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RESEARCH ARTICLE

A Quantitative Method to Assess the Vehicle-To-Grid Feasibility of a Local Public Transport Company

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ABSTRACT In this paper, a quantitative model is implemented with the main goal of building a decision support tool to assess the feasibility of applying a Vehicle-To-Grid (V2G) service by a company operating a fleet of electric buses. The proposed model can calculate the energy that a vehicle within a depot can deliver back to the grid during periods of peak energy demand, based on the operational schedule that must be guaranteed (number of buses in service). After a presentation of the main features of V2G and the main benefits this technology can bring to the transportation company, the model structure, and related algorithms, as well as input and output data, are presented and discussed. To verify the effectiveness and validity of the proposed model, a case study related to the company that manages public transportation in the city of Milan, Italy, is described. 2 depots were analyzed considering the energy load during peak hours and the energy that could be injected into the grid considering the vehicles parked in the depot. From a quantitative point of view, V2G could feed about 7 MW to 10 MW into the grid, depending on the day of the week and time of day. Considering an average connection of 3 kW for a household, between 2,300 and 3,300 households could be served. In addition, an economic evaluation was performed considering energy trading: monthly, total revenues are 45,922 € and total costs are 42,848 €; the economic benefit can be estimated at about 6.7% of total monthly revenues.

INDEX TERMS Public transport management, transport planning, vehicle-to-grid, sustainable transportation, charging strategies, smart grid.

I. INTRODUCTION

Transport systems for the mobility of people and goods can be considered essential elements for the economic growth and welfare of a country and for the quality of life of a community especially in urban areas. Transportation, or rather mobility, is today part of social cohesion and demographic development of a territory. People move for different reasons: from work to study to entertainment.

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The use of vehicles that produce pollutants can also cause damage to human health over time, thus imposing costs that will have to be sustained by the community. This implies that the vehicle user at the time of choice does not consider the possible effects on those who suffer health damage.

With reference to environmental impact, carbon dioxide emissions from road, air, and maritime transport account for 74%, 12% and 12% respectively. Today more than ever, decarbonization policies for the transport sector offer an important opportunity to combine climate and environmental protection, while ensuring the economic and social balance of different countries [1], [2], [3], [4].

Hence the need to seek the planning, design and adoption of sustainable transport and mobility systems as a global and no longer optionable goal. This goal has been consolidated as the sensitivity and attention of the political world towards the environment have increased in recent decades; the European Council has approved the goal of becoming climate neutral by 2050 and reducing greenhouse gas emissions by at least 55% by 2030 [5], [6].

The European Commission is developing strategic plans and programs under Climate Neutral and Smart Cities to achieve decarbonization goals by 2030 in many European countries. These programs incentivize public transport and to the use of mass transit, walking and cycling, and automated, connected, and multimodal mobility [7]. As mentioned above, planning and designing the various transportation systems and, more generally, the mobility of people and goods in an area, requires a strong attention to the issue of sustainability; decarbonization policies provide an important incentive in the use of Electric Vehicles (EVs) that have at least two advantages: i) local emissions almost zero (as well as noise), ii) possibility to store energy to be reused at specific times as needed.

One possible solution to carbon emissions, the fossil fuel crisis and climate change concerns the adoption of EVs [8]; these vehicles, compared to traditional Internal Combustion Engine Vehicles (ICEVs), feature zero carbon emissions, high operating efficiency, lower maintenance costs and reduced noise [9]. Thanks in part to policy strategies and incentives and technological advances, the electric vehicle industry is expected to experience growth in the coming years [10]. In addition to the spread of EVs, there is also an increase related to the installation of charging infrastructure, which can be slow, fast, or ultrafast charging also depending on the specific needs of the user [11]. Fig. 1 shows the increasing trend of electric vehicles over the period 2010 - 2021 for the EU-27 context. It also shows that the percentage of new electric vehicles in 2021 reached about 18 percent of the total.

Regarding private transportation (cars), it is important to consider that in many cases vehicles spend much of the day stationary (e.g., after a destination has been reached); in these cases, vehicles can be used as virtual power plants by supplying electricity from (stationary) vehicles to homes and/or grids and vice versa. In this way the system is flexible, efficient and balanced [12], [13], [14]. Virtual power plants also called cloud-based distributed power plants can i) connect energy generation and storage units in a complex power plant and ii) manage energy control. Distributed energy sources and the integration of EVs into virtual power plants can certainly contribute to the operation of the system.

As for electric buses, European cities are increasingly purchasing this type of vehicle. Fig. 2 shows the increasing number of electric buses in the period 2015 - 2021 and a percentage of the total.

Vehicle-to-Grid (V2G) plays an important role in this perspective: EVs, when not in use for the transport of people or goods, can be used as distributed energy resources in an area to provide electricity to the grid when needed. This situation occurs, for example, during peak periods of the day when the electric grid is heavily stressed, and the vehicle's battery can be connected to the grid providing an energy contribution. From a technical point of view, the V2G operating logic is based on a simple concept: since car batteries do not have a high capacity, it is necessary to use many vehicles at the same time to introduce into the grid the electricity needed to meet user demand. This also could improve the resilience and reliability of the electricity system.

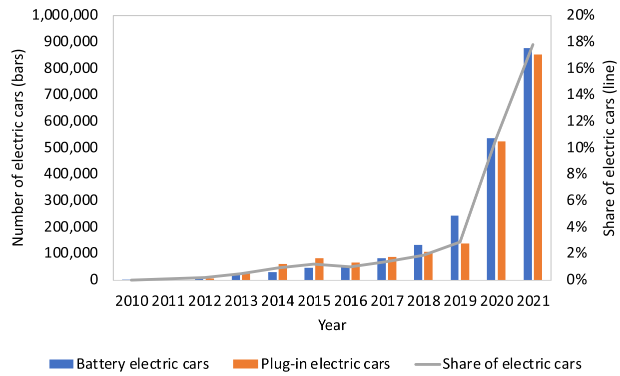


FIGURE 1. New registrations of electric cars in the period 2010-2021, EU-27, adapted from [15].

