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Techno Economic Analysis of Electric Vehicle Grid Integration Aimed to Provide Network Flexibility Services in Italian Regulatory Framework

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Abstract: The recent forecasts regarding the penetration of electric vehicles (EVs) in the transport market and their impact on national electricity distribution grids has presented new challenges in the fields of both of application and research. In this context, vehicle-to-grid (V2G) technology presents itself as an extremely valid solution in terms of application of the "demand side flexibility" paradigm. In this context, the aim of the paper is to analyze from a technical and economical point of view the use of EVs as new flexibility resources to provide network flexibility services in an Italian framework. Within this scope, a methodology for evaluating the flexibility service that a single EV or an EV fleet can offer, and therefore for estimating the EV storage system charge and discharge profile and determining its economic benefit, is proposed. Some numerical results and observations are reported to highlight possible incentive mechanisms for motivating EV end-users to offer flexibility services.

Keywords: electric vehicle; flexibility service; V2G technology; storage system; dispatching services market; renewable energy sources; energy community

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1. Introduction

The transport sector has been recognized as one of the major sources of pollutant emissions. Electric vehicles (EVs) have attracted increasing interest and the global EV market is booming today consequently.

Increasing of EV utilization will lead to several environmental advantages including lower transport costs and carbon emissions. The spread of EVs is an important phenomenon to consider due to the effects that could be observed on the electricity grid's infrastructure. In particular, the additional load represented by EVs further exasperates the power peaks in some critical hours of the day. In addition, fast charging causes an increase in power load, especially in the evening hours. It is clear that the electricity grid allows for a low penetration of EVs, which on the contrary will spread starting in 2025. However, it will introduce various challenges in the power systems operation (mainly in distribution grids).

The term "dispatching" includes a complex set of activities carried out at different levels (in planning, in real time analysis, in real time of collected data) by the transmission system operator (TSO) to guarantee the service of the electricity system in full compliance with operational constraints (admissible limit values of frequency and voltage). The management of the electrical power system by the system operators (SOs) must guarantee the following standards: safety, adequacy, quality, efficiency, and resilience.

To pursue the objectives listed above, a SO acquires power reserves (active and reactive) from appropriate production units, called upon to offer the so-called "ancillary services" [1].

With the progressive reduction of power production from conventional generations, it is necessary to make explicit new services that were previously unnecessary (since they are partly "implicit" and obtained free of charge from conventional generation). For example, the mechanical inertia of the electrical system will be reduced, and a "fast reserve" service [2] will have to be introduced to reduce frequency transients in the first few moments. The increased need for flexibility of the electricity system makes it necessary to procure network services from all available units, including non-dispatchable renewable sources and storage and demand systems.

Now, in Italy, for the actual regulatory framework, the only units with the ability to offer services to the network are the thermoelectric and hydroelectric power stations (although some pilot projects have been launched to extend the number of eligible plants). The TSO procures resources for safe management and control through the dispatching services market (DSM), which is managed by an energy market manager. The ancillary services that the dispatching units must be able to provide are resources for the resolution of congestions in the planning phase; and resources for the primary, secondary, and tertiary frequency reserve.

With the decree [3], for the first time, ARERA (Italian Regulatory Authority for Energy, Networks, and the Environment) has defined the criteria to allow production units not already enabled, for instance, renewable energy sources (RES), plants and storage systems, and loads to participate in the DSM. It considers the aggregation of units as part of a pilot project, inspired by the principle of technological neutrality, to set univocal qualification requirements for all technologies in a non-discriminatory perspective.

A leading role is played by storage systems, both for "power intensive" services which, being characterized by very short discharge times, provide support for network security, and for "energy intensive" services intended to solve network congestion and make themselves available for "load shifting".

The decree outline in [4] establishes criteria and methods to promote the spread of integration technology between electric vehicles and the electricity grid as part of the DSM reform. It is essential to highlight how the presence within the aggregation of recharging infrastructures that use vehicle one grid (V1G; unidirectional power flow) and vehicle two grid (V2G bidirectional power flow) technologies allows EVs to be considered as "storage systems on wheels" and therefore makes them capable of absorbing and suppling energy when connected to the network.

It is important to observe that in the scenario of a possible participation of the EVs to offer flexible services according to the V2G operating mode, the factor considered critical by most end-users is the deterioration of vehicle performance. The second limiting aspect is the impact on EV availability (i.e., the residual capacity of the EV and therefore of the battery capable of ensuring the autonomy necessary for the end-user's mobility needs).

In [5], the issue of using EV to provide services to the network is highlighted as being of particular importance and topicality. Indeed, there is a need to analyze the issue from different points of view: from a technological point of view, to have an infrastructure that allows these services to be carried out; from the point of view of government policies that define the operating methods as well as the incentives themselves; and from the point of view of social and market acceptability of this technology. Furthermore, it is shown how, since this technology is not fully developed, there is still some uncertainty in defining the economic feasibility of this technology, requiring more studies that use real data as much as possible concerning vehicles, the electricity market, and regulations in force.

In this context, the aim of the paper is to analyze from the technical and economical point of view the use of EVs as new flexibility resources to provide network flexibility services in Italian regulatory framework.

1.1. State of Art

There are several studies that concern EVs and their ability to provide services to the grid. Each one analyzes different aspects. Indeed, various stakeholders are identified in [6] as regards the V2G, also focusing on some of the aspects that should be studied for the coordinated development of V2G technology. Some aspects are also underlined in [5].

Some of the works that are interesting for this topic are then described below, also focusing on the differences with respect to those implemented by the authors in this work.

In [7], the authors propose an "agent based" simulation tool for generating power curves in a "smart city" environment, in which EVs and household appliances are modeled as classes that act for events on a probabilistic basis. The primary purpose of the tool is to simulate the entire behavior of a smart city from an energy consumption point of view. The individual classes relating to electric vehicles and household appliances are modeled in a probabilistic way. However, the following are not considered: traffic variability, plug-in/-out instants.

In [8], the authors publish a case study in which the insertion of a certain percentage of EV in a Danish distribution system is simulated to evaluate the energy impact in a pre-existing distribution system. Vehicle charging is concentrated more in time periods with lower energy costs. Again, no traffic information is considered in the modeling.

In [9,10] two models of EV and smart charging station at the circuit level, oriented to the study and simulation of bidirectional AC/DC and DC/DC charge/discharge strategies, have been proposed. Obviously, this type of study lacks the behavioral modeling of individual users (commuting distance, routine, etc.), including instants of plug-in/-out and traffic modeling.

The authors in [11] present a study on the optimization of the "scheduling" of the energy resource considering a fleet of EVs, whose behavior is simulated stochastically through the DER-CAM software [12]. The optimization model minimizes the total cost of energy as a function of the energy balance, constraints relating to charging stations, electrical storage. Relatively less attention is paid to the modeling of the individual electric vehicle and user behavior.

In [13], a case study in which the energy impact of introducing a fleet of EVs into the Croatian energy distribution system is modeled, has been illustrated. The used tools are MATSim and EnergyPLAN. Also in this case, the modeling of the EV is sacrificed in favor of an accurate model of production, import and export of energy.

In [14] the authors present a tool to simulate the impact of changes in electricity prices on the behavior of EV owners. In the same work, the tool is integrated with an optimization model to determine the variability of charge prices. The main purpose of the work, as stated by the authors themselves, is to show the advantages of the variability of electricity prices per consumer. The construction of a real simulation environment for the generation of V2G data seems to be secondary to the study.

In the literature, there are several cases in which EVs and their storage systems are used to perform services to the network. Generally, the services offered are ancillary services and real-time services.

These services are often integrated with the charging and discharging techniques of the storage systems, requiring the aggregation of multiple EVs, often in the same charging location as well as in multi-charge stations.

In [15] a real-time controller for the bidirectional charging efficiency and in particular the design of charging schedules to provide ancillary services to the grid is presented; different schedules that consider the level of accuracy for the service provided and the battery cycles are proposed. One of the results of this work was that higher accuracy in following regulation signals coincides with less cycling of the batteries, which means a longer battery life. To allow a better regulation capacity, it is necessary to maintain the battery state of charge (SOC) away from the boundaries.

In [16] an aggregation of EVs is used to provide ancillary services to the power grid. In particular, the EVs are used to participate to the secondary frequency regulation. To make this possible, the users' preferences are considered. It results that EVs have a potential to provide services to the grid; but it results that there are not particular benefits for the regulation upward, mainly due to the EV user's flexibility and their uncertainty in the real use of batteries from the aggregator.

It easy to suppose and it is shown by the literature that to provide ancillary services or any kind of services to the grid, an aggregation of EV users is necessary. Indeed, the aggregation of EVs, in parking station equipped with (Photovoltaic) PV system can increase the reliability and flexibility of the electric power system [17]. In this framework an aggregator can operate both in the energy or ancillary services markets, opportunely managing the charge and discharge power profile for each EV interfaced to the charging point [18]. To maximize the profits, several works have been provided and one of the main assumptions, to optimize the charge/discharge profile, is that vehicle arrival and departure are known [17–20]. In [19,20] the unplanned departures and arrivals are considered. If the aggregation is made up by many EVs, the aggregator such loss of capacity and it provides a further dispatch on the remaining EVs, that is possible only if the aggregation consists in many EVs, on the contrary for a small number of EVs.

In [21] an optimization strategy to manage the exchange power scheduling has been introduced, also considering the peer-to-peer energy trading and the provision of ancillary services, showing how the users obtain the positive revenues for the participation to such markets.

A further service that EVs can provide, and moreover if they are considered in an aggregate form, is the frequency regulation and virtual inertia provision. It can be provided if such vehicles are used together with other resources [22].

One of the main issues due to the provision of services to the grid using the EVs batteries is the degradation of the same batteries. Indeed, this can represent one of the issues that slows the end-users' participation in this kind of markets [17–22].

In [23], a feasibility study regarding the use of EV storage to provide services to the network is carried out. It is highlighted how potential income can be obtained by providing services to the network; the analysis also shows how net revenues are dependent on the degradation costs of the battery of the EV. In particular, the study is carried out considering the electricity system and therefore the electricity market in the UK; it shows how the provision of services in the short term can cause repeated discharge cycles of the EV battery and it can lead to a deterioration of the battery that could not justify the cost of this operation. In the present work, instead, the cost of the battery and the recharging system is not considered, assuming that they are present for the normal use of the EV. Moreover, the required services must be provided for a determined time, reducing the presence of micro charge/discharge cycles.

In [24], on the other hand, it is shown how the problem encountered in [23] can be reduced by 67% if suitable optimization algorithms are used, also showing how the same energy costs are reduced by about 90%. The use of optimization algorithms can limit the users' behavior; in the present paper any optimization algorithm is used, leaving the user free to implement their own routine.

As opposed to [25], where the mobility routine is considered, showing how EVs owned by business entities can obtain the highest feasibility for ancillary services, and can potentially reduce the cost of charging. Despite taking into consideration the mobility patterns to identify vehicle stops, to determine the time needed to provide the service, it does not determine the amount of energy necessary to make the trip, and therefore the costs associated with the further recharging of the vehicle, as instead carried out in the present paper, where the further recharging represents a principal issue.

