EV Flexibility Supply via Participation in Balancing Services: Possible Profitability for Italian End Users

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***Abstract*—Thanks to their fast and highly controllable power response, Battery Energy Storage Systems (BESS), including those in Electric Vehicles (EVs), could usefully contribute to ancillary service supply, thus enhancing power system flexibility. In this work, the supply, by EVs, of balancing services on the Italian Balancing Market (BM) is simulated, to inquire the related possible profitability for the EV owners. More precisely, for a domestic and a non-domestic end user, with different recharge needs, the EV electricity bill related to supplying the service - in a one-directional (V1G) or bi-directional (V2G) way - while recharging is evaluated, in comparison to carrying out standard ("benchmark") recharge where energy is assumed to be bought at day-ahead market prices. A sensitivity analysis of the results is carried out, by adopting different (although constant) prices to bid for the service. With the V2G recharge, the increased energy exchanges, with respect to the V1G and to the benchmark recharge, can yield increased bills due to the charges and taxes on such exchanges. However, both for the V1G and for the V2G recharge, price regions are found for which the service can be deemed to be profitable, i.e. with the bill lower than or equal to the benchmark bill. The profitability price regions are widened, and the maximum saving with respect to the benchmark bill is increased, if partial reliefs from charges in the bill and/or an additional remuneration for capacity availability are introduced.**

***Index Terms*—battery energy storage system, balancing service, electric vehicle, V1G, V2G**

I. Introduction

Variable and unpredictable power flows generated from non-programmable renewable energy sources can deeply affect needs related to Ancillary Service (AS) supply, both for voltage and for frequency regulation. Increased performance, e.g. in terms of speed of response or ramp rates, is needed [1], [2]. Besides, since conventional power plants have to be shut down more frequently, support from other assets could become necessary. Thanks, e.g., to their fast power response, easy control and scalability, Battery Energy Storage Systems (BESS) can supply different, and also combined, AS [3]–[7]. However, cost-benefit analyses are needed to inquire AS profitability for BESS owners, since BESS investment costs are still rather high [8]. Besides, the limited amount of stored energy can cause temporary unavailability to do a service and thus economic penalties, and battery aging due to non-standard charge-discharge cycles related to the service itself can require additional costs for early battery replacement [5], [6].

This work starts from the recent measures (see Decision 300/2017/R/EEL [9]) taken by the Italian Regulatory Authority for Energy, Networks and the Environment to open the Ancillary Service Market (ASM) to new providers, including BESS and also aggregated storage units (within Virtual Eligible Units - VEUs). Thus, attention is here devoted to the possible supply of Balancing Services (BS) by the small distributed BESS installed in Electric Vehicles (EVs). In particular, their participation in the Italian ASM real-time stage, called Balancing Market (BM), is simulated (for simplicity, the ASM procurement stage, called *ex-ante* ASM, is not considered).

In [10], a simple heuristic bidding strategy for EVs to participate in the Italian BM to supply BS (the set of active power "step variation" services) is proposed. The EV daily recharge is assumed to be carried out, as far as possible, by doing the service, as an alternative to the usual recharge - assumed as a *benchmark* - carried out by buying all the energy on the Day-Ahead Market (DAM). The energy exchanges carried out with the strategy and the EV user's annual electricity bill thus obtained are compared to the ones of the Benchmark Recharge (BR). In this work, the possible profitability, for the EV owners, of recharging their EVs by supplying BS is inquired. More precisely, by using the same computational approach (described in Sections II, III, IV), a sensitivity analysis of the strategy results is carried out with respect to the prices adopted to bid for the service (in [10], only the hourly average accepted

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prices are used), with particular care for how the bill is affected (Section V). Conclusions are drawn in Section VI.

II. Assumptions and Methodology

As in [10], attention is focused on a single electric car, assumed, for simplicity, to participate directly in the energy market, here the DAM, and in the BM. The interaction of its owner with a balancing responsible party or with a Balancing Service Provider (BSP) aggregating multiple distributed resources is neglected.