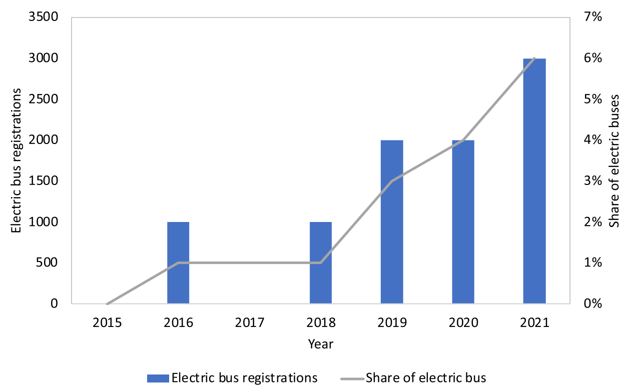


FIGURE 2. Electric bus registrations and sales shares, EU-27, adapted from [16].

Following a systems approach, it is necessary to analyze which vehicles may be able to contribute to V2G. In addition to passenger cars, it is possible to consider buses used for public transport characterized by a higher battery capacity. These vehicles, in fact, can be used for V2G when they do not provide passenger service and are parked in depots or stations (terminals).

In the city of Milan in Italy, the public company that manages collective transport (buses, tramways, and subways) implemented the Milano Full Electric project in 2017; the idea is to have a fully electric public transport service by 2030. This goal includes the gradual replacement of current diesel-powered buses with electric vehicles by promoting and incentivizing sustainable mobility in urban areas. The project also provides for the renewal of the depots by renovating the existing ones and building new facilities and technologically advanced systems that allow the recharging of vehicles in service.

The goal of this work is to implement a decision support tool to assess the feasibility of applying a V2G service from a company that operates a fleet of buses. The model can calculate the energy that a vehicle within a depot can return to the grid during periods of peak energy demand, based on the operating schedule that needs to be guaranteed. The case study refers to the city of Milan (Italy). This has been done using the timesheet of buses during the daily service: this data framework also contains useful information for our analysis, like the travelled distance and the consumption of buses according to the considered month. Fig. 3 shows the framework of the research.

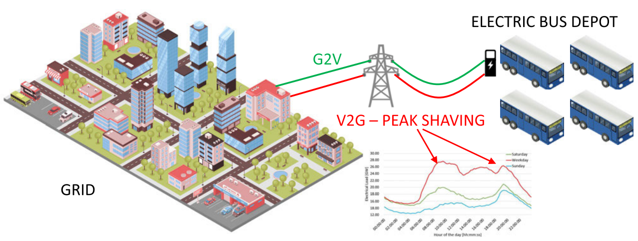


FIGURE 3. Framework of the research.

The paper is organized as follows: the second section is dedicated to the literature review related to electric vehicles, V2G and their relationship with renewable energy sources, the third section highlights the main gap between the literature review and the present paper, the fourth section contains the description of the analytical model, in the fifth section it is presented the case study in Italy with 2 bus depots managed by LPT company, while the sixth and the seventh sections respectively contain the analysis and discussion of the results and the conclusions with further developments of the work.

II. LITERATURE REVIEW

Between now and 2050 we will be traveling on electrified vehicles using only sustainable energy, one of the most important issues to be addressed will be that of the "conservation" of the energy itself. Especially solar energy, which is already emerging as one of the most valuable renewable resources. While widely available, in fact, solar energy has a limitation: it accumulates during daylight hours, but it must be able to be harnessed at night, when most vehicles will be at rest and under charge for the following day. In an increasingly electric ecosystem, that means having to store the overproduction of energy during off-demand hours and make it available again when needed. And the solution could come from the cars themselves. Vehicle-To-Grid (V2G) technology is, according to some manufacturers who are already experimenting with it, a possible answer to the potential problems of energy imbalance and even grid stress that an electrified world is likely to face [17], [18], [19]. Indeed, it is proposed to use the batteries of the cars themselves as reservoirs in which to store energy that can then be partly returned to the grid in times of need, precisely. Reducing the need to equip power plants with expensive and complex storage facilities, and thus the need for additional batteries that might be insufficient anyway [20], [21]. But also, by avoiding sending the grid into crisis by feeding in too much energy or limiting its production. The basic element of the V2G process is bidirectional charging, that is, the one that allows car charging systems not only to absorb energy but also to release it, allowing cars to be connected to the smart management systems of modern homes equipped with their own systems, representing "in a small way" the prototype of the shared electric ecosystem theorized by manufacturers and energy providers [20], [21], [22]. The idea stems from the observation that most cars on average stay parked and stationary for more than 90 % of the time, or more than 20 hours a day, and those that travel on urban routes usually consume just 10 % of their energy reserve [22], [23]. Thus, those who would charge the car during quieter hours could theoretically surrender some of the energy at times of higher demand [24], [25]. In addition to contributing to grid stability and better utilization of energy, it would then also gain a potential economic benefit by surrendering it during the times of day when energy costs are highest [26].

The bidirectional link between Electric Vehicles (EVs) and the power grid provides the adjustable, economic, and fast-responding V2G applications [27] and reduces the long-term cost of electricity supply [28]. However, the large-scale V2G introduces stochastic effects on the power grid, range anxiety, cost benefits, or EVs battery degradation, which prevents the fast expansion of V2G [29], [30], [31]. Thus, various studies investigated different issues associated with V2G and proposed state-of-the-art solutions to revamp the integration of this new technology worldwide.

Reference [32] proposed the new optimization solution for purchasing energy from the small grid, equipped with solar Photovoltaic (PV), battery storage system, and electric vehicle charging stations, through the multi objective Mixed Integer Liner Programming (MILP) to find the optimal scheduling solution for maximizing the cost-benefit. The study in [31] found out the net incomes of the V2G are more significant than zero in V2G peak shaving services, while the peak electricity price, which fed into the power grid, is more than three times compared to the valley price of peak shaving. A stochastic optimization model and a battery model are developed in [33] to schedule the operation of PEV - considering the charging/discharging capacity of V2G, solar power, the arrival and departure time of vehicles, and real-time electricity price to improve the revenues in carbon and energy markets.

The power loss and voltage drop are studied in [34] to locate the optimal charging station locations by applying Grey Wolf Optimization (GWO) and Whale Optimization Algorithm (WOA) and keep the power loss minimum and voltage profile standard. In addition, [35] studied the frequency regulation and presented an effective strategy to optimize the economic benefits of aggregator and regulate the power allocation module to bypass over-discharging of EVs taking into account EV driving demand and battery SOC of 10 EVs with different battery capacities of 35 kWh, 24 kWh and 16 kWh.