As in the present work, in [26–29] the V2Gs are analyzed taking into consideration the Italian electricity system.

In [26], for example, the V2G is considered to provide ancillary frequency regulation services, but the cost of charging the storage system, due to the discharge to perform the services, is not considered in the economic analysis; only the earnings deriving from the services performed are considered, unlike what is proposed in this paper. In [27], instead, it is shown how selling energy in peak periods is not economically sustainable, so the remuneration should be provided by performing other services, as is carried out in this paper.

In [28], still considering the Italian electricity market, it is assumed that a fleet of EVs can provide balancing services, but the authors consider a fixed remuneration price for the services, without considering the mobility pattern of the vehicles themselves (and therefore their needs).

1.2. Paper Contribution

The aim of this study is to propose a methodology to evaluate from a technical and economic point of view the opportunity for an end-user by his EV to provide flexibility services as defined by the actual Italian regulation code. At the same time, it preserves the autonomy necessary to meet their mobility needs and to obtain an adequate benefit from providing this service.

In particular, the work has a dual aim: it wants to propose an evaluation methodology that, starting from the EV end-users' typology and habits and considering the actual regulation, policies, and incentives framework; and provide a technical and economic analysis on the V2G to provide services to the grid. This is useful to analyze in any context the possibility and the suitability of V2G services.

On the other hand, using the same methodology, the actual Italian regulatory framework has been considered. Different EV patterns and habits have been considered and the results have been shown, analyzing the different incentive and remuneration possibilities that the current Italian electricity market offers.

The paper is structured in the following steps:

(1) Definition of end-user mobility patterns;
(2) Electric vehicle modeling to assess energy needs based on the planned mobility pattern;
(3) Implementation of a methodology for evaluating the flexibility service that a single EV can offer and therefore determining the charge and discharge profile and the economic benefit for the end-user;
(4) Implementation of a methodology for evaluating the reserve that an electric vehicle belonging to a fleet can offer and therefore determining the charge and discharge profile and the economic benefit for the end-user;
(5) Numerical simulation testing the effectiveness of the adopted methodology.

2. Brief Review on EV Technical Characteristics

EV vehicle is defined as a purely electric vehicle [19]. It consists of a battery pack which is recharged thanks to the connection to the electrical network, through a charger on board the EV (see Figure 1) (AC-DC charger converter). The power stored in the storage system feeds the electric motor by means of a converter (DC-AC), which in turn converts the electrical power into mechanical power, allowing the vehicle to move forward (Figure 2). The battery is also recharged during the "regenerative braking" phase in which the electric motor changes its operating mode, becoming a generator.

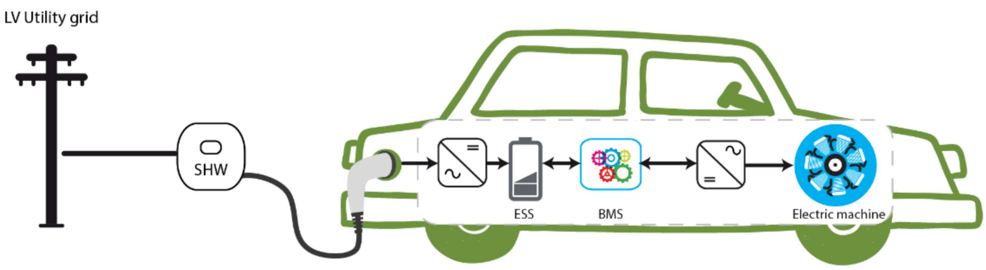

Figure 1. EV mechanical scheme.

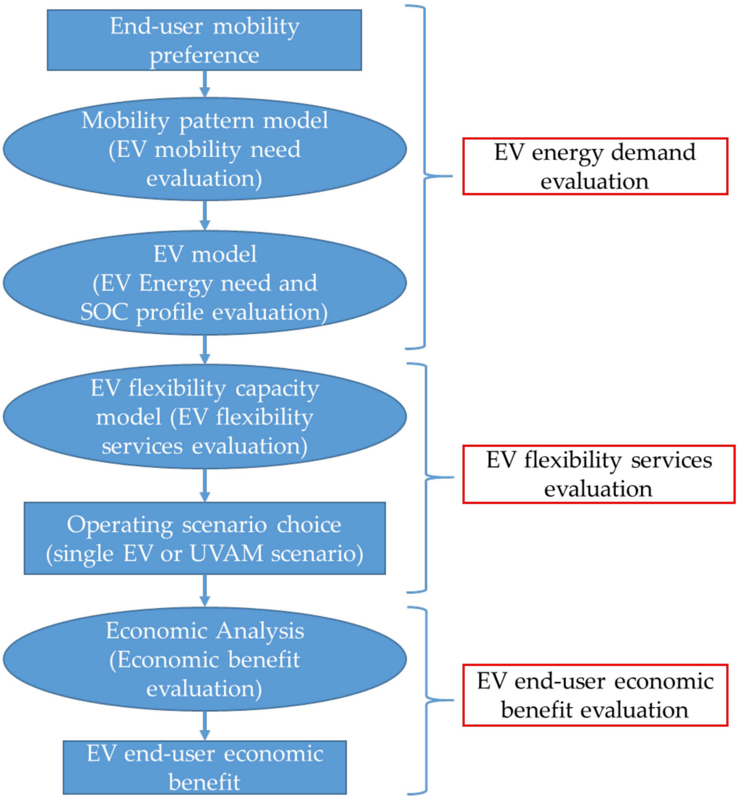

Figure 2. EVFlex flow chart.

To ensure the safe operation of the grid by preventing the occurrence of congestion, the electric vehicle must be integrated into the grid according to one of two technologies:

- V1G. This usage scenario enables smart charging, defined as the one-way exchange (the vehicle absorbs power from the grid only) that must be managed to combine the end-user's mobility need and at the same time guarantee the safe operation of the electric system.
- V2G. This EVs use method provides for bi-directional energy exchanges with the grid to offer the so-called "ancillary services", without violating the end-user's mobility needs.

3. Proposed EV Day-Ahead Charging Scheduling Approach to Provide Flexibility Service

As known, the capacity of the EVs battery limits the energy that can be exchanged. There are many variables that have to be considered to determine the power to exchange with the grid.

The charging station location, the battery management system and the equipment for the electric vehicle supply are three important elements to fix the environment for the exchange of between the EV and the grid.

The charging station can be generally installed at the EV-user house, office, working place, or public parking area.

In this context the bi-directional converter is useful for allowing the power flow exchange from the grid to the battery of the EV and vice-versa. The charger is structured in two steps: an AC/DC converter for the grid interface and a DC-DC converter for the battery connection. These two converters are interfaced on a common DC-bus.

The EVs are used for travel less than 45% of the time, the remaining time they are not used or are in a parking area, for this reason the V2G applications are justified [21].

The V2G can provide different functions that are summarized below:

(1) Support and Compensation of the Intermittent Renewable Energy Sources;

(2) Provision of Ancillary Services (aim of the paper);
(3) Load Shifting.

In this paper, the methodology, called EVFlex and represented by the flow chart of Figure 2, is proposed to evaluate the day-ahead EV charging profile so to provide flexibility services to the SOs, maximizing the economic convenience for the end-user without compromising his daily mobility need. It consists of three principal stages. The first stage is the EV energy demand evaluation explained in Section 4. The second one is the EV flexibility services evaluation explained in Section 5. The last stage is the EV end-user economic benefit evaluation reported in detail in Section 6.

4. EV Energy Demand

The energy demand evaluation stage has the scope to determine the energy needs required by the EV to cover the daily mobility routine (Figure 3) based on the end-user mobility preference. It represents the principal input of the procedure and considers that the EV charge can be performed using a smart home wall box (SHW) and/or a public charge station (PCS) at the workplace.

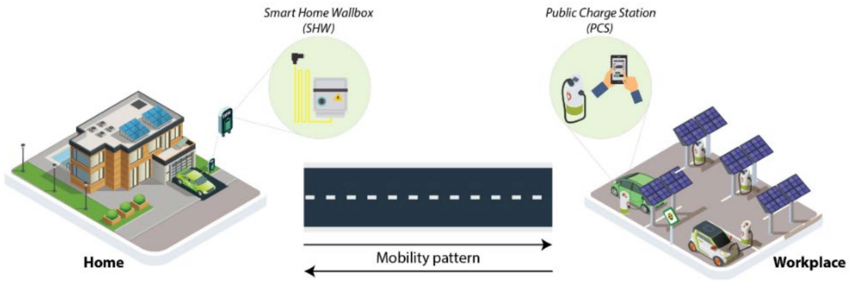

Figure 3. End-user daily mobility routine.

4.1. Mobility Pattern Model

Starting from the homologation cycle of a vehicle, using the New European Driving Cycle (NEDC), elementary cycles have been defined whose composition gives rise to different daily mobility patterns.

Table 1 shows the operations performed in sequence that define the NEDC elementary cycle in an urban setting.

Table 1. Operations of the elementary urban cycle [30].

Op. Number	Type	Acceleration [m/s^2]	Speed [km/h]	Duration	Time [s]
1	Stop	0	0	11	11
2	Acceleration	1.04	0–15	4	15
3	Constant Speed	0	15	8	23
4	Deceleration	−0.83	15–0	5	28
5	Stop	0	0	21	49
6	Acceleration	0.69	0–15	6	55
7	Acceleration	0.79	15–32	6	61
8	Constant Speed	0	32	24	85
9	Deceleration	−0.81	32–0	11	96
10	Stop	0	0	21	117
11	Acceleration	0.69	0–15	6	123
12	Acceleration	0.51	15–35	11	134
13	Acceleration	−0.46	35–50	9	143
14	Constant Speed	0	50	12	155
15	Deceleration	−0.52	50–35	8	163
16	Constant Speed	0	35	15	178
17	Deceleration	−0.97	35–0	10	188
18	Stop	0	0	7	195

In Table 2, the homologation procedure includes an elementary extra-urban cycle consisting of the operations. The elementary cycle has the objective of simulating a route on high-speed roads such as main and secondary suburban roads without motorway routes, also minimizing stopping operations.

Table 2. Operations of the elementary extra-urban cycle [30].

Op. Number	Type	Acceleration [m/s^2]	Speed [km/h]	Duration	Time [s]
1	Stop	0	0	20	20
2	Acceleration	0.69	0–15	6	26
3	Acceleration	0.51	15–35	11	37
4	Acceleration	0.42	35–50	10	47
5	Acceleration	0.40	50–70	14	61
6	Constant Speed	0	70	50	111
7	Deceleration	−0.69	70–50	8	119
8	Constant Speed	0	50	69	188
9	Acceleration	0.43	50–70	13	201
10	Constant Speed	0	70	50	251
11	Acceleration	0.24	70–100	35	286
12	Constant Speed	0	100	30	316
13	Acceleration	0.28	100–120	20	336
14	Constant Speed	0	120	10	346
15	Deceleration	−0.69	120–80	16	362
16	Deceleration	−1.04	80–50	8	370
17	Deceleration	−1.39	50–0	10	380
18	Stop	0	0	20	400

The test conditions foreseen by the NEDC procedure are far from the real driving methods on the road. Therefore, it was decided to modify the urban and extra-urban mobility profiles by varying the number of accelerations and decelerations whose values are respectively 0.2 g and 0.3 g and are to be considered valid for all phases of vehicle speed modification. Furthermore, the constant velocity phases have a longer time duration than the base case. Indeed, the considered values are closer to the real values.