We recall that each bid on the BM consists of an energy quantity $\Delta E_{bid}(h)$ (MWh) and a unit price $p_{bid}(h)$ (€/MWh), with reference to each hour h within a BM session. Bid acceptance/rejection is on a quarter-of-an-hourly basis; if a bid is accepted, it is paid as bid and a dispatching order is issued by the Transmission System Operator (TSO) so that the BESS has to exchange the accepted quantity. For each hour h, $\Delta E_{bid}(h)$ is assumed here to be associated to power $P_{bid}(h) = \Delta E_{bid}(h)/1$ h (MW) and, in case of acceptance in a quarter of an hour ($\frac{1}{4}$ h) in hour h, the accepted energy in that $\frac{1}{4}$ h is assumed to be the whole $P_{bid}(h) \cdot \frac{1}{4}$ h $= \Delta E_{bid}(h)/4$, with the related accepted power $P_{bid}(h)$. Therefore, in the following, reference is made equivalently to the power or the energy associated to a bid. The amounts of energy or power absorbed from the grid or bought (injected into the grid or sold) by the EV, i.e. by the recharge infrastructure, are assumed to be ≥ 0 (≤ 0, respectively). Upward and downward bids, respectively, for the upward and downward service are labeled here as "UPs" and "DWs"; the related unit prices (in €/MWh) are indicated as $p_{UP}(h)$ and $p_{DW}(h)$, respectively, and the related bid power values (in MW) as $P_{UP}(h)$ and $P_{DW}(h)$, respectively. We also recall that, letting E_n be the battery nominal energy and $E(t)$ the energy content at time t, the battery State of Charge (SoC) at time t can be simply defined as $SoC(t) := E(t)/E_n$. Here t is measured in $\frac{1}{4}$ h.

The algorithm described in [10] to simulate one-directional (V1G, allowing only absorption from the grid) or bi-directional (V2G, allowing also injection into the grid) EV recharge, via participation in the BM to supply the BS, is adopted here. Its aim is to make the EV recharge by a pre-defined amount of internal energy ΔE_{rech} during a pre-defined time interval T_r called *recharge period*, spanning some hours from time t_{ini} to time t_{end}; the algorithm is repeated for the recharge periods of all the days or of a set of days in a year. At the beginning of T_r, the battery SoC (SoC_{ini}) is assumed to be known, so the aim is to reach a target value $SoC_{tgt} = SoC_{ini} + \Delta E_{rech}/E_n$ for the SoC (but trying to avoid reaching a higher value [10]) at the end of T_r; if SoC_{tgt} cannot be reached by service supply only, the recharge left to carry out, called the "residual" recharge, is simulated as to be obtained by absorbing energy bought at the DAM price. The EV energy exchanges are simulated also taking into account the possible presence of a recharge program. This consists of a pre-established power absorption profile $P_{prg}(h), h \in T_{prg}$, declared in advance by the EV owner with reference to a time interval T_{prg} included in T_r; thus, it is assumed as an input for the bidding algorithm.

The power made available by the EV for recharging, so for the service, is assumed to be identical for each considered day and equal to P_n, which is the maximum recharging power of the considered recharge infrastructure; the maximum power with which the EV BESS can charge or discharge, called $P_{max,abso}$ and $P_{max,erog}$ respectively, are assumed to be both equal to P_n. The bidding algorithm simulates, throughout T_r,

- the hourly formulation of bids on the BM by the EV;
- the bid acceptance or rejection by the TSO, on a quarter-of-an-hourly basis;
- hourly energy purchases on the DAM by the EV; these can be for the residual recharge or, if present, for the recharge program, to which BS supply is superimposed.

Bids on the BM and energy purchases on the DAM are issued, for simplicity, neglecting the actual timetable of the market sessions. For comparison, the algorithm also computes the hourly energy exchanges, purchased on the DAM, for the BR.

Bid acceptance is simulated according to a simple *ex post* criterion [10], [11]. Let $h(t)$ be the hour to which $\frac{1}{4}$ h t belongs. An UP (DW, respectively) issued for hour $h(t)$ is assumed to be accepted in t if its price $p_{UP}(h(t)) \leq$ the maximum historical price accepted for UPs ($p_{DW}(h(t)) \geq$ the minimum historical price accepted for DWs) in t. If, in $h(t)$, the algorithm issues both an UP and a DW and these are both acceptable based on such price comparison, then the UP (the DW, respectively) only is assumed to be accepted in t if the total quantity historically accepted in t for UPs (DWs) is greater than the total quantity historically accepted in t for DWs (UPs); if the two total historical accepted quantities are the same, then the UP is assumed to be accepted. Since the profitability evaluations in this work are performed *ex post*, the prices to be used in the bids on the BM are taken as input data, and so is the price of energy purchases on the DAM [12]. This last is assumed as the Unique National Price (UNP, in Italian "Prezzo Unico Nazionale" - PUN).