Reference [36] presented a new model, based on the backward-forward algorithm, to explore the effect of the power exchange between EVs and the grid on the power demand profile and deduced that V2G increases the stability and reliability of the power grid performance while low charging power can transit the demand to the off-peak hours. The Nelder-Mead heuristic mathematical algorithm is used in [28] to find the optimal number of V2G stations constrained to the operation cost reduction, considering EVs battery size, charging stations capacity, EVs arrival and departure rates, dispatching limitations and interest rates, and their uncertainties. On the other hand, some studies such as [37] and [36] tried to implement machine learning methods so improve the grid efficiency based on the accurate prediction of V2G capacity. The proposed data framework in [37], with low prediction error, lowered the load peak by 31.3% and 58% compared to the random charging scenarios. The Model Predictive Control (MPC) mechanism by using an online and offline supervised learning method is presented in [38] to predict the energy consumption of the EV to determine the required energy demand for the V2G service.

In [39], a MILP algorithm is used to optimize the charging EVs with PV power production while increasing the V2G revenues. The Dynamic Tariff Subsidy (DTS) is proposed in [40] to solve the congestion issue of power flow of PVs and EVs in V2G mode. Reference [41] investigated the viability of the EVs integration into the existing distribution system without augmentation regarding slow- and fast-charging stations. This study utilized a backward–forward sweep based optimal load flow approach. It concluded that the maximum penetration of EVs in the current distribution network is 80%, with a slow charging rate, considering the reduction of the charging price.

In the presence of Renewable Energy Sources (RESs), the degradation cost of EVs batteries is optimized by a proposed model in [42] to guarantee active participation in the V2G market. Furthermore, the long-term effect of battery aging of commercial EVs in V2G services for five years illustrated that battery capacity of 23 kWh decreased on average to 20.7 kWh after two and 19.9 kWh after five years for delivering power to a grid for 15 hours per day [43]. The anti-aging scheduling mechanism is presented in [44] based on the Rain-flow Cycle Counting (RCC) algorithm, multi-objective optimization model, and a developed multi-population collaborative scheme to minimize the battery degradation and the grid load fluctuations. In V2G mode, charge-discharge of EV battery is optimized by [45] to decrease the battery degradation assessing predicted battery life, a day ahead electricity price, and frequency regulation signals.

III. SUMMARY OF THE LITERATURE REVIEW AND FRAMING OF THE RESEARCH

Given the growth and spread of electric vehicles, V2G technology will also have a role beyond ensuring the mobility of people and goods; energy re-injected into the grid can be used by local distribution companies, while vehicle batteries can be used to storage it, helping distributors stabilize the grid. In addition to managing the energy supply at peak times and contributing to the decarbonization of the electricity system, this technology will also be able to generate financial benefits for vehicle owners (e.g., fleets) and grid distributors, while providing a significant benefit to the environment. The use of V2G technology will require strong compliance and behavioral changes on the part of vehicle owners (e.g., light and/or heavy duty) on the one hand, and digitization of electric grids (smart grids), and greater collaboration among the various stakeholders on the other. In this transitional period, V2G will help to identify feasible solutions that can provide benefits for vehicle owners and operators, especially at a time in history characterized by rising prices and energy scarcity from a growing number of EVs. For this reason, this paper contributes to developing a quantitative model to support a Local Public Transport (LPT) company interested in evaluating the feasibility of a V2G service. Fig. 4 represents the flow-chart of the proposed approach.

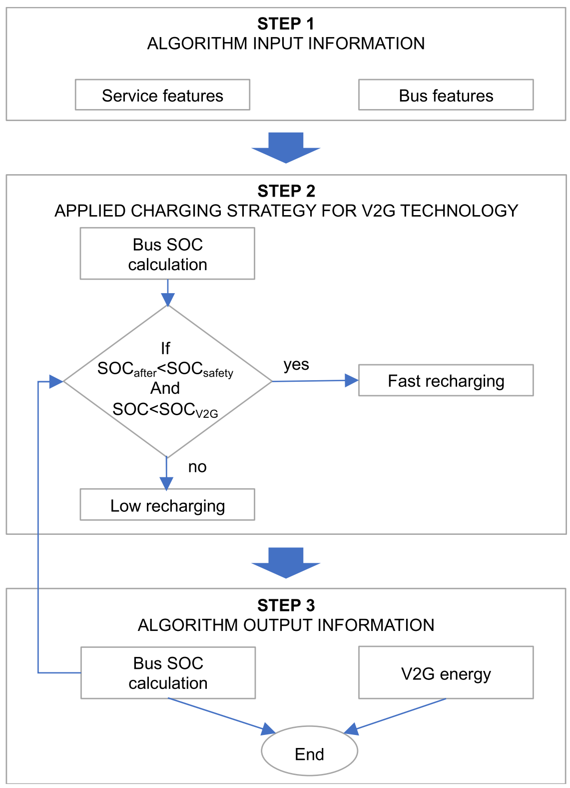


FIGURE 4. Flow-chart of the V2G proposed model.

IV. V2G QUANTITATIVE MODEL

The proposed model aims to evaluate the possibility of providing V2G services using electric vehicles. This is a technology that can benefit the stability of the electric grid and the economics of a company. The purpose of the model is to provide an analytical method that is scalable and applicable to any case study, whether for a fleet of cars or an entire transportation system. The final output of the model provides the result in terms of the number of V2G vehicles used and the relative energy that the vehicles considered can supply to the grid based on various constraints, such as the hours of service and utilization of the vehicle, the charging and discharging power of the available facilities, and the needs of the power grid relative to the energy demand curve. With reference to Fig. 4, the 3 steps of the proposed model are described below.

A. STEP 1: ALGORITHM INPUT INFORMATION

The model takes as first inputs a data frame containing the time schedule of the trips performed by the vehicles of the fleet and the distance travelled between the exit and return time from the depot:

- Exit time [hh:mm:ss]
- Return time [hh:mm:ss]
- Travelled distance [km]

Three more data are needed, in this case inherent to the characteristics of the vehicle under consideration:

- Consumption [kWh/km]
- Battery capacity [kWh]
- SoC threshold – SOC_{safety}[%]

The vehicle battery SoC should never exceed the identified threshold set to limit battery pack degradation. Higher or lower values can be set to adopt a behavior that will safeguard the health of the battery or make more use of its capacity.

A sensitivity analysis is performed with the aim of assessing the influence of these parameters on the results: in addition to the obvious influence of battery capacity and lower threshold, it is interesting to repeat the procedure using different consumption values, corresponding to different times of the year, since it is known that the operating temperature strongly influences battery performance. Moreover, due to the presence of the air heating and cooling systems during cold and hot days, the vehicle's consumption is quite high compared to the periods when the temperature is warm, thus not requiring the air conditioner to be turned on.