4.1.1. Mobility Pattern Creation

To analyze the different mobility patterns, the day is divided into 48 equal time steps.

A mobility pattern is composed using the two identified elementary cycles (urban/extra urban). Every end-user provides the information such as the mobility need, the route type (urban/extra urban) and the distance. In this way it is possible to know the number of elementary cycles that must be used to create the desired route.

From the above illustrated elementary cycle, mobility patterns have been defined as follows.

Specifically, the end-user provides the mobility time interval and distance in accordance with his daily mobility needs and the type of road (urban/extra urban) to obtain the daily mobility profile.

It is assumed that the distance requested by the end-user is such as to provide the number of elementary urban and extra-urban cycles respectively equal to 10 and 5, thus covering the entire basic time interval of the mobility pattern (1800 s).

Depending on the provided distance, the EV model determines the number of elementary cycles to combine reaching the desired mileage, also evaluating the corresponding associated energy flows.

In the following sections, three possible mobility patterns are individuated so as to perform the numerical analysis applying the proposed methodology.

4.1.2. Mobility Pattern 1

The first mobility pattern consists only in the combination of urban cycle. In Table 3, the definition of the mobility pattern 1 is reported.

Table 3. Mobility pattern 1 definition.

Time Interval	Route Type	Length [km]	Cycles Number
8:00–8:30	Urban	12.28	10
13:00–13:30	Urban	12.28	10
14:30–15:00	Urban	12.28	10
18:30–19:00	Urban	12.28	10
19:00–19:30	Urban	12.28	10

4.1.3. Mobility Pattern 2

In terms of mobility need, this pattern is more severe than pattern 1 since the EV will also be used in an extra-urban context. The different mobility intervals, defined by the end-user, lead to the achievement of a daily mileage of 168.7 km.

In Table 4 the definition of mobility pattern 2 is reported.

Table 4. Mobility pattern 2 definition.

Time Interval	Route Type	Length [km]	Cycles Number
7:30–8:00	Urban	12.28	10
8:00–8:30	Extra-urban	32.97	5
13:00–13:30	Extra-urban	32.97	5
14:30–15:00	Extra-urban	32.97	5
18:30–19:00	Extra-urban	32.97	5
19:30–20:00	Urban	12.28	10
21:30–22:00	Urban	12.28	10

4.1.4. Mobility Pattern 3

The last pattern is the most severe of those proposed since it involves intensive use of the EV on an extra-urban route through which the end-user reaches the workplace.

The elementary extra-urban cycle is modified as regards the maximum speed reached which passes from 90 to 100 km/h, as can be seen from the graph in Figure 4.

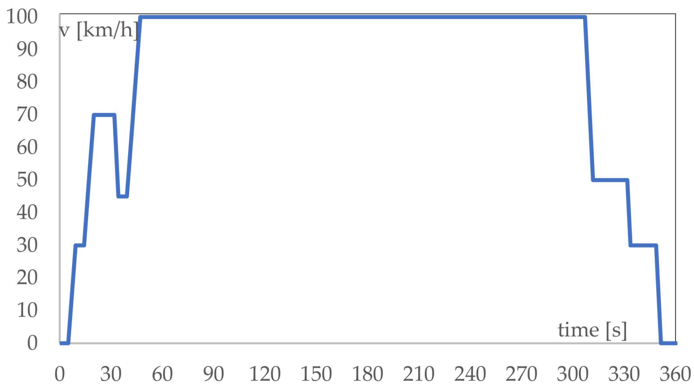

Figure 4. Speed profile in the modified elementary extra-urban cycle.

In addition, the duration of the constant speed phases is increased while maintaining an overall duration of the entire cycle equal to 360 s. In Table 5 the definition of mobility pattern 3 is reported.

Table 5. Mobility pattern 3 definition.

Time Interval	Route Type	Length [km]	Cycles Number
7:30–8:00	Extra-urban	10.04	5
8:00–8:30	Extra-urban	10.04	5
17:30–18:00	Extra-urban	10.04	5
18:00–18:30	Extra-urban	10.04	5
18:30–19:00	Urban	2.88	10
21:30–22:00	Urban	2.88	10

4.2. EV Model

The EV chosen for the numerical analysis is an Opel Corsa E-elegance, whose technical characteristics are summarized in Table 6 [31].

Table 6. Characteristics of the chosen EV.

Characteristic	Value
Maximum Engine Power [kW]	100
Maximum Engine Torque [Nm]	260
Rated battery capacity [kWh]	50
Real battery capacity [kWh]	45
Frontal area [m^2]	2.089
Aerodynamic Coefficient (CX)	0.29
Electrical efficiency (ηel)	0.9
Pneumatic radius [m]	0.31

For each operation that constitutes the elementary cycle (urban and extra-urban) it is necessary to determine the energy needs required by the EV to proceed at a certain speed or to accelerate or the amount of energy recovered during a deceleration. Therefore, defining F_{tr} and F_{br}, respectively, as driving and braking force, it is possible to write the traction equation for the EV:

$$F_{tr} = F_r + F_s + F_{aer} + F_a \rightarrow (\mathrm{a} > 0), \tag{1}$$

$$F_{br} = F_r + F_{aer} - F_s - F_a \rightarrow (\mathrm{a} < 0) \tag{2}$$

where F_r is the rolling force, F_s is the climb forward force, F_{aer} is the aerodynamic force and F_a is the vehicle inertia force.

To determine F_r, the rolling coefficient "a" not depending from the speed of the vehicle is equal to 0.015, and that depending from the vehicle speed b is equal to 6.48×10^{-3} s^2/m^2.

$$F_r = W cos\alpha \left(a + bv^2 \right) \tag{3}$$

where W is the weight strength, α the road surface inclination angle, and v is the vehicle speed.

Since the operation of the EV refers to winter/summer climatic conditions, an average electrical power required for the passenger compartment air conditioning and thermal management of the battery pack is assumed to be equal to 2 kW [3]. In Table 7 the elementary urban cycle is considered: the driving force F_{tr} and power P_m, the electrical power P_{el} and the necessary electrical energy E_{el} are evaluated. To calculate them, an electrical efficiency in motor operation and one in generator operation, respectively, equal to 90% and 80% are assumed, while the mechanical transmission efficiency has been chosen to be equal to 93%.

Table 7. Energy quantities of the chosen elementary urban cycle.

Op. Number	Type	F_{tr} [N]	P_m [kW]	P_{el} [kW]	E_{el} [kWh]
1	Stop	0	0	2	0.003
2	Acceleration	3425.8	10.2	13.37	0.011
3	Constant Speed	240.0	1.4	3.15	0.018
4	Deceleration	−4566.6	−11.8	−7.44	−0.004
5	Stop	0	0	2	0.010
6	Acceleration	3424.2	7.7	10.52	0.006
7	Acceleration	3442.6	24.2	28.85	0.019
8	Constant Speed	263.2	2.5	4.80	0.036
9	Deceleration	−4560.8	−18.9	−13.08	−0.011
10	Stop	0	0	2	0.008
11	Acceleration	3424.2	7.7	10.52	0.006
12	Acceleration	3445.4	25.7	30.59	0.024
13	Acceleration	3489.3	44.3	51.21	0.030
14	Constant Speed	318.1	4.8	7.28	0.071
15	Deceleration	−4503.2	−49.4	−37.55	−0.015
16	Constant Speed	270.7	2.8	5.14	0.039
17	Deceleration	−4558.9	−20.6	−14.49	−0.013
18	Stop	0	0	2	0.005

The numerical results for the elementary extra-urban cycle, for each phase of the cycle, are highlighted Table 8. Then, the numerical results, which are reported in Tables 7 and 8, are used to analyze the above defined mobility patterns.

Table 8. Energy Quantities of the chosen elementary extra-urban cycle.

Op. Number	Type	F_{tr} [N]	P_m [kW]	P_{el} [kW]	E_{el} [kWh]
1	Stop	0	0	2	10
2	Acceleration	3430.5	15.4	19.0	81.0
3	Constant Speed	258.6	2.3	4.5	64.0
4	Acceleration	3481.6	41.6	48.2	136.5
5	Acceleration	3555.9	63.7	72.8	206.2
6	Constant Speed	407.3	8.5	11.4	802.3
7	Deceleration	−4447.4	−66.1	−50.8	−120.0
8	Constant Speed	300.4	4.0	6.4	162.2
9	Acceleration	3534.6	58.1	66.5	188.3
10	Acceleration	3645.4	84.4	95.7	338.9
11	Constant Speed	526.2	14.1	17.7	2657.6
12	Deceleration	−4388.2	−79.4	−61.4	−232.1
13	Constant Speed	318.1	4.8	7.2	254.7
14	Deceleration	−4510.9	−46.6	−35.2	−66.6
15	Constant Speed	258.6	2.3	4.5	114.4
16	Deceleration	−4562.0	−17.7	−12.1	−34.4
17	Stop	0	0	2	18

Starting from the defined cycles, the energy needs for mobility pattern 1 are reported in Table 9.

Table 9. Mobility pattern 1 energy needs.

Time Interval	Consumed Electric Energy [kWh]	Electric Energy Recovered [kWh]	Net Consumed Electric Energy [kWh]
8:00–8:30	2.88	−0.43	2.45
13:00–13:30	2.88	−0.43	2.45
14:30–15:00	2.88	−0.43	2.45
18:30–19:00	2.88	−0.43	2.45
19:00–19:30	2.88	−0.43	2.45

In Figure 5 the daily trend of the SOC is reported. It shows that the capacity of the battery pack is clearly overabundant compared to the end-user's need for daily mobility.

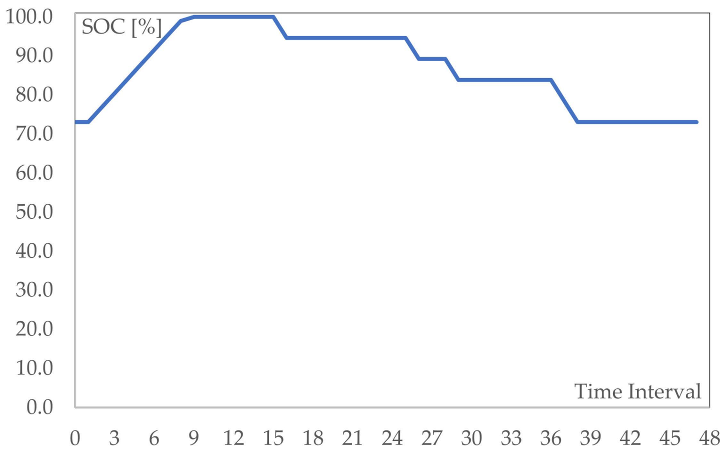

Figure 5. SOC profile for the mobility pattern1.

The daily distance of 61.4 km requires an energy demand from the storage system of 12.2 kWh. At the end of the day, the charge level EV battery pack is equal to 72.8% which corresponds to 32.8 kWh of stored energy. The EV's energy consumption is 0.199 kWh/km.