In the presence of a recharge program, in addition to the pay-as-bid remuneration for the energy exchanged for the BS, the EV is assumed to gain also a capacity remuneration, with unit price R_{cap} (€/MW/yr), similar to the one foreseen for VEUs pilot projects [13]. Of course, $P_{prg}(h) \leq P_n, \forall h$. Here, for simplicity, $P_{prg}(h) = P_{prg} = const$ and T_{prg} is at the beginning of T_r: the first three hours of T_r, as in [10] again.

After running the bidding algorithm for the recharge periods considered in a year, the related overall annual energy exchanges with the grid are computed, together with their overall economic value, and finally the annual electricity bill for the EV recharge is evaluated. In the bill, the fixed costs related to the connection point to the grid are neglected, since they are assumed as not to be affected by the new recharge mechanism; only the costs and revenues proportional to energy exchanges are considered: i) the costs for energy purchase on the BM for downward BS supply or for energy purchase on the DAM (for residual recharge or for the recharge program); ii) the costs for charges (system charges, network and metering charges, dispatching charges and other charges), the excise taxes and the Value Added Tax (VAT); iii) the revenues for the energy sold on the BM for upward BS supply. In case a recharge program is present, the remuneration for capacity made available, namely $R_{cap} \cdot P_{prg} \cdot 1yr$, is considered too.

III. Bidding Algorithm

With reference to each recharge period T_r simulated, the implemented bidding strategy is summarized in Table I.

Values $P_{DW}(h)$ and $|P_{UP}(h)|$ (each of which can also be zero) are the maximum compatible with the SoC at the beginning of hour h, the SoC_{tgt} value, P_n and the time left, in hours, to t_{end} (the end of T_r): this to have the EV battery always able, in case of acceptance, to exchange the bid power and thus not to incur imbalances associated with incomplete service supply, since they could imply economic penalties.

As t_{end} approaches, if the SoC has not reached SoC_{tgt} yet and there is not time enough left to reach it by playing on the BM, then the residual recharge is carried out: the EV is charged, from the current hour to t_{end}, up to SoC_{tgt} without participating in the BM, but by absorbing (for sure) energy bought on the DAM, at the UNP (see [10] for more details).

For each recharge period T_r, the BR is also simulated. If, in particular, t_{ini} and t_{end} are expressed as integer hours and are on two consecutive days, as it occurs in overnight recharge (starting in the evening on a day and ending in the morning on the next day), then the BR is assumed to be carried out for $N_h := t_{end} + 24h - t_{ini}$ hours starting from t_{ini}, at power

$$P_{DAM,bnc} = \min\left(P_{max,abso}, \frac{P_{max,abso}\Delta E_{rech}}{N_h P_{max,abso}\eta_{ch}}\right), \quad (1)$$

where η_{ch} is the EV BESS charge efficiency.

The overall energy exchanges (in MWh) obtained running the algorithm with reference to a one-year time interval are listed in Table II; in brackets, if needed, there are the related average prices (expressed in €/MWh), computed as the ratio of the overall costs or revenues related to such overall energy exchanges and the overall energy exchanges themselves.

IV. Bill Computation

Starting from the energy exchanges computed by the bidding algorithm, the end user's electricity bill along a year is computed, according to different options for comparison purposes. Let p_{on} (€/MWh) be the average price of all the charges; p'_{on} (€/MWh) the average price of the sum of the system charges and the network and metering charges; p_{ex} (€/MWh) the excise price. The annual bill for the BR (no participation of the EV in the BM) is

$$C_1 = Q_{DAM,bnc}(p_{DAM,bnc} + p_{on} + p_{ex})(1 + VAT). \quad (2)$$

The annual bill in case of participation of the EV in the BM, simulated via the described bidding strategy, is

$$\begin{aligned} C_2 = [&Q_{DW}p_{bal,abso} + Q_{DAM,res}p_{DAM,res} + \\ &+ Q_{DAM,prg}p_{DAM,prg} + Q_{in,tot}(p_{on} + p_{ex})] \cdot \\ &\cdot (1 + VAT) + Q_{UP}p_{bal,erog}, \end{aligned} \quad (3)$$