The model then calculates the battery SoC at the end of the trip using the Eq. (1):

$$SoC_{after} = \frac{\textit{Battery Capacity}\,[\text{kWh}] - \textit{Energy Used}\,[\text{kWh}]}{\textit{Battery Capacity}\,[\text{kWh}]} \times 100 \tag{1}$$

At the end of the journey, it may be the case that the battery's SoC is below the threshold set by the user, but the battery should operate within an optimal SoC range to take full advantage of its characteristics and maximize its lifespan. Vehicle-To-Grid services, for this reason, are intended only for vehicles that return to the depot with an SoC above this threshold and can therefore be discharged until this point is reached; thereafter, the vehicle must be recharged to be used to perform the service again. For vehicles that end their journey with a SoC below the lower threshold (SoC_{safety}), a recharging stop must be made, as it is not acceptable for the battery level to fall below the "safe" limit. Opportunity charging refers to a charging phase in which the vehicle stops at a high-powered charging station (this can be a charging station or even a pantograph, for large vehicles such as buses) and charges its battery to a level that allows it to complete the journey. Opportunity charging can also be used for vehicles that have an SoC above the safe threshold but have a value that is not high enough to perform V2G services. The only constraint that vehicles must meet to send power to the grid during peak load periods is to have a post-trip SoC above the safety threshold. When energy is not required by vehicles (thus outside the V2G window), we are in a phase of the day when energy is cheapest and when the load curve is not peaking.

This energy can be stored in vehicle batteries when it is cheapest and sold to grid operators later, during the peak hours of energy demand, when the price of energy is highest, and this is an advantage for both the grid and the utilities. To achieve this, it is necessary to define another threshold, higher than the first, set only to safeguard the health of the battery (SoC_{V2G}). The vehicle must return to the depot with a SoC at least equal to this threshold if the purpose is to provide V2G services, and in this case the battery is discharged during the V2G phase up to the first threshold (SoC_{safety}). This rapid charging strategy is designed only for vehicles that are on the road during periods close to the V2G window; for vehicles that return to storage long before the onset of the peak load curve, it makes more sense to charge the battery until SoC_{V2G} is reached using the standard low/medium power station, which is cheaper and less stressful on the grid and the battery. Therefore, two different charging powers are requested from the company as inputs in the model: High-power charging [kW] and Low/medium power charging [kW].

B. STEP 2: APPLIED CHARGING STRATEGY FOR V2G TECHNOLOGY

The first part of the algorithm calculates when the vehicle is available to provide V2G-type services after the adopted charging strategy. The decision between fast or slow charging is made under certain constraints, and it depends on the beginning and end of the time window established to be able to perform V2G, which directly depends on the energy demand curve, as described above. The time is asked as an input to the company, who will analyze the load curve of the day and decide when to start and to end the V2G window: V2G start time [hh:mm:ss] and V2G end time [hh:mm:ss]. At this point, the type of charging strategy is implied based on certain constraints. Specifically, the threshold is chosen by the LPT company: if SoC_{V2G} is present, then it means the company wants to apply V2G technology, otherwise SoC_{safety} is chosen (in this case the company adopts a strategy to preserve battery health); this process is shown in Algorithm 1.

Algorithm 1 Application Threshold

if SoC_{V2G} is present **then**
  $SoC_{des} = SoC_{V2G}$
else
  $SoC_{des} = SoC_{safety}$
end if

At this point, defined the threshold, the charging strategy, represented by Algorithm 2, is implemented. In this case, the algorithm calculates the time when the vehicle is ready to provide V2G services, identified with the variable V2Gready; and calculates the SoC, preferring AC charging. If the SoC of the battery at the end of the trip is less than the threshold (SoC_{safety}, always present and SoC_{V2G} set for V2G service, if present), and if the vehicle ends the trip before the V2G window begins, then the vehicle must be recharged. The first choice is indicated through low-power charging where at best the battery can be fully charged: $SoC = 100\%$ and can be discharged later during the peak period of the charging curve. If the battery cannot be fully charged before the V2G window begins, the charging phase ends when SoC_{V2G} is reached, and this is achieved by using, again, the low-power charging station. If the battery cannot be charged up to the SoC_{V2G} in time, in this case it is necessary to stop along the way and perform DC fast charging to return to the station in storage with the required SoC.

In the worst case, the desired SoC cannot be reached before the start of V2G even with fast charging: in this case, the vehicle is charged until the start of the V2G window. The main constraint is to avoid charging the vehicle during the V2G time window because the network is stressed at this stage of the day. For this reason, the vehicle can be recharged during V2G only if without a recharge the SoC falls below the safe threshold thus going to the detriment of battery health. Finally, in case the SoC after the trip is above the threshold, the V2Gready time is equal to the return time. It is worth noting that although the purpose is to event V2G, the travel time schedule must always be respected, since the primary requirements to ensure service. At the end of this first part, the model provides the $V2G_{ready}$ time of the vehicle and its SoC according to the constraints introduced.

The second part of the charging strategy deals with vehicles that may have an SoC above the defined threshold and thus could be fully charged obviously before the start of V2G, using a slow charging station (Algorithm 3).

At this point, the SoC of the vehicle at the beginning of the time window for V2G technology application and time are available. The vehicle can then discharge the battery until it reaches the SoC_{safety} during the time interval defined to perform V2G it is then possible to calculate the energy that the vehicle can send to the grid. The only constraint in this case is the time at which the V2G window ends: the vehicle stops sending energy to the grid when the V2G window is over.