In Table 10 the results of the energy quantities for each time interval are reported.

Table 10. Mobility pattern 1 results.

Time Interval [h]	Consumed Electric Energy [kWh]	Electric Energy Recovered [kWh]	Net Consumed Electric Energy [kWh]	Length [km]	Charge Energy [kWh]
0:00–0:30	0	0	0	0	0
0:30–1:00	0	0	0	0	0
1:00–1:30	0	0	0	0	−1.67
1:30–2:00	0	0	0	0	−1.67
2:00–2:30	0	0	0	0	−1.67
2:30–3:00	0	0	0	0	−1.67
3:00–3:30	0	0	0	0	−1.67
3:30–4:00	0	0	0	0	−1.67
4:00–4:30	0	0	0	0	−1.67
4:30–5:00	0	0	0	0	−0.47
5:00–8:00	0	0	0	0	0
8:00–8:30	2.85	−0.43	2.42	12.28	0
8:30–13:00	0	0	0	0	0
13:00–13:30	2.85	−0.43	2.42	12.28	0
13:30–14:30	0	0	0	0	0
14:30–15:00	2.85	−0.43	2.42	12.28	0
15:00–18:30	0	0	0	0	0
18:30–19:00	2.85	−0.43	2.42	12.28	0
19:00–19:30	2.85	−0.43	2.42	12.28	0
19:30–24:0	0	0	0	0	0

In Table 11, the energy needs for mobility pattern 2 are reported.

Table 11. Mobility pattern 2 energy needs.

Time Interval	Consumed Electric Energy [kWh]	Electric Energy Recovered [kWh]	Net Consumed Electric Energy [kWh]
7:30–8:00	2.85	−0.43	2.45
8:00–8:30	6.99	−0.63	6.36
13:00–13:30	6.99	−0.63	6.36
14:30–15:00	6.99	−0.63	6.36
18:30–19:00	6.99	−0.63	6.36
19:30–20:00	2.85	−0.43	2.45
21:30–22:00	2.85	−0.43	2.45

The night-time recharging phase, by a SHW, leads to an increase in the recharging power from 3.33 kW to 4.05 kW in the time slot 00:00/06:00 to reach a SOC equal to 100% by 07:00.

Analyzing the energy flows, it is possible to observe a greater energy demand associated with the extra-urban route, the value of which is equal to 32.80 kWh. The state of charge of the battery pack at the end of the day is equal to 27.1% which corresponds to approximately 12.2 kWh of stored energy. As carried out for mobility pattern 1, in Table 12 the results of the energy quantities for each time interval are reported. In Figure 6 the daily trend of the SOC for mobility pattern 2 is reported.

Table 12. Mobility pattern 2 results.

Time Interval [h]	Consumed Electric Energy [kWh]	Electric Energy Recovered [kWh]	Net Consumed Electric Energy [kWh]	Length [km]	Charge Energy [kWh]
0:00–0:30	0	0	0	0	−2.03
0:30–1:00	0	0	0	0	−2.03
1:00–1:30	0	0	0	0	−2.03
1:30–2:00	0	0	0	0	−2.03
2:00–2:30	0	0	0	0	−2.03
2:30–3:00	0	0	0	0	−2.03
3:00–3:30	0	0	0	0	−2.03
3:30–4:00	0	0	0	0	−2.03
4:00–4:30	0	0	0	0	−2.03
4:30–5:00	0	0	0	0	−2.03
5:00–5:30	0	0	0	0	−2.03
5:30–6:00	0	0	0	0	−2.03
6:00–6:30	0	0	0	0	−1.67
6:30–7:00	0	0	0	0	−0.08
7:00–7:30	0	0	0	0	0.00
7:30–8:00	2.85	−0.42	2.42	12.28	0
8:00–8:30	6.99	−0.62	6.36	32.97	0
8:30–13:00	0	0	0.00	0	0
13:00–13:30	6.99	−0.62	6.36	32.97	0
13:30–14:30	0	0	0.00	0	0
14:30–15:00	6.99	−0.62	6.36	32.97	0
15:00–18:30	0	0	0.00	0	0
18:30–19:00	6.99	−0.62	6.36	32.97	0
19:00–19:30	0	0	0.00	0	0
19:30–20:00	2.85	−0.43	2.42	12.28	0
20:00–21:30	0	0	0.00	0	0
21:30–22:00	2.85	−0.42	2.42	12.28	0
22:00–22:30	0	0	0.00	0	−1.67
22:30–23:00	0	0	0.00	0	−1.67
23:00–23:30	0	0	0.00	0	−1.67
23:30–24:00	0	0	0.00	0	−1.67

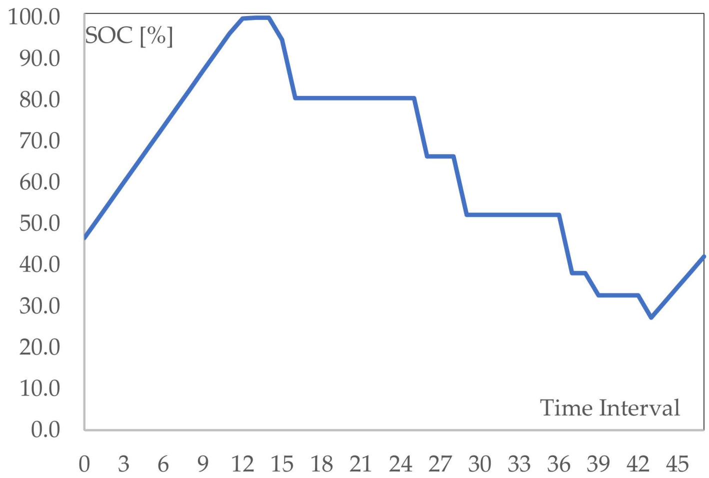

Figure 6. SOC profile for mobility pattern 2.

The last pattern is the most severe of those proposed. The demand for electricity from the battery pack due to the constant speed section is high, while due to a lower number of decelerations, the recovered electricity is even more contained than the elementary extra-urban cycle adopted for mobility pattern 2.

The daily mileage of mobility pattern 3 is 192.3 km, which corresponds to an energy requirement of 42.1 kWh. Although the need for mobility from a physical point of view is satisfied by the actual capacity of the EV battery pack equal to 45 kWh, at the end of the day there would be a residual SOC% of 6.5% which violates the minimum charge level constraint equal to 20% (Figure 7).

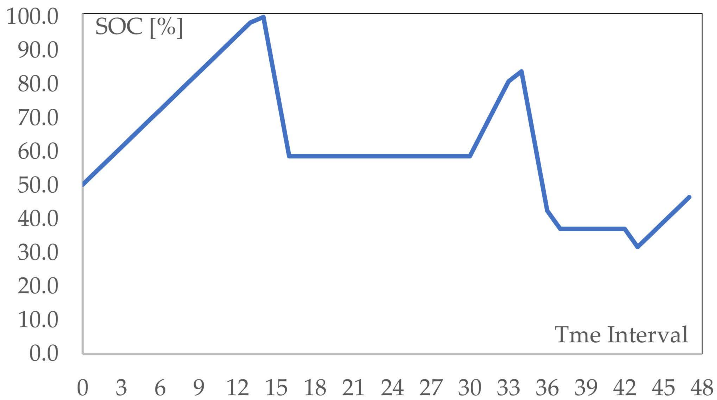

Figure 7. SOC profile for the mobility pattern 3.

Therefore, the recharging phase must be carried out by a PCS at the workplace, where a maximum power of 6.66 kW can be supposed. For each time interval, the energy quantities are shown in Table 13.

In Figure 8, a synthesis of the three different mobility patterns can be found. It can be useful, together with the tables which describe the mobility patterns, to understand the charge and discharge cycles of the storage systems and at the same time to understand the differences among the three mobility patterns in terms of route and charging necessity.

Table 13. Mobility pattern 3 results.

Time Interval [h]	Consumed Electric Energy [kWh]	Electric Energy Recovered [kWh]	Net Consumed Electric Energy [kWh]	Length [km]	Charge Energy [kWh]
0:00–0:30	0	0	0	0	−1.67
0:30–1:00	0	0	0	0	−1.67
1:00–1:30	0	0	0	0	−1.67
1:30–2:00	0	0	0	0	−1.67
2:00–2:30	0	0	0	0	−1.67
2:30–3:00	0	0	0	0	−1.67
3:00–3:30	0	0	0	0	−1.67
3:30–4:00	0	0	0	0	−1.67
4:00–4:30	0	0	0	0	−1.67
4:30–5:00	0	0	0	0	−1.67
5:00–5:30	0	0	0	0	−1.67
5:30–6:00	0	0	0	0	−1.67
6:00–6:30	0	0	0	0	−1.67
6:30–7:00	0	0	0	0	−1.67
7:00–7:30	0	0	0	0	−0.73
7:30–8:00	10.03	−0.73	9.30	41.92	0
8:00–8:30	10.03	−0.73	9.30	41.92	0
8:30–15:30	0	0	0.00	0	0
15:30–16:00	0	0	0.00	0	−3.33
16:00–16:30	0	0	0.00	0	−3.33
16:30–17:30	0	0	0.00	0	0
17:30–18:00	10.03	−0.73	9.30	41.92	0
18:00–18:30	10.03	−0.73	9.30	41.92	0
18:30–19:00	2.85	−0.42	2.42	12.28	0
19:00–21:30	0	0	0.00	0	0
21:30–22:00	2.85	−0.42	2.42	12.28	0
22:00–22:30	0	0	0.00	0	−1.67
22:30–23:00	0	0	0.00	0	−1.67
23:00–23:30	0	0	0.00	0	−1.67
23:30–24:00	0	0	0.00	0	−1.67

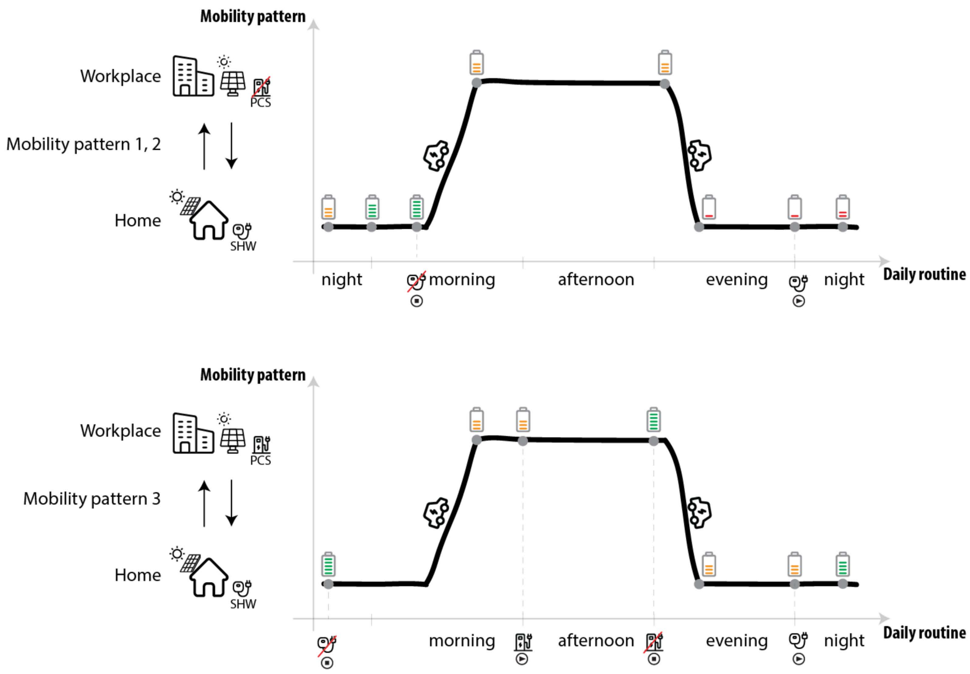

Figure 8. Mobility patterns synthesis.