$$Q_{in,tot} = Q_{DW} + Q_{DAM,res} + Q_{DAM,prg,act} \quad (4)$$

$$Q_{DAM,prg,act} = Q_{DAM,prg} + Q_{UP,prred} \quad (5)$$

$$Q_{UP,prred} = Q_{UP} - Q_{out,tot}. \quad (6)$$

If $C_2 > C_1$, in order to encourage EVs to participate in service supply, some subsidies could be introduced. By assuming, e.g., an exemption from paying the system charges and the network and metering charges (with overall average price p'_{on}) for the energy absorbed for the downward BS, the annual bill is

$$C_3 = C_2 - Q_{DW}p'_{on}. \quad (7)$$

Finally, by assuming an exemption from p'_{on} both for the energy absorbed for the downward BS and for the net energy injected into the grid for the upward BS ("net" because such injection results from the superposition of the upward BS and of the recharge program), with a weight equal to the percentage of energy absorbed from the grid which has not benefitted yet of the exemption considered in C_3, the annual bill is

$$C_4 = C_3 + \frac{Q_{out,tot}}{\eta_{round-trip}} \frac{Q_{in,tot} - Q_{DW}}{Q_{in,tot}} p'_{on}, \quad (8)$$

where $\eta_{round-trip}$ is the EV BESS round-trip efficiency.

V. Simulation Results

As in [10], eight study cases are considered (see Tables III and IV), derived by combining three (independent) features: i) V1G/V2G recharge; ii) the absence/presence of a recharge program; iii) being a domestic/non-domestic EV user. Simulations are carried out for the one-year-long period T from 1st August 2016 to 31st July 2017. Reference is made to the working days only (252 days): this means that, in case of a weekend, T_r is assumed to start on Friday and to end on the next Monday; similarly, in case of a festivity, T_r is assumed to start on the previous working day and to end on the following working day; thus, T_r is much longer for weekends or festivities than for consecutive working days, to have much more time to participate in the BM and supply the BS. As a comparison term to determine bid acceptance in the bidding algorithm, the maximum and minimum historical accepted prices, over T, in the Northern market zone [11] are adopted.

Here, a sensitivity analysis is carried out with respect to the bid prices. The DW price, p_{DW}, is assumed to be constant throughout T and so is the UP price, p_{UP}. Thus, in the bill values, $p_{bal,abso} = p_{DW}$ and $p_{bal,erog} = p_{UP}$. The bidding algorithm is run along the recharge periods of the working days of T, for each couple (p_{DW}, p_{UP}), where $p_{DW}, p_{UP} \in \{0, 10, 20, \ldots, 990, 1000\}$ €/MWh (higher prices, up to 3000 €/MWh, allowed in the Italian BM, are neglected). For each run, the annual results are computed, in terms of the already mentioned overall energy exchanges and bill values C_1 to C_4, also in the presence of the capacity remuneration. In order to analyse service profitability for the end user, a per cent saving index with respect to the benchmark bill is also defined:

$$\begin{aligned} S_i &= (1 - C_i/C_1) \cdot 100, \; if \; R_{cap} = 0 \\ S_{iR} &= [1 - (C_i - R_{cap}P_{prg} \cdot 1yr)/C_1] \cdot 100, \; if \; R_{cap} \neq 0, \end{aligned} \quad (9)$$

for $i = 2, 3, 4$. Doing the service can be deemed to be profitable if the related bill is lower than or equal to the

TABLE I
BIDDING ALGORITHM DESCRIPTION, FOR EACH RECHARGE PERIOD T_r SIMULATED

V1G with Recharge Program	- $\forall h \in T_{prg}$, make an UP, with power $P_{UP}(h)$ (to reduce absorption with respect to P_{prg}); $\|P_{UP}(h)\| \leq P_{prg}$; - in the following hours of T_r, $\forall h$, make a DW, with power $P_{DW}(h)$ (to absorb power from the grid); $P_{DW}(h) \leq P_n$.
V1G without Recharge Program	$\forall h \in T_r$, make a DW on the BM, with power $P_{DW}(h)$ (to absorb power from the grid); $P_{DW}(h) \leq P_n$.
V2G with Recharge Program	- $\forall h \in T_{prg}$, make an UP, with power $P_{UP}(h)$; $\|P_{UP}(h)\| \leq P_{prg} + P_n$, to be able to inject, into the grid, power up to P_n; - in the following hours of T_r, $\forall h$, make a DW (to absorb power from the grid) and an UP (to inject power into the grid); $P_{DW}(h) \leq P_n$ and $\|P_{UP}(h)\| \leq P_n$.
V2G without Recharge Program	$\forall h \in T_r$, make a DW (to absorb power from the grid) and an UP (to inject power into the grid); $P_{DW}(h) \leq P_n$ and $\|P_{UP}(h)\| \leq P_n$.