Algorithm 2 Charging Strategy (First Part)

if $SoC_{after} < SoC_{des}$ **then**
  if Return Time $< V2G_{start}$ **then**
    $\text{ReadyTime}_{HP} = \text{Return Time} + \frac{\frac{(SoC_{des}-SoC_{after})C_{batt}}{100}}{HP_{charg}}60$
    $\text{ReadyTime}_{LP} = \text{Return Time} + \frac{\frac{(SoC_{des}-SoC_{after})C_{batt}}{100}}{LP_{charg}}60$
    $\text{ReadyTime}_{Full} = \text{ReturnTime} + \frac{\frac{(100-SoC_{after})C_{batt}}{100}}{HP_{charg}}60$
    if $\text{ReadyTime}_{Full} < V2G_{start}$ **then**
    $\text{ReadyTime}_{Ch} = \text{ReadyTime}_{Full}$
    $V2G_{ready} = V2G_{start}$
    $SoC_{after} = 100$
    Charging = LowPower
  else if $\text{ReadyT ime}_{LP} <$ V2Gstart **then**
    $\text{ReadyTime}_{Ch} = \text{ReadyTime}_{LP}$
    $V2G_{ready} = V2G_{start}$
    $SoC_{after} = SoC_{des}$
    Charging = LowPower
  else if $\text{ReadyTime}_{HP} < V2G_{start}$ **then**
    $\text{ReadyTime}_{Ch} = \text{ReadyTime}_{HP}$
    $V2G_{ready} = V2G_{start}$
    $SoC_{after} = SoC_{des}$
    Charging = HighPower
  else
    $\text{ReadyTime}_{Ch} = V2G_{start}$
    $V2G_{ready} = V2G_{start}$
    $SoC_{after} = SoC_{des} - \frac{\frac{(ReadyTime_{HP}-V2G_{start})}{60}HP_{charg}}{BatteryCapacity}$
    Charging = HighPower
    if $SoC_{after} < SoC_{safety}$ **then**
    $\text{ReadyTime}_{Ch} = \text{ReturnTime} + \frac{\frac{(SoC_{safety}-SoC_{after})C_{batt}}{100}}{HP_{charg}}60$
    $SoC_{after} = SoC_{safety}$
    $V2G_{ready}$ = No
  else
    $\text{ReadyTime}_{Ch} = V2G_{start}$
    $V2G_{ready} = V2G_{start}$
   end if
  end if
else
  if $SoC_{after} < SoC_{safety}$ **then**
    $\text{ReadyTime}_{Ch} = \text{ReturnTime} + \frac{\frac{(SoC_{safety}-SoC_{after})C_{batt}}{100}}{HP_{charg}}60$
    $V2G_{ready}$ = No
    $SoC_{after} = SoC_{safety}$
    Charging = HighPower
  else
    ReadyTime_{Ch} = ReturnTime
    $V2G_{ready}$ = ReturnTime
    Charging = No
   end if
  end if
end if

The last part of the algorithm identified with the number 4 then calculates the SoC at the end of V2G, which can be equal to SoC_{safety} or a higher value.

Algorithm 3 Charging Strategy (Second Part)

if $\mathrm{SoC_{after}} > \mathrm{SoC_{des}}$ **then**
  if Return Time $< \mathrm{V2G_{start}}$ **then**
    $\mathrm{ReadyTime_{Full}} = \mathrm{ReturnTime} + \frac{\frac{(100-SoC_{after})C_{batt}}{100}}{LP_{charg}}60$
    if $\mathrm{ReadyTime_{Full}} < \mathrm{V2G_{start}}$ **then**
      $\mathrm{SoC_{after}} = 100$
      $\mathrm{ReturnTime_{Ch}} = \mathrm{ReadyTime_{Full}}$
      $\mathrm{V2G_{ready}} = \mathrm{V2G_{start}}$
      Charging = LowPower
    else
      $\mathrm{SoC_{after}} = \frac{V2Gstart-ReturnTime}{60}LPcharg + \mathrm{SoC_{after}}$
      $\mathrm{ReturnTime_{Ch}} = \mathrm{V2G_{start}}$
      Charging = LowPower
  end if
else
      $\mathrm{V2G_{ready}} = \mathrm{ReturnTime}$
      Charging = No
  end if
end if

Algorithm 4 Charging Strategy (Third Part)

if $\frac{\frac{(SoC_{after}-SoC_{safety})C_{batt}}{100}}{V2G_{power}}60 + \mathrm{V2G_{ready}} > \mathrm{V2G_{end}}$ **then**
  $\mathrm{SoC_{endV2G}} = \frac{SoCafter-\frac{(V2G_{end}-V2G_{ready})V2G_{power}}{60C_{batt}}}{100}$
else
  $\mathrm{SoC_{endV2G}} = \mathrm{SoC_{safety}}$
end if

However, it may be the case that the TPL company needs the vehicle for a trip that occurs after the time window identified to perform V2G, and in this case Algorithm 5 is tasked with ensuring that the SoC after the "offload" phase can complete the trip thus guaranteeing service. The company is then asked for the distance to be traveled during this second trip and the start time of the trip, allowing the algorithm to calculate the level of SoC needed to guarantee the trip.

Algorithm 5 Charging Strategy (Last Part)

if SecondDuty is present **then**
  if 2ndDutyStart > V2Gend **then**
    $\mathrm{SoC_{endV2G}} = \mathrm{SoC_{safety}} + \frac{Distance2ndxConsumption-(2ndDutyStart-V2G_{end})LP_{charg}}{Cbatt}$
  else
    $\mathrm{SoC_{endV2G}} = \mathrm{SoC_{safety}} + \frac{Distance2ndxConsumption}{Cbatt}$
  end if
end if

The SoC at the end of the V2G application time window is therefore dependent on the start time of its second trip: if this trip starts before the end of V2G, the battery cannot be charged, and the algorithm must ensure that the vehicle's SoC is sufficient to allow it to complete the second trip. On the other hand, if some time elapses between the end of the V2G window and the start of the second trip, the vehicle can be charged (at the depot, thus at low power) until the driver must leave to start the service. This algorithm then calculates the SoC of the vehicle at the end of V2G based on the needs of the transportation company.

C. STEP 3: ALGORITHM OUTPUT INFORMATION

Once the V2G window is entered and the charging strategy (low or high power) is decided, the model calculates the SoC of the vehicles at the end of the V2G interval. At this point, it is possible to know the energy that the vehicle can send to the grid to provide peak shaving service: it is calculated using the $\mathrm{SoC_{after}}$, i.e., the SoC after the completion of the first trip (before the start of V2G) and the $\mathrm{SoC_{endV2G}}$, i.e., the SoC after the end of the V2G application by the Eq. (2):

$$E_{V2G} = \frac{SOC_{after} - SOC_{endV2G}}{100} \times C_{battery} \tag{2}$$

Table 1 provides the list of inputs and the output of the proposed model. The output is provided in form of table with each row that represent the vehicles and beside the relevant information.

TABLE 1. Input and output parameters of the proposed model.