5. EV Flexibility Service Evaluation

The mobility need must be the primary purpose to which the possible provision of flexibility services to the network is subordinated. Therefore, the end-user, owner of the EV, must provide the operator responsible for ancillary service (balancing service provider—BSP) his daily mobility profile and using it the BSP can plan the services provision.

Two operating scenarios can be considered. The first one concerns the assessment of the flexibility to go upward (injecting energy into the grid as upward flexibility service) or downward (drawing energy from the grid as downward flexibility service) in the hypothesis of home recharging by SHW only. The second one concerns the possibility of EV recharging at the workplace by a PCS also.

In both scenarios, a residual SOC value, equal to 20%, is considered as constraint so to reduce the cyclic degradation of the battery but also to cope with unforeseen mobility needs.

The upward and downward flexibility availability (Flex_{up}, Flex_{do}) for each mobility pattern is evaluated by the following relationships:

$$\text{Flex}_{\text{up},i} = SOC_i - SOC_{min,i} \text{ if } SOC_i > SOC_{min,i}, \quad (4)$$

$$\text{Flex}_{\text{do},i} = SOC_{max,i} - SOC_i \text{ if } SOC_i < SOC_{max,i} \quad (5)$$

where:

$SOC_{min,i}$ is the state of charge of the storage system in the i-th interval to meet the need for residual mobility;

$SOC_{max,i}$ is the maximum state of charge that can be reached by the storage system, set equal to 100%.

5.1. EV Flexibility Capacity Model

5.1.1. Mobility Pattern 1

The EV charging is carried out during the night by the SHW whose nominal power is supposed to be 3.7 kW. The real charging power is equal to 3.33 kW due to the efficiency of the EV's on-board charger which is equal to 0.9.

By observing the progress of the SOC of Figure 5, it is possible to detect the possibility of offering flexibility services.

The results of daily flexibility profile are reported in Figure 9, where it can be observed that during the morning and afternoon working hours, there is the possibility to offer flexibility services to the network, especially in the upward functionality.

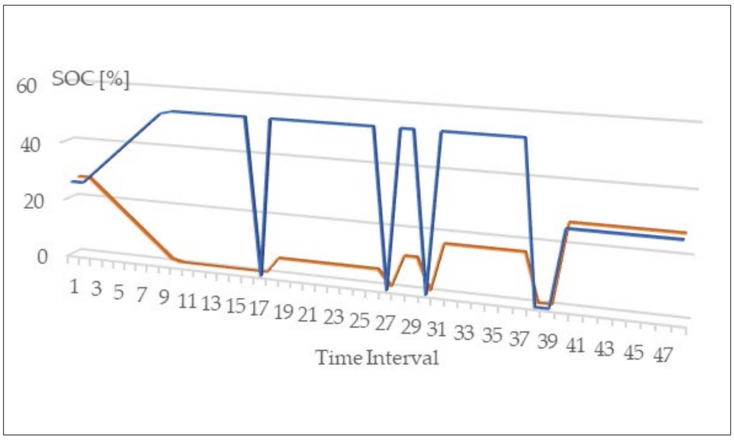

Figure 9. Daily profile of up (blue) and downward (orange) flexibility that the EV can offer.

5.1.2. Mobility Pattern 2

Three charging scenarios are considered as described below:

(a) Charging scenario 1: using the SHW only;

(b) Charging scenario 2: using both the SHW and the PCS;
(c) Charging scenario 3: using both the SHW and the PCS, in which the method of calculating the minimum SOC of mobility has been changed. The energy necessary for mobility needs, with reference to the time slot 8:30/13:00, considers only the need to return home and to the workplace by 15:00, and in this way the up-flexibility increases.

The daily flexibility profiles are shown for both services and for the examined scenarios in Figures 10 and 11.

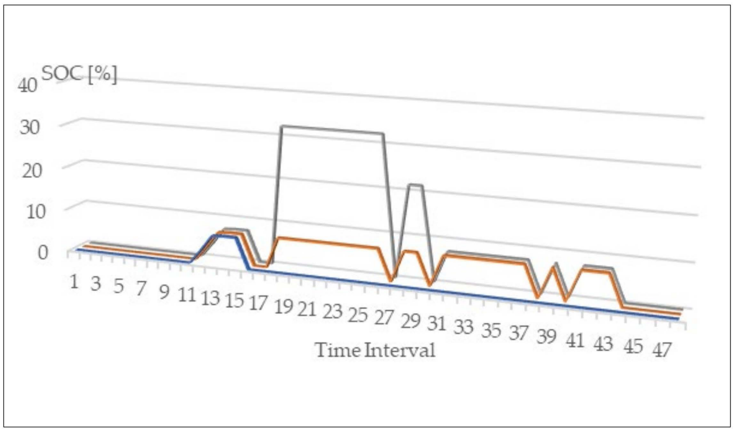

Figure 10. Mobility pattern 2—daily profile of upward flexibility: scenario (a) in blue, scenario (b) scenario in orange, and scenario (c) in grey.

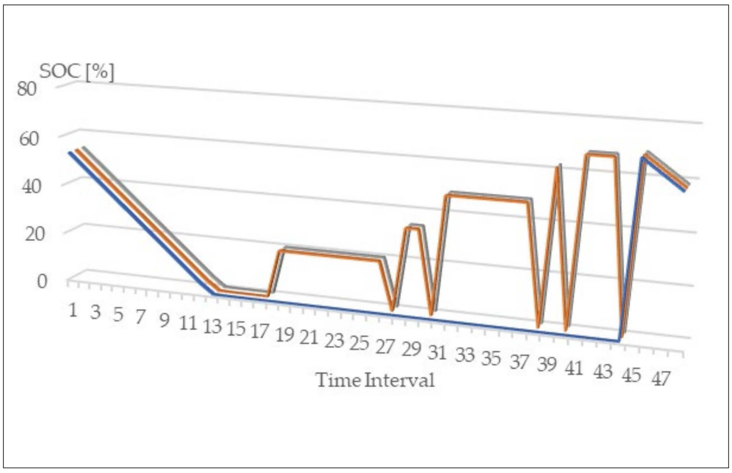

Figure 11. Mobility pattern 2—daily profile of downward flexibility: scenario (a) in blue, scenario (b) scenario in orange, and scenario (c) in grey.

5.1.3. Mobility Pattern 3

In terms of flexibility services that can be offered, the upward flexibility is very limited, as can be seen in Figure 12, due to the high need for mobility. The possibility of recharging in the downward service is high especially in the middle hours of the day.

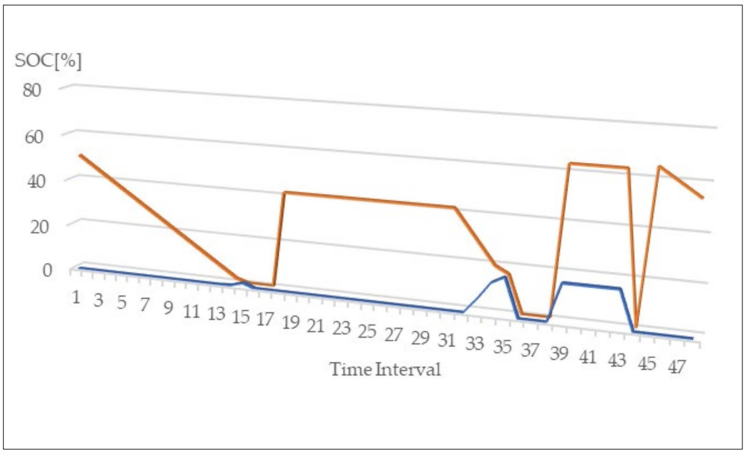

Figure 12. Mobility pattern 3—daily profile of downward (orange) and upward (blue) flexibility.

6. Economic Analysis

In this section, the economic analysis relating to the possibility of offering flexibility services without compromising the end-user's mobility need is illustrated. The economic benefit for the end-user is evaluated for each considered mobility pattern and considering two use cases: (1) EV operating as EV single; and (2) EV operating as belonging to a fleet.

6.1. Use Case 1

6.1.1. Mobility Pattern 1

Three different solutions in terms of supplying the flexibility service are assumed:

- Basic solution: in this case, the upward flexibility is offered in the time slot 5:00/8:00 by the SHW and 8:30/9:30 by the PCS.
- Solution A: the upward flexibility is offered only by the PCS during working hours.
- Solution B: this is a situation like scenario A in terms of recharging infrastructure, but which has a maximum SOC value of the storage system equal to 90%.

The detailed economic evaluation is carried out by considering all of the cost items associated with the domestic recharging phase (to which is added the income from participation in the DSM).

The contractual conditions considered in the analysis concern an end-user in the low voltage enhanced protection regime with annual consumption greater than 1800 kWh. The cost items refer to the Italian electricity market and to the quarter between January and March 2019, in order not to consider the economic effects produced by the Covid-19 pandemic.

A decisive aspect is the sale of the upward and downward flexibility services whose quantifications are based on the evaluation of an average upward and downward price obtained from the daily average with reference to the month of January 2019 in relation to the northern area of the Italian electricity market.

Concerning the daily cost incurred by the end-user, Table 14 shows the numerical results for the three different solutions.

The results show the economic inconvenience to offer flexibility services due to modest revenues respect the increased recharging costs due to the higher rate of energy involved. To make participation in the V2G service attractive, one of the hypotheses that could be adopted involves the reduction of some tariff components. For the basic solution, it is proposed to reduce the cost of recharging energy in the 19:30/01:00 time slot by placing it equal to the average downward price and in the same time interval to cancel the cost items relating to charges, transport, and excise duties.

Table 14. Summary of costs and revenues for the analyzed solutions—mobility pattern 1.

	No Services to the Grid	Basic Solution	Solution A	Solution B
Recharged energy from SWH [kWh]	12.12	31.64	30.87	32.23
Total cost [€]	2.48	6.48	6.32	6.60
Injected energy for upward services [kWh]	0	18.81	18.68	19.98
Revenue for upward services [€]	0	1.64	1.74	1.86
Net daily cost [€]	2.48	4.84	4.59	4.74

6.1.2. Mobility Pattern 2

The upward and downward flexibility service can be provided both by the SHW and the PCS. To make the upward flexibility service available in the working morning hours, it is necessary to restore an adequate charge level in the afternoon, so as to not affect the mobility needs in relation to the post-work and evening time slot. Therefore, the economic evaluation of the service provided must consider the tariff conditions of public recharging that differ from those in use for domestic recharging.