TABLE II
OVERALL ANNUAL ENERGY EXCHANGES WITH THE GRID; IN BRACKETS, WHERE NEEDED, THE RELATED AVERAGE PRICES

Symbol	Description
$Q_{DAM,bnc}$ ($p_{DAM,bnc}$)	energy absorbed on the DAM in the benchmark recharge
$Q_{DAM,prg}$ ($p_{DAM,prg}$)	energy which would be absorbed on the DAM according to the recharge program if there were no participation in service supply (remark: in each T_r, such energy can also be $< \Delta E_{rech}/\eta_{ch}$, since the program can also be for a partial recharge)
$Q_{UP,prred}$	that part of the energy sold for the upward BS whose power exchange is a reduction of the recharge program profile
$Q_{DAM,prg,act}$	energy actually absorbed (i.e. in case of participation in service supply) on the DAM for the recharge program
Q_{DW} ($p_{bal,abso}$)	energy bought, and absorbed, for the downward BS
Q_{UP} ($p_{bal,erog}$)	energy sold for the upward BS, i.e. to reduce the recharge program power absorption or to inject power into the grid
$Q_{DAM,res}$ ($p_{DAM,res}$)	energy absorbed for the residual recharge on the DAM
$Q_{in,tot}$	energy globally absorbed from the grid, for the recharge program (if present), the downward BS, the residual recharge
$Q_{out,tot}$	energy globally injected into the grid, for the upward BS, which can also be superimposed to the recharge program

benchmark bill, so if the saving index is greater than or equal to zero. The main results are now briefly discussed.

First of all, Table V reports, for each study case, those annual results which are invariant, i.e. independent of (p_{DW}, p_{UP}): i) the benchmark energy absorption, around 2.1 MWh in the domestic cases and around 3.6 MWh in the non-domestic ones, and the related average price on the DAM, always around 49-50 €/MWh; ii) the annual benchmark bill C_1, about 390 € in the domestic cases and about 600 € in the non-domestic ones, with slight differences from case to case due to the one-hour difference in T_r duration in the presence or absence of the recharge program; iii) in the cases with the recharge program, the energy which would be absorbed on the DAM according to the program - about 1.5 MWh in the domestic cases and about 3.0 MWh in the non-domestic ones, - and the related average price, which is always around 64 €/MWh.

Then, the saving index is analysed as a function of (p_{DW}, p_{UP}). For each study case, the values of (p_{DW}, p_{UP}) for which the service, itself or with partial exemptions from charges, is profitable, i.e. for which $S_i \geq 0$, $i = 2$ or 3 or 4 (without the capacity remuneration) or $S_{iR} \geq 0$, $i = 2$ or 3 or 4 (with the capacity remuneration), are selected. Results about the profitable instances are reported in Tables VI to VIII.

The number of the profitable instances, denoted as N_i or N_{iR} for S_i or S_{iR} respectively, is reported in Tables VI and VII. Notice that N_i and N_{iR} have to be compared to the total number of instances (i.e. the total number of bid prices simulated), which is 101 in study cases A and E, because there is the downward service only (so there are 101 p_{DW} values only), and 101 × 101 in the other study cases, because there are both the downward and the upward service (so 101 × 101 (p_{DW}, p_{UP}) values). As to S_2 (Table VI, top part), associated to profitability of bill C_2, N_2 increases when passing from V1G to V2G recharge and, in case of V2G recharge, also when adding the recharge program, since there are more chances to do the upward BS and thus to sell energy (Q_{UP}); however, N_2 decreases in passing from the domestic to the non-domestic cases (because the energy bought for the downward BS, i.e. Q_{DW}, increases), except for the V2G plus program recharge (i.e. N_2 increases in passing from case D to H, due to higher $|Q_{UP}|$). Similar considerations hold for N_3 and for N_4 (Table VI again); notice, anyway, that N_4 is lower in case D than in case H. Of course, in general $N_3 > N_2$, because bill C_3 is a reduction of bill C_2, and similarly $N_4 > N_3$, because bill C_4 is a reduction of bill C_3 (of course, $N_4 = N_3$ in case there are no net injections into the grid, i.e. in cases A, B, E, F: indeed, in such cases $C_3 = C_4$ by construction, so $S_3 = S_4$). By considering the capacity remuneration (Table VII), the number of profitable instances increases, as expected.