Input	Output
Buses exit time Buses return time Travelled distance [km] Consumption [kWh/km] Battery capacity [kWh] SoC safety threshold [%] High power charging [kW] Low power charging [kW] V2G start time V2G end time SoC V2G threshold [%] Duty after V2G start time Duty after V2G distance [km]	$(SOC_{after} - SOC_{endV2G})$: SoC after V2G E_{V2G} – Energy sent to the grid

V. CASE STUDY: LPT COMPANY DEPOTS

To verify the validity and consistency of the proposed model, a case study was implemented. The case study regards the implementation of the V2G services in the two bus depots in the city of Milan (Italy) managed by LPT company: DEPOT_1 and DEPOT_2. LPT Company - Azienda Trasporti Milanesi is the public company that manages collective transport in the city of Milan. The total length of the bus network in Milan is estimated at about 870 km. The number of buses operated is 1,150 of which 925 buses (80%) are 12 meters long, while 225 buses (20%) are 18 meters long.

The 12-meter-long buses have a capacity of about 25 seated passengers and 75 standing passengers, while the 18-meter long buses have a capacity of 30 seated passengers and about 120 standing passengers.

The buses are characterized by different types of power supply: 974 (85%) are diesel, 149 (13%) are hybrid, and only 27 (2%) are electric with an average life of about 11 years, just over one year and almost 2 years respectively. The analysis of the feasibility of such implementation is carried out by means of the model developed in Python and explained in section IV. The main reason to analyze the possibility of V2G in Milan is for sustainability helping the process of moving towards a smart city; the second reason is to achieve the target set in 2030 of a Full Electric bus fleet and to maximize the benefits of the usage of electric buses. In fact, the company has implemented and is realizing the Full Electric project with the goal of having a bus fleet of 1,150 full electric units by 2030. Fig. 5 and Fig. 6 illustrate an electric bus model and a charging station/opportunity charger used by LPT company. The main features of the bus model are reported in Table 2.

FIGURE 5. **Electric bus model (12 meters long) and example of opportunity charger (pantograph) in the terminal used by LPT company.**

TABLE 2. **Main features of the bus model.**

Parameter	Value
Height [m]	3.3
Width [m]	2.55
Length [m]	12
Battery pack capacity [kWh]	50.8
Battery pack capacity [number]	5
Overall battery capacity [kWh]	254
Effective battery capacity [kWh]	216
Charging system	Plug-in & pantograph

The required data for the implementation of the case study was provided by LPT company, such as:

- Timesheet of buses;
- Bus model (with battery type and capacity);
- Energy consumption;
- Characteristics of charging stations in the depots and of pantographs along the city routes.

The whole set of different work shifts, which have the same conditions imposed (e.g., the V2G time window), are

FIGURE 6. **Example of charging station used by LPT company in the depots.**

acquired by the model instead of just one vehicle. The timesheet of the duties for the buses was given in the form of a dataset in which each row represents a workshift in the public transport service. It should be noted that some work shifts are very short, and a single bus can perform more than one trip. Therefore, the number of work shifts is higher than the number of vehicles. Nonetheless, the analysis was conducted in such a way that a bus selected for V2G services can fulfill its own work shifts. The current bus fleet, which is composed of 110 electric buses in both depots, was used for the analysis.

The analysis was performed for the two depots in the city of Milan, considering two different time windows during the day, as two peaks are shown in the electrical load demand curve, one in the morning and one in the evening. The V2G windows were set for 08:00 - 11:30 and 18:00 - 20:30, as shown in Fig. 7.

The model, which has been fed with these inputs, then returns the following outputs:

- Return time according to opportunity charging at the pantograph;
- SoC at the end of the trip;
- The energy that can eventually be sent back to the grid for remuneration.

Based on the preliminary analysis, it is determined that mandating an opportunity charge for this case study would not

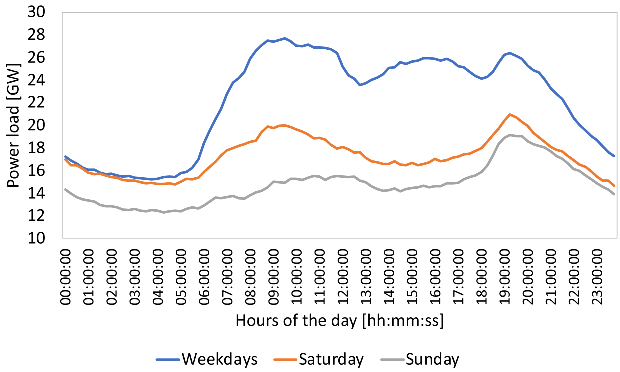


FIGURE 7. Daily electrical load curve in North Italy for Weekdays, Saturday, and Sunday.

be advantageous, as it would require altering the fixed transportation service schedule and potentially impact the quality of the service. The analysis was split into three cases based on the day of the week (weekdays, Saturdays, and Holidays) due to the varying bus timetables provided by the company.

Once the public service timetable was obtained, it was determined which buses could not be held in depots during the V2G time window, as they were required to continue their work shifts. Therefore, the output of the model, containing all the necessary information, had to be examined. From this output, only the number of buses that were desired for V2G purposes or deemed valuable could be selected in a manner that ensured the public service was maintained and the V2G service was utilized intelligently.

Through the imposition of time constraints, the number of "buses in operation" during the V2G time windows, running their work shifts or required to leave immediately afterward, was determined. The remaining vehicles, known as "V2G buses," were identified as the available units capable of performing peak shaving during the designated time windows while also completing one workshift.

Table 3 displays the number of buses in operation and the number of V2G buses for each day of the week, during the morning and evening services. The sum of these two numbers gives the total size of the current bus fleet, which is 110. The first column of the table provides the meaning of the acronyms, with DEPOT_1 (San Donato) and DEPOT_2 (Sarca) representing the two depots where the buses are located. The other parameters listed in the column pertain to the time of day and week.

- SD: San Donato – DEPOT_1
- S: Sarca – DEPOT_2
- WD: Weekday
- SAT: Saturday
- HOL: Holidays
- M: Morning service
- E: Evening service

The term "buses in operation" pertains to the number of buses engaged in the local public transport service during V2G time, thereby rendering them unable to transfer

TABLE 3. Busses clusters: buses in operation and V2G buses.