The "other use" contract tariff conditions are applied to the public recharging infrastructure, relating to low voltage end-users with an available power greater than 16.5 kW in the quarter between January and March 2019.

In addition, for mobility pattern 2, three different solutions in terms of supplying the flexibility service are assumed:

- Basic solution: the up-flexibility service is offered during the morning, providing an afternoon recharge by the PCS at the workplace.
- Solution A: the flexibility service is offered in the same range as the basic solution, with the aim of minimizing recharging from the PCS.
- Solution B: in this scenario, the up-and-downward flexibility service is offered by the SHW in the time slot 6:00/7:30 and subsequently also by the PCS.

For the different solutions, by adding the values referring to each time interval, it is possible to obtain the total cost incurred by the end-user. Table 15 summarizes the numerical results relating to the energy and economic rates of the analyzed solutions.

Table 15. Summary of costs and revenues for the analyzed solutions—mobility pattern 2.

	No Services to the Grid	Basic Solution	Solution A	Solution B
Recharged energy from SWH (kWh)	32.71	35.94	42.88	38.91
Total cost [€]	6.70	7.36	8.82	8.01
Recharged energy from PCS	0	11.26	4.33	5.99
Total cost [€]	0	5.08	1.95	2.71
Injected energy for upward services [kWh]	0	14.46	14.46	12.15
Revenue for upward services [€]	0	1.34	1.34	1.09
Net daily cost [€]	6.70	11.11	9.44	9.62

The tariff conditions applied to a domestic customer are cheaper than those applied for charging from the PCS. Indeed, by minimizing the rate of energy recharged from the PCS (solution A) there is a reduction in the daily cost compared to the basic solution.

It is important to highlight that the total cost of charging from the PCS also includes a rate for the management and maintenance of the infrastructure, assumed to be 85 €/MWh. Also, for mobility pattern 2, the increase in the sale price of energy at the DSM and the reduction of some tariff components (transport and charges) make it possible to improve the economic attractiveness of the flexibility service functionality compared to the absence of services offered.

6.1.3. Mobility Pattern 3

Let us consider only the two following solutions:

- Basic solution: the EV during the early morning hours (8: 30/10: 00) provides the pick-up service and recharges in the afternoon to meet mobility needs.
- Solution A: the energy recharged by the PCS is minimized, increasing energy exchanges by the SHW.

Table 16 summarizes the total results relating to the energy and economic rates of the analyzed solutions.

Table 16. Summary of costs and revenues for the analyzed solutions—mobility pattern 2.

	No Services to the Grid	Basic Solution	Solution A
Recharged energy from SWH (kWh)	35.43	35.40	35.24
Total cost [€]	7.26	7.25	7.22
Recharged energy from PCS	6.66	16.65	15.18
Total cost [€]	3.00	7.52	6.85
Injected energy for upward services [kWh]	0	9.99	8.33
Revenue for upward services [€]	0	0.93	0.70
Net daily cost [€]	10.26	13.84	13.38

6.2. Use Case 1 Discussion

From Tables 14–16 the provision of flexibility services results is not economically convenient for a single end-user. A limiting factor is by the cost of recharging which increases with respect to the condition of no services due to the higher rate of energy recharged from the grid to guarantee the daily mobility need. To encourage the increase in the economic attractiveness in order to offer flexibility services, it is necessary to act on the cost of recharging by exploiting supply from renewable sources.

For example, the end-user could have a photovoltaic system with a storage system or become a member of an energy community to minimize the energy taken from the grid. Furthermore, the growing penetration of RES plants requires that the upward flexibility service has to offer in the afternoon and evening hours, while during the day the EV is recharged by exploiting the availability of primary sources (sun and wind) or as part of the downward flexibility service.

In Italy, the start of pilot projects with which new entities, the mixed enabled virtual unit (UVAMs), admitted supplying ancillary services, have been established, brings out an alternative possibility of making the participation economically advantageous for an EV operating in an EV fleet, as illustrated in the following section.

7. Use Case 2

A UVAM is recognized as an eligible unit to participate in the DSM and can obtain not only the remuneration deriving from the offer of the flexibility service but can participate and win long-term supply auctions through which the TSO ensures further margins of flexibility.

7.1. EV Fleet Configuration

The qualification as UVAM imposes certain obligations towards the TSO. The overall flexibility offered must be equal to 1 MW both upward and downward. To obtain the fixed remuneration paid, the service must be provided for at least two consecutive daily hours between 3:00 and 9:00 p.m.

To reach a power of 1 MW, it is assumed that the virtual unit is made up of different parts such as generation units and storage systems so that the EV fleet must provide 50% and 500 kW.

In a first scenario named UVAM, considering the power of the on-board charger unit that equips the Opel Corsa-e equal to 6.66 kW, the number of EV that make up the fleet is obtained by dividing the total capacity offered by the EV-fleet (500 kW), by the power of the EV charger. The obtained number of EVs is equal to 75.

The daily fixed remuneration (CF_g) for each EV is evaluated as [32]:

$$CF_g = CF/12 \cdot N_m \tag{6}$$

where the *CF* (fixed fee) is assumed to be equal to 15.000 €/MW year, while N_m (number of working days) is set equal to 70% of the days of the month of January (15 days), assuming to respect the minimum constraint of obligation to offer.

Then, the fixed daily remuneration for the EV fleet amounts to €81.17/MW, and so a daily fee for each EV is equal to €0.54.

A second scenario, named UVAMbis, considers the increase in the power offered by each EV equipped with a three-phase on-board charger, whose nominal power is equal to 11 kW which become 9.9 kW by counting the power losses. In this way, with the same flexibility offer, the EV fleet consists of 51 EVs, so a daily fee for each EV equal to €0.80 is paid.

For a more profitable aggregated management of the EV fleet, let's consider a parking area realized through PV shelters and equipped with PCSs enabled for V2G functionality. The PV shelter consists of 48 photovoltaic modules connected in 3 strings of 16 modules of P_{nom} = 395 Wp to supply 6 stalls for EV charging with a peak electrical power of 18.96 kWp.

For the evaluation of PV daily generation, it is assumed that the parking area is in the municipality of Settimo Milanese, setting an angle of inclination with respect to the horizontal plane (tilt) equal to 10° while the exposure is supposed to be perfectly aligned to the south direction (azimuth even at 0°). Moreover, the DSM results for the northern area of the Italian electricity market are considered.

The economic convenience of offering flexibility services is evaluated in a similar way to what was carried out for the case of a single EV, by making a comparison between the cost incurred in the absence of services and the outlay resulting from the flexibility provided.

The energy generated by the photovoltaic system is considered, indicated as E_{PV}, equal to the energy requested for recharging ($E_{r,PV}$) if the stall is occupied. Therefore, self-produced energy allows one to reduce the rate to be withdrawn from the grid during the hours of recharging at the workplace ($E_{r,grid}$).

7.2. Economic Benefits Evaluation

7.2.1. Mobility Pattern 1

Three different solutions in terms of supplying the upward and downward flexibility services are assumed:

- Solution A: the EV offers the upward flexibility in the time slots 06:30/08:00 a.m. and 08:00/09:00 p.m. by the SHW, while the recharging takes place in night and morning at home.

- Solution A*: the connection time to the home charging infrastructure is minimized, sufficient to reach the workplace with a residual SOC equal to 35% and so to charge the EV during the working hours using the PCS and the PV generation.
- Solution A**: which derives from solution A* providing that the recharge in the 09:00/11:00 a.m. time slot takes place as a downward flexibility service offer, benefiting from a lower cost than the supply contractual condition as well as deleting the cost of charges and transport components.

The numerical results for the three analyzed solutions are summarized in Table 17 for the UVAM scenario, which shows a reduction in the daily recharge cost considering the reduction in the fixed fee passing from solution A* to scenario A**.

Table 17. Results of different solutions for mobility pattern 1—UVAM.

	No Services to the Grid	**Solution A**	**Solution A***	**Solution A****
Recharged energy from SWH (kWh)	12.19	27.81	5.56	5.56
Total cost [€]	2.27	5.70	1.14	1.14
Recharged energy from PCS	2.5	5.35	17.65	18.67
Total cost [€]	0	2.41	7.97	4.88
Injected energy for upward services [kWh]	0	22.37	13.32	13.32
Revenue for upward services [€]	0	2.01	1.21	1.21
Net daily cost [€]	2.5	5.57	7.36	4.27

In Table 18 the results for UVAMbis scenario are reported. They show the economic convenience for the solution A**, like the UVAM scenario but with a daily net cost slightly increased with respect it.

Table 18. Results of different solutions for mobility pattern 1—UVAMbis.

	No Services to the Grid	**Solution A**	**Solution A***	**Solution A****
Recharged energy from SWH (kWh)	12.19	33.30	11.53	11.53
Total cost [€]	2.27	6.82	2.39	2.39
Recharged energy from PCS	2.5	5.18	17.65	18.67
Total cost [€]	0	2.34	7.97	4.88
Injected energy for upward services [kWh]	0	27.18	19.80	19.80
Revenue for upward services [€]	0	2.45	1.79	1.79
Net daily cost [€]	2.5	5.91	7.76	4.67

7.2.2. Mobility Pattern 2

The obligation to offer the upward flexibility service between 04:30 and 06:30 p.m. requires a change in the energy flow management strategy with respect to the case of a single EV. The solutions analyzed for providing flexibility services are:

- Solution A: the recharging is in the morning by the PCS replacing the discharge of the battery pack to provide the up-ward flexibility service respect to the mobility pattern

1. A charging at night allows to reach a charge level of 90% so to meet the end user's daily mobility needs for the next day.

- Solution A*: Unlike solution A, SOC increases during the morning hours and a controlled discharge is also provided (upward flexibility service) during the time slot 08:00/09:30 p.m.
- Solution A**: similar to the case of mobility pattern 1.

The numerical results for the three analyzed solutions are summarized in Table 19 for the UVAM scenario. It is worth noting that solution A** is always the more economically convenient option.

Table 19. Results of different solutions for mobility pattern 2—UVAM.

	No Services to the Grid	Solution A	Solution A*	Solution A**
Recharged energy from SWH (kWh)	32.73	36.13	27.27	27.27
Total cost [€]	6.71	7.40	5.62	5.62
Recharged energy from PCS	0	14.33	22.42	23.45
Total cost [€]	0	6.47	10.12	7.03
Injected energy for upward services [kWh]	0	19.98	19.98	19.98
Revenue for upward services [€]	0	1.81	1.81	1.81
Net daily cost [€]	6.71	11.53	13.39	10.30

For the UVAMbis scenario, the greater offer of flexibility provided by the EV requires that one modify the solutions A and the A*. For solution A, the offer of the upward flexibility service in the 08:00/09:00 time slot is replaced by the recharge phase to guarantee an adequate residual SOC equal to 18.3%, sufficient for coming back to home.

For solution A*, there is an increase in the energy stored in upon departure from home in the morning compared to the UVAM scenario, to which is associated a SOC% equal to 82.1% meant to cope with the increased demand for flexibility in the afternoon.

In Table 20 the numerical results for UVAMbis scenario are reported. They show that the more economically suitable solution is solution A**, as with the UVAM scenario with a daily net cost slightly decreased.

Table 20. Results of different solutions for mobility pattern 2—UVAMbis.

