round trips are shorter than 3 kms with the stop time reported in Figure 3d. Figure 3c also plots attracted and produced trips according to the zoning of Figure 3a. According to this preliminary results of the investigation of FCD for characterising the car flows, the next step is the implementation of a vehicle type choice model in order to identify which is the potential shift towards electric vehicles and to identify the travel demand by EVs(Buhmann and Criado, 2023; Buranelli De Oliveira et al., 2022; Dong et al., 2020; Donkers et al., 2020; Jin et al., 2020). Furthermore, the analysis of land use for the identification of PoIs as well as for inferring the V2G activity including the propensity to become V2G users are under development (Liu et al., 2021; Salari, 2022; Shipman et al., 2019; Wang et al., 2021).



a) b) c) d)

Figure 3. The proposed methodology a) zoning; b) trip origin and destination; c) attracted and produced trips; d) stop-time distribution of car trips in the study area.

5. Conclusions

The paper presented recent developments in the methodology for forecasting the potential energy to be transferred to the grid through V2G services. In particular, the opportunity to exploit FCD is pointed out.

The paper was organized into two main parts. The first part gave an overview of the methodology and recalled the recent studies on V2G. The second part presented some preliminary results obtained by implementing the proposed methodology on a sample of private vehicles operating in a city in the southern Italy. The methodology is structured into three levels: car trip detection, land use analysis and V2G activity. The car trip detection focuses on the car trip identification procedure, which was implemented in order to obtain the trips, and hence trip chains, for each vehicle surveyed as well as the location of stops and their duration. The land use analysis allows us to identify the potential point of interest where there is a large number of vehicles stopped for a significant time in relation to V2G requirements. Finally, the V2G activity points out the availability to become "*energy producers*" and to forecast the energy that can be transferred to the grid. The further analysis are ongoing for the modelling: vehicle type choice (i.e., traditional versus electric), numerical analysis of the contribution in terms of energy capacity that can be transferred to the geographical area under study, energy consumption for travelling according to the driving characteristics that can be identified through the FCD, the choice to become V2G users.

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