Depot and period	Buses in operation	V2G Buses	Bus fleet
SD (WD) - M	78	32	110
SD (WD) - E	40	70	110
SD (SAT) - M	62	48	110
SD (SAT) - E	40	70	110
SD (HOL) - M	41	69	110
SD (HOL) - E	35	75	110
S (WD) - M	72	38	110
S (WD) - E	54	56	110
S (SAT) - M	61	49	110
S (SAT) - E	54	56	110
S (HOL) - M	50	60	110
S (HOL) - M	51	59	110

energy to the grid. As mentioned earlier, "V2G buses" represents the number of buses that can be utilized for V2G purposes, and the model calculates the corresponding available energy, as explained previously. The algorithm then computes the entire energy exchanged with the grid during the V2G time window, which is the sum of the energy from each bus.

At this point, consideration must be given to how to connect the buses to the grid for V2G service, considering the overall grid connection limit power for the depot and the maximum power that can be connected at a time. These final values are necessary for arranging the bus connections and displaying the V2G peak-shaving strategy.

VI. RESULTS ANALYSIS AND DISCUSSION

This section presents the results related to a typical working day and the overall computation, but it is noteworthy that analogous outcomes were obtained for the Holidays and Saturdays cases. The task of arranging the bus fleet to perform the V2G service was accomplished by utilizing the following parameters, which are summarized below, and considering the information provided.

- Opportunity charging power: 200 kW
- Depot charging power: 80 kW
- V2G discharging power (to the grid): 80 kW
- SoC safety: 40%
- Ratio bus/charging column equal to 1
- Power connection limit of depots 6 MW
- Max power connection at a time: 480 kW

To avoid grid balance issues, six buses at a time are being connected to the grid, with a temporal distance of 5 minutes:

- 6 buses at 08:20 a.m.
- 12 buses at 08:25 a.m.
- 18 buses at 08:30 a.m.

And so on until the 6 MW connection power limit for the depot is reached.

A. TECHNICAL ANALISYS

Considering the three time periods (weekdays, Saturday, and Holiday), it is possible to visualize in Fig.8, Fig. 9, and Fig. 10 the energy fed into the grid through V2G service considering the contribution of individual depots (orange line and blue line) and the total contribution (green line).

In general, two peaks are always observed: one in the morning and one in the late afternoon when more buses are available at the depot. Considering the trend in Fig. 8 (weekdays) it is observed that the maximum value given by the contribution of the two depots (green line) is obtained in the afternoon with a value of about 10 MW while in the morning peak there is a value of total of about 7 MW.

Regarding the V2G during Saturdays (see Fig. 9), it is still observed that the maximum power occurs in the afternoon peak (about 10 MW) and in the morning peak there is a value of about 8 MW.

Finally, regarding holidays (see Fig. 10), it is observed that the curve is characterized by two very similar peaks (morning and afternoon) with a power value of about 10 MW (green line). From a practical point of view, it is possible to consider that in general the connection power of an average household in Italy is 3 kW; thus, it is feasible to estimate the potential number of homes that could be served by V2G system:

- 7 MW: about 2,300 homes
- 8 MW: about 2,600 homes
- 10 MW: about 3,300 homes

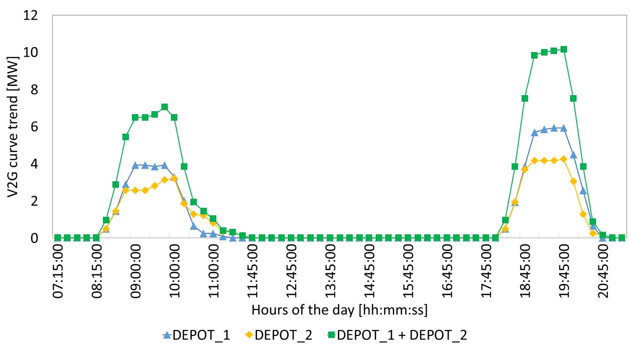


FIGURE 8. Electrical power provided to the grid using V2G service during weekdays.

B. ECONOMIC ANALISYS

At the end of the technical evaluation, an economic evaluation was also performed although there are few available data. The total energy exchange revenues and costs of the V2G system are derived from the sales revenues and purchase costs of each *i-th* bus belonging to the fleet. Revenues can be calculated as Eq. 3:

$$Rev_{V2G} = \sum Rev_i \tag{3}$$

where Rev_i represents the revenue associated with the single bus and is calculated as Eq. 4:

$$Rev_i = \sum Esell_i \times EP_{V2G} \tag{4}$$

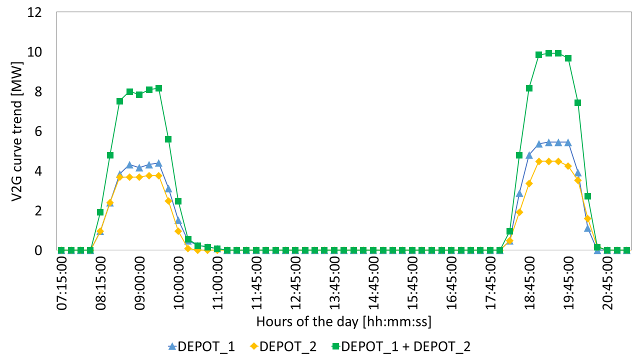


FIGURE 9. Electrical power provided to the grid using V2G service during Saturday.

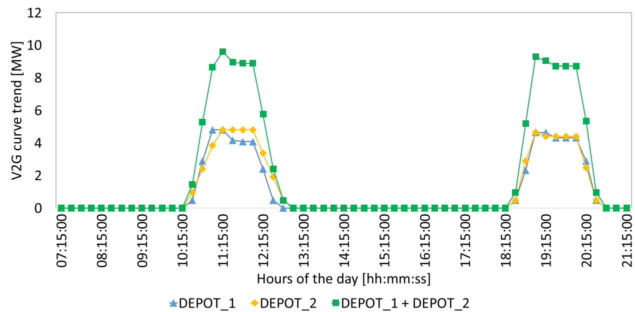


FIGURE 10. Electrical power provided to the grid using V2G service during holidays.

where $Esell_i$ is the energy injected into the grid by the single vehicle while EP_{V2G} is the price of energy injected through the V2G service. The same evaluation is performed for costs with Eq. 5:

$$Cost_{V2G} = \sum Cost_i \tag{5}$$

where $Cost_i$ represents the cost associated with the single bus and is calculated as Eq. 6:

$$Cost_i = \sum Ebuy_i \times EP_{buy} \tag{6}$$

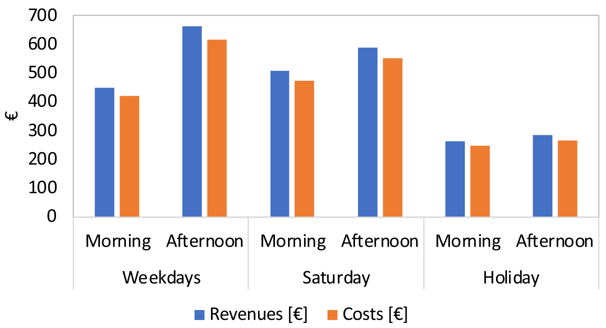
where $Ebuy_i$ is the energy purchased from the grid for the single vehicle while EP_{buy} is the price of purchased energy.