	No Services to the Grid	Solution A	Solution A*	Solution A**
Recharged energy from SWH (kWh)	32.73	35.96	33.79	33.79
Total cost [€]	6.71	7.37	6.95	6.95
Recharged energy from PCS	0	17.30	19.56	20.12
Total cost [€]	0	7.81	8.83	5.74
Injected energy for upward services [kWh]	0	23.13	23.13	23.13
Revenue for upward services [€]	0	2.08	2.10	2.10
Net daily cost [€]	6.71	12.29	12.89	9.80

7.2.3. Mobility Pattern 3

Mobility pattern 3 requires a significant energy demand for daily mobility need with the direct impossibility of considering different solutions for offering flexibility service. Therefore, in the two scenarios, UVAM and UVAMbis, the technical and economic analysis of solutions A and A* is assessed only.

The upward flexibility service is guaranteed from 15:30 to 17:30, which is one hour ahead of mobility patterns 1 and 2 due to the different daily mobility need.

The recharging in the morning by the PCS allows to reach a SOC equal to 99.4% with the aim of offering the upward flexibility service as prescribed by the UVAM rules, without affecting the end-user mobility need of the afternoon which requires a SOC_{min} of 67.2%. Moreover, the residual SOC at the time slot in which the end-user returns to home does not drop below the level of 20%. Finally, for the time slot 09:30/10:00 p.m. a recharge is carried out via the SHW.

The solution A* considers a downward flexibility service from 9:00 to 11:00. The numerical results for the analyzed solutions are summarized in Table 21 for UVAM scenario. The solution A* is the more convenient.

Table 21. Results of different solutions for mobility pattern 3—UVAM.

	No Services to the Grid	Solution A	Solution A*
Recharged energy from SWH (kWh)	35.43	37.09	37.09
Total cost [€]	7.26	7.60	7.60
Recharged energy from PCS	6.66	16.31	17.33
Total cost [€]	3.00	7.36	3.21
Injected energy for upward services [kWh]	0	13.32	13.32
Revenue for upward services [€]	0	1.20	1.20
Net daily cost [€]	10.26	13.22	9.07

In the UVAMbis scenario, a single strategy of offering flexibility to the network is considered that is the solution A. The greater availability of flexibility request causes the impossibility of guaranteeing the residual charge level of the battery pack to satisfy the end-user mobility need. An upward flexibility service can be guaranteed only in the time slot of 03:30/05:30 p.m.

7.3. Use Case 2 Discussion

Comparing the different mobility patterns for each solution in UVAM scenario, and also considering the fixed fee recognized, an economic convenience is only observed for the solution A* for the mobility pattern 3, due to the low revenues for the remuneration of the upward flexibility service. The result does not change also if the fleet consists of a lower number of EVs (UVAMbis scenario). The higher fixed daily fee amounting to €0.80 does not produce a significantly contained net daily cost so to encourage the end-user to provide the expected flexibility.

From a purely theoretical point of view, an EV fleet management strategy that would make it cost effective is to offer services for only one day of the month in question. Indeed, assuming Nm in eq. 2 equal to 1, the daily fixed fees is €8.33 for the UVAM scenario and €12.38 for the UVAMbis one. The economic convenience would be guaranteed for the solutions related to mobility pattern 1. Nonetheless, this operating mode is in contravention with the regulatory constraint of a minimum number of working days in a month in which the aggregate must submit offers for upward or downward flexibility services.

To make joining the EV fleet by an end-user attractive from an economic point of view to participate in the DSM, it is necessary to put forward some management hypotheses that consider some proposals suggested by ARERA [33].

The possible scenarios, investigated in the following sections, are:

(a) Scenario B: return of some tariff components relating to the energy withdrawn from the grid and subsequently reinjected.
(b) Scenario C: return of some tariff components relating to the energy adsorbed from the grid and subsequently reinjected, to which is added the possibility of recharging the EV using local generation as self-consumption (PV and/or storage system), as illustrated in Figure 13. It is supposed that the PV plant already exists and only a part of its energy is used to supply the EV, in particular, the self-produced energy by the PV plant will be equal to the 50% of the energy consumed by the SWH.

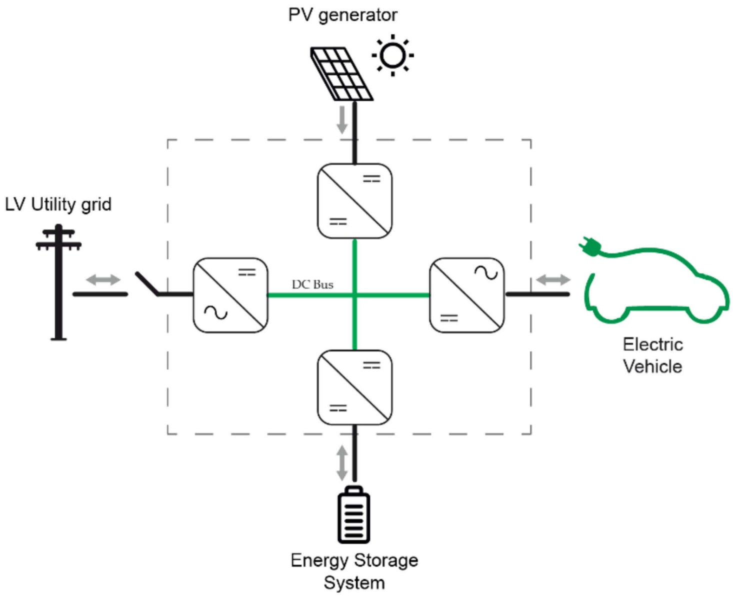

Figure 13. Possible configuration of a charging station.

7.3.1. Scenario "B"

The EV as a storage system is recognized, pursuant to some specific Italian decrees, to exemption of some tariff components for the electricity quantity withdrawn and subsequently reinjected into the grid, such as general charges, transport, and dispatching. These tariff components vary depending on whether it consider a domestic supply (by SHW) or a supply of the "other uses" type (by PCS). Therefore, the cost component that gives the right to the exemption is calculated as a weighted average between the economic conditions associated with each charging mode, taking as weights the rates for the energy recharged by the SHW and PCS. The numerical results for the mobility pattern 1 show (see Tables 22 and 23) for both scenarios, UVAM e UVAMbis that only the solution A** ensures a small profit margin for both assets thanks to the tariff reduction enjoyed by the downward flexibility service.

Also, for mobility pattern 2 the same trend can be observed for both scenarios, UVAM e UVAMbis (Tables 24 and 25). In the last, for mobility pattern 3 only the results for the UVAM scenario can be provided since the EV mobility need does not reconcile with the increased supply of flexibility service of the UVAMbis scenario (Table 26).

Table 22. Results for mobility pattern1—UVAM (Scenario B).

	No Services to the Grid	Base Solution	Solution A*	Solution A**
Recharged energy from SWH (kWh)	12.19	27.81	5.56	5.56
Total cost [€]	2.50	5.70	1.14	1.14
Recharged energy from PCS	0	5.35	17.65	18.67
Total cost [€]	0	2.41	7.97	4.88
Injected energy for upward services [kWh]	0	22.37	13.32	13.32
Revenue for upward services [€]	0	2.01	1.21	1.21
Return of tariff components [€]	0	2.30	2.19	1.82
Fixed fee [€]	0	0.54	0.54	0.54
Net daily cost [€]	2.5	3.27	5.17	2.45

Table 23. Results for mobility pattern1—UVAMbis (Scenario B).

	No Services to the Grid	Base Solution	Solution A*	Solution A**
Recharged energy from SWH (kWh)	12.19	33.30	11.53	11.53
Total cost [€]	2.50	6.82	2.39	2.39
Recharged energy from PCS	0	5.18	17.65	18.67
Total cost [€]	0	2.34	7.97	4.88
Injected energy for upward services [kWh]	0	27.18	19.80	19.80
Revenue for upward services [€]	0	2.45	1.79	1.79
Return of tariff components [€]	0	2.72	2.94	2.35
Fixed fee [€]	0	0.8	0.8	0.8
Net daily cost [€]	2.5	3.19	4.82	2.32

Table 24. Results for mobility pattern 2—UVAM (Scenario B).

	No Services to the Grid	Base Solution	Solution A*	Solution A**
Recharged energy from SWH (kWh)	32.73	36.13	27.27	27.27
Total cost [€]	6.71	7.40	5.62	5.62
Recharged energy from PCS	0	14.33	22.42	23.45
Total cost [€]	0	6.47	10.12	7.03
Injected energy for upward services [kWh]	0	19.98	19.98	19.98
Revenue for upward services [€]	0	1.81	1.81	1.81
Return of tariff components [€]	0	2.31	2.65	2.28
Fixed fee [€]	0	0.54	0.54	0.54
Net daily cost [€]	6.71	9.22	11.28	8.02

Table 25. Results for mobility pattern 2—UVAMbis (Scenario B).

	No Services To The Grid	Base Solution	Solution A*	Solution A**
Recharged energy from SWH (kWh)	32.73	35.96	33.79	33.79
Total cost [€]	6.71	7.37	6.95	6.95
Recharged energy from PCS	0	17.30	19.56	20.12
Total cost [€]	0	7.81	8.83	5.74
Injected energy for upward services [kWh]	0	23.13	23.13	23.13
Revenue for upward services [€]	0	2.08	2.10	2.10
Return of tariff components [€]	0	2.77	2.87	2.39
Fixed fee [€]	0	0.8	0.8	0.8
Net daily cost [€]	6.71	9.52	10.02	7.41

Table 26. Results for mobility pattern 3—UVAM (Scenario B).

	No Services to the Grid	Base Solution	Solution A*
Recharged energy from SWH (kWh)	35.43	37.09	37.09
Total cost [€]	7.26	7.60	7.60
Recharged energy from PCS	6.70	16.31	17.33
Total cost [€]	3.00	7.36	4.08
Injected energy for upward services [kWh]	0	13.32	13.32
Revenue for upward services [€]	0	1.20	1.20
Return of tariff components [€]	0	1.57	1.28
Fixed fee [€]	0	0.54	0.54
Net daily cost [€]	10.26	11.66	8.66

7.3.2. Scenario "C"

It is considered that the rate of PV generation consumed and/or supplied by a local storage system for charging the EV battery is equal to 50% of the entire amount of energy recharged by the SHW. The numerical results for mobility pattern 1, summarized in Tables 27 and 28, highlight the economic convenience obtaining a net daily cost lower than that associated with the case without services.

The UVAMbis scenario is particularly profitable thanks to the higher rate of energy offered as a flexibility service that allows to obtain a greater income due to the increase in the daily fee. For both scenarios the solution A* is not advantageous since it provides for the predominance of charging from the PCS whose tariff conditions are less profitable than SHW. However, it is evident that recharging through public infrastructure offered as a downward service (solution A**) plays a positive role. It should be underlined that the solution with no service does not include the presence of a domestic photovoltaic system with storage system for recharging the EV.

Table 27. Results for mobility pattern 1—UVAM (Scenario C).