In Italy, the energy market tariff has 3 price bands, depending on the time of day, and thus the demand for energy:

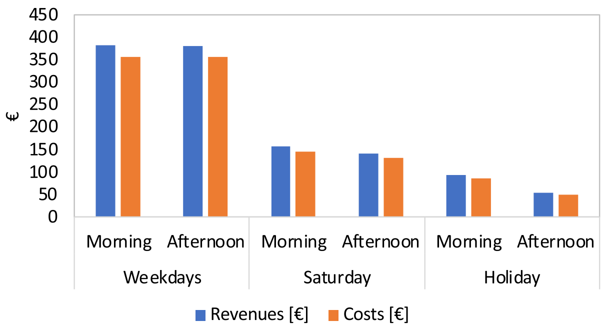
- F1, the most expensive tariff, Monday to Friday from 08:00 am to 07:00 pm;
- F2, intermediate tariff, Monday to Friday, from 07:00 to 08:00 and 19:00 to 23:00;
- F3, the cheapest tariff, Monday through Saturday, 11:00 p.m. to 07:00 a.m. and all day on Sundays and holidays.

The cost of energy considered for the V2G service comes from the ARERA (Regulatory Authority for Energy Networks and Environment) report for October 2019 and is 0.07 €/kWh during the F1 tariff, when peak shaving is required due to the grid stress period. As for tariff F2 and

F3, the cost of energy is 0.06 €/kWh. Fig. 11 represents the result of the cost and revenue analysis of energy trading for DEPOT_1 and DEPOT_2.



a)



b)

FIGURE 11. Cost and Revenues analysis from energy trading for a) DEPOT_1 and b) DEPOT_2.

Considering the contribution of the two depots, the result of the daily cost and revenue analysis for the three periods considered (weekdays, Saturday, and holiday) is shown in Table 4.

TABLE 4. Daily cost and revenues for the 2 depots.

Period	A - Revenues [€]	B - Costs [€]	A-B [€]
Weekdays	1,877.4	1,751.9	125.5
Saturday	1,396.0	1,302.3	93.7
Holiday	697.4	650.2	47.2

Therefore, considering that in a month there are four weeks consisting of five weekdays, one Saturday and a holiday (Sunday) it is possible to determine total revenues and total monthly costs:

- Total Revenues 45,922 €
- Total costs 42,848 €

It follows that at the monthly level the economic benefit can be quantified as approximately 3,074 €.

The proposed model offers a more comprehensive analysis of V2G feasibility and cost savings during various hours, as compared to naive models. It utilizes readily available information on electric buses, making it scalable and adaptable for different case studies. Consequently, this model can serve as a benchmark for assessing V2G feasibility. Moreover, the data-driven nature of the model enables easy customization with other battery characteristics, such as discharging properties or aging, to enhance result accuracy.

Additionally, the proposed model can help decision-makers understand the potential impact of V2G on the electricity grid and assess the economic feasibility of V2G implementation for electric buses. The ability to easily modify the model with additional battery characteristics can also provide insights into the optimal use of electric bus fleets for V2G applications. Overall, the proposed model can be a valuable tool for cities and transit authorities looking to integrate V2G technology into their electric bus fleets, helping them make informed decisions that can contribute to a more sustainable and efficient energy system.

VII. CONCLUSION

This model was implemented with the main purpose of implementing a decision support tool to assess the feasibility of implementing a V2G service from a company that operates a fleet of buses. The model can calculate the energy that a vehicle within a depot can return to the grid during periods of peak energy demand, based on the operating schedule that needs to be guaranteed. The primary objective of V2G is to leverage vehicles as energy reservoirs during their idle state, thereby facilitating the integration of renewable energy sources. As renewable sources of energy are not dispatchable and must be conserved to meet peak energy demands, V2G offers a viable solution. The proposed model prioritizes the use of vehicles for mobility service (passenger transport) and allows V2G operations only if they do not delay work shifts and bus schedules.

The case study regards the analysis of the feasibility of implementing V2G services using the bus fleet, the main local public transport player in the city of Milan (Italy), which has undertaken a strong electrification policy aimed at replacing the current ICE fleet with a greener and more sustainable electric one. By considering the timesheet of buses throughout the day, the power that they can send to the grid when parked in the two depots during peaks of the power demand curve can be computed: it was found that this service could feed about 7 MW to 10 MW into the grid depending on the day of the week and time of day. Considering an average power connection of 3 kW for a household, between 2,300 and 3,300 households could be served.

Vehicle-To-Grid is a cost-effective strategy that local public transport providers can use to increase revenue. It involves charging vehicles when energy is cheap and selling energy to the grid when it is expensive. Vehicles can also be used for ancillary services like frequency and voltage regulation when parked in depots, without draining or refilling the battery, resulting in a "net zero" energy process. In addition, an economic evaluation was made considering energy trading from which it appears that monthly the total revenues are

45,922 € and the total costs are 42,848 €; it follows that the economic benefit can be estimated at about 3,074 €.

To further investigate the economic potential of V2G, two important factors should be considered: the provision of ancillary services and battery degradation. The latter is a concern as battery health deteriorates over time with use, potentially resulting in higher replacement costs. However, as renewable energy sources become more prominent, the potential for second-life use of batteries in stationary storage systems may offer new opportunities for V2G. Finally, a further development of the work concerns the comparison of the obtained results with consolidated optimization models in the literature. This makes it possible to compare the proposed method and highlight its advantages and disadvantages with other models analyzed. However, it will be interesting to perform further validations of the model using data obtained from full-scale projects that will address the implementation of V2G.

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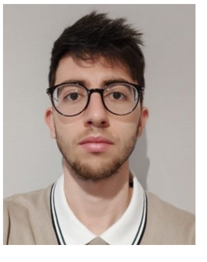

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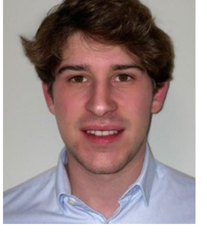

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