	No Services to the Grid	Base Solution	Solution A*	Solution A**
Recharged energy from SWH (kWh)	12.19	27.81	5.56	5.56
Self-consumption energy recharged [kWh]	0	13.90	2.78	2.78
Total cost [€] without self-consumption	2.50	5.70	1.14	1.14
Total cost [€] with self-consumption	0	2.85	0.57	0.57
Recharged energy from PCS	0	5.35	17.65	18.67
Total cost [€]	0	2.41	7.97	4.88
Injected energy for upward services [kWh]	0	22.37	13.32	13.32
Revenue for upward services [€]	0	2.01	1.21	1.21
Return of tariff components [€]	0	2.21	2.33	2.05
Fixed fee [€]	0	0.54	0.54	0.54
Net daily cost [€]	2.50	0.51	4.45	1.65

Table 28. Results for mobility pattern 1—UVAMbis (Scenario C).

	No Services to the Grid	Base Solution	Solution A*	Solution A**
Recharged energy from SWH (kWh)	12.19	33.30	11.53	11.53
Self-consumption energy recharged [kWh]	0	16.65	5.77	5.77
Total cost [€] without self-consumption	2.50	6.82	2.39	2.39
Total cost [€] with self-consumption	0	3.41	1.21	1.21
Recharged energy from PCS	0	5.18	17.65	18.67
Total cost [€]	0	2.34	7.97	4.88
Injected energy for upward services [kWh]	0	27.18	19.80	19.80
Revenue for upward services [€]	0	2.45	1.79	1.79
Return of tariff components [€]	0	2.41	3.24	2.69
Fixed fee [€]	0	0.80	0.80	0.80
Net daily cost [€]	2.50	0.09	3.34	0.80

Also, mobility pattern 2 is to incite the end-user to offer the flexibility service thanks to the economic benefit (Tables 29 and 30). Finally, Table 31 highlights the economic convenience of the mobility pattern 3 in both two solutions.

Table 29. Results for mobility pattern 2—UVAM (Scenario C).

	No Services to the Grid	Base Solution	Solution A*	Solution A**
Recharged energy from SWH (kWh)	32.73	36.13	27.27	27.27
Self-consumption energy recharged [kWh]	0	18.06	13.64	13.64
Total cost [€] without self-consumption	6.71	7.40	5.62	5.62
Total cost [€] with self-consumption	0	3.70	2.82	2.82
Recharged energy from PCS	0	14.33	22.42	23.45
Total cost [€]	0	6.47	10.12	7.03
Injected energy for upward services [kWh]	0	19.98	19.98	19.98
Revenue for upward services [€]	0	1.81	1.81	1.81
Return of tariff components [€]	0	2.63	3.00	2.60
Fixed fee [€]	0	0.54	0.54	0.54
Net daily cost [€]	6.71	5.19	7.60	4.91

Table 30. Results for mobility pattern 2—UVAMbis (Scenario C).

	No Services to the Grid	Base Solution	Solution A*	Solution A**
Recharged energy from SWH (kWh)	32.73	35.96	33.79	33.79
Self-consumption energy recharged [kWh]	0	17.98	16.90	16.90
Total cost [€] without self-consumption	6.71	7.37	6.95	6.95
Total cost [€] with self-consumption	0	3.68	3.49	3.49
Recharged energy from PCS	0	17.30	19.56	20.21
Total cost [€]	0	7.81	8.83	5.74
Injected energy for upward services [kWh]	0	23.13	23.13	23.13
Revenue for upward services [€]	0	2.08	2.10	2.10
Return of tariff components [€]	0	3.16	3.27	2.68
Fixed fee [€]	0	0.80	0.80	0.80
Net daily cost [€]	6.71	5.44	6.15	3.66

Table 31. Results for mobility pattern 3—UVAM (Scenario C).

	No Services to the Grid	Base Solution	Solution A*
Recharged energy from SWH (kWh)	35.43	37.09	37.09
Self-consumption energy recharged [kWh]	0	18.55	18.55
Total cost [€] without self-consumption	7.26	7.60	7.60
Total cost [€] with self-consumption	0	3.80	3.80
Recharged energy from PCS	6.66	16.31	17.33
Total cost [€]	3.00	7.36	4.08
Injected energy for upward services [kWh]	0	13.32	13.32
Revenue for upward services [€]	0	1.20	1.20
Return of tariff components [€]	0	1.79	1.39
Fixed fee [€]	0	0.54	0.54
Net daily cost [€]	10.26	7.63	4.75

7.4. Final Use Case 2 Discussion

The economic convenience to provide flexibility service is not reached in scenario B for most of the analyzed solutions. Favorable conditions are registered for mobility pattern 1 (solution A**) for both scenario UVAM and UVAMbis due to the rate of energy recharged as a downward flexibility service subject to lightened economic conditions, an aspect in common with mobility pattern 3 (solution A*).

The increase in the revenue recognized in the case of UVAMbis scenario, due to the reduction in the number of EV in the fleet, allows for an increase in the profit margin of the two solutions mentioned above.

Scenario C is promising for the management of an EV fleet due to the possibility of recharging by exploiting the PV power produced and also stored in a storage system coupled with the system itself. The solutions in which the recharging by the PCS is minimized, such as solution A, are economically convenient. The economic attractiveness becomes even more tangible in the case of the UVAMbis scenario, where the differences between the costs incurred with and without services are considerable.

It should be noted that scenario C may represent a situation not too far from real-life. Indeed, in Italy, considering the actual RES incentive mechanism of the Superbonus 110% [34], it is possible to install a PV plant integrated with a storage system and a SHW with a zero outlay for the end-user.

This different use case and in particular Scenario C shows how the incentive tools are necessary to make V2G economic suitable and how there is an active and constant development of the remuneration opportunity which allows one to earn end-users that would not have otherwise had economic profitability (as explained also in [5]).

8. Conclusions

In this paper, the authors have proposed the EVflex methodology to explore the technical capacity of an EV in order to provide a network flexibility service which prioritizes satisfying the user daily mobility need and evaluating the economic convenience in the two cases of a single EV and an EV belonging to a fleet.

After having illustrated the methodology, it is shown that it can be easily used and adapted to the current regulatory framework. Indeed, the methodology is applied to various case studies which consider the Italian regulatory and incentive framework, highlighting the economic results.

The obtained numerical results have demonstrated that the proposed EVflex methodology allows one to assess the technical feasibility and the economic convenience in providing flexibility services to the grid by an EV, considering as input data the user daily mobility routine and the type of EV used.

Three mobility patterns are individuated, which are intended to best represent the real conditions of EV use: mobility pattern 1 which is predominantly urban, and mobility patterns 2 and 3 which are predominantly extra-urban. The weight of short trips, characterized by less than 50 km, is predominant in the current use of EVs. Therefore, mobility pattern 1, which has 61.4 km above the limit value of 50 km, represents over 50% of the recorded use cases [8]. Mobility patterns 2 and 3 foresee distances greater than 100 km, representative of a more demanding use of the vehicle which, however, at present is carried out on a weekly basis in 27% of cases and daily in just 9% of cases [8].

From the numerical results, the main parameters that significantly influence the technical-economic possibility of the EV participation in offering flexibility services are summarized below.

8.1. Economic Charging Conditions

As evidenced by the numerical results in all three analyzed mobility patterns, the return of the tariff components due to the charges and transport for the energy rate reinjected into the grid or in the hypothesis of downward flexibility service significantly reduces the net daily cost.

8.2. RES Generation and Self-Consumption

The presence of an integrated PV-storage system opportunely coordinated with the SHW allows one to reduce or delete the recharge cost, minimizing the withdrawal from the grid (scenario C).

A considerable economic convenience for both scenario B and C is due to the condition according to which the energy injected as an upward flexibility service consists of an energy rate as self-consumption associated with a zero-production cost and a remuneration according to the average price to rise, while the remaining part withdrawn from the network is entirely worthy of the exemption from the tariff components, optimizing the revenue for the end-user.

Solution A* is the least advantageous from an economic point of view in all of the cases analyzed due to the increase in the rate of energy absorbed from the grid by the PCS which is not subject to tariff components exemptions. Therefore, in the case of prevalence of recharging by PCS, the inclusion of the PCS within an energy community could be particularly useful in order to recharge the EV as shared energy, benefiting from incentives provided [35] and reducing the recharge cost for the end-user. This additional incentive, which has not been considered in the analysis carried out (since it is currently not well regulated) can make solution A* even more economically attractive.

8.3. Flexibility Service Remuneration

From the numerical results, the economic convenience lies in increasing the rate of energy recharged from the grid as a downward flexibility service that allows a lower energy cost (A** and A* solutions). The price recognized for the upward flexibility service in the case of UVAM is not good insofar as it increases recklessly in order not to result in the network operator's rejection of the offer, considering that the EVs of the fleet are perfectly equivalent to other units enabled for the DSM (in the spirit of technological neutrality).

8.4. UVAM Fixed Benefit

The fixed amount recognized to the members of the fleet depends on the fixed tariff with which the UVAM was awarded the auction procedure. It should be noted that in the scenario of widespread use of fleets of DSM-enabled EV, the single virtual unit will have to offer the flexibility service at a lower cost than the auction base to be selected by the network operator, thereby reducing the fixed benefit. As highlighted from the numerical results, the economic convenience of offering flexibility services is not guaranteed by the fixed remuneration, the influence of which becomes significant only as the number of the aggregate decreases (i.e., UVAMbis scenario).

Finally, the numerical results show that from a technical point of view greater flexibility is offered by mobility pattern 1 for all considered scenarios. Mobility pattern 1 is particularly successful since the energy is poured into the network not only in the time slot 04:30/06:30 p.m. but also in the early morning and evening hours when the safety of the electrical system is compromised by the high load power demand characterized by high gradients. From an economic point of view, mobility patterns 1 and 3 are particularly advantageous for solution A.

Future work will be focused on the design of a online tool that implements the proposed EVflex methodology.

8.5. Summary Economic Results

After having illustrated the evaluation methodology and having applied it to the Italian regulatory context, it was observed how, depending on the different mobility patterns, there may or may not be some economic convenience as well as some technical feasibility. It was observed that the predominantly urban mobility pattern is the pattern that always presents an economic convenience, contrary to the mobility patterns which are are prevalently extra-urban. In fact, the latter become convenient if other incentive mechanisms are considered. It is supposed to consider end-users as part of a UVAM, so they can receive the different forms of incentives.

Subsequently, it is assumed that part of the energy used to recharge the vehicle is self-produced through a pre-existing PV plant.

The major issue, which occurs when considering the extra-urban patterns, is mainly a result of the need to recharge the EV from the PCSs which generally have a higher recharge cost.

These costs could be lowered if there were incentive systems that would reduce them, or if, for example, these PCS were part of a renewable energy community (REC) for which it would be more incentivized.

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Abbreviations

ARERA	Italian Regulatory Authority for Energy, Networks and the Environment
DSM	Dispatching Services Market
EV	Electric Vheicle
EVSE	Electric Vehicle Supply Equipment
NEDC	New Europea Driving Cycle
PCS	Public Charge Station
PV	Photovoltaic

RES	Renewable Energy Sources
SHW	Smart Home Wall box
SO	System Operator
SOC	State of Charge
TSO	Transmission System Operator
V1G	Smart Unidirectional Charge
V2G	Vehicle-to-Grid (bidirectional)

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