Let us now focus on S_2, the per cent saving (wrt C_1) associated to bill C_2. Table VI, again, shows, in the assumption that condition $C_2 \leq C_1$ holds (i.e. in the profitable conditions), the minimum and maximum values attained by S_2, together with the related values of (p_{DW}, p_{UP}), and also the mean value of S_2, denoted as $\mu(S_2)$, and its standard deviation $\sigma(S_2)$. Values $min(S_2)$ are very small, almost always lower than 1% or 0.1%, while values $max(S_2)$ range from some per cent to even more than 100% (more precisely, for domestic study cases $max(S_2)$ is around $7-8\%$ for V1G recharge, around $23-24\%$ for V2G recharge, for non-domestic cases it is between 12 and 20% for V1G recharge, between 101 and 113% for V2G recharge). $S_2 > 100\%$ means that the minimum value of bill C_2 reaches a negative value, i.e. it becomes a revenue instead of a cost; this result is obtained for non-domestic cases, as just recalled, because the related amount of energy sold for the upward service ($|Q_{UP}|$) is higher than in the domestic cases (see Table VIII). One can also observe that introducing the program profile (cmp case B with A, D with C, F with E, H with G) brings about a decrease both of $min(S_2)$ and of $max(S_2)$ and of $\mu(S_2)$ (and of $\sigma(S_2)$ as well), because there is an increase of the energy bought at DAM prices (due to $Q_{DAM,prg,act}$); besides, $max(S_2)$, $\mu(S_2)$, $\sigma(S_2)$ are higher when considering V2G recharge than when considering V1G recharge, and they are higher when considering non-domestic recharge than when considering domestic recharge.

The same qualitative patterns described for $max(S_2)$, $\mu(S_2)$ and $\sigma(S_2)$ are found for $max(S_i)$, $\mu(S_i)$ and $\sigma(S_i)$, $i = 3, 4$. As expected, the maximum and the mean (and also the standard deviation) values increase when moving from S_2 to S_3 to S_4, thanks to the increasing reliefs in the bill. For case G, $max(S_3)$ reaches even more than 150% and $max(S_4)$ more than 160%, while $\mu(S_3)$ reaches around 62% and $\mu(S_4)$ around 65%.

When adding the capacity remuneration (Table VII) in the presence of a recharge program (cases B, D, F, H), $max(S_{2R})$, $\mu(S_{2R})$ and $\sigma(S_{2R})$ increase when passing from V1G recharge plus program to V2G recharge plus program, both in the domestic and in the non-domestic cases. This consideration holds for $max(S_{iR})$, $\mu(S_{iR})$ and $\sigma(S_{iR})$, $i = 3, 4$, too. Again, maximum, mean and standard deviation values of the saving index increase when moving from S_{2R} to S_{3R} to S_{4R}, thanks to the increasing reliefs in the bill.

Table VIII shows a sample of the energy results: the annual energy exchanges corresponding to $max(S_2)$ of Table VI, i.e. to the maximum saving when bill C_2 is found to be profitable. One can observe, e.g., that, in the presence of a recharge program, the energy absorbed for the downward service (Q_{DW}) is smaller than in its absence, and so is the energy exchange on the DAM for residual recharge ($Q_{DAM,res}$), while the total absorbed energy ($Q_{in,tot}$) and the total injected energy (i.e. $|Q_{out,tot}|$) tend to be larger. Most energy exchanges are larger in the non-domestic cases than in the domestic ones, since the energy requested for recharge is higher, power P_n is higher and power P_{prg} is also higher; however, $Q_{DAM,res}$ turns out to be smaller in case E than in case A, and in F than in B.

Finally, let us focus on cases D and H, i.e. the V2G plus program ones, to describe the energy flows associated to the maximum saving $max(S_2)$. In case D, $max(S_2)$ is around 23% and it is reached for p_{DW} = 0 €/MWh (this is an ideal instance, where all DWs are accepted provided that they are formulated in hours when there are historically accepted DWs) and p_{UP} = 350 €/MWh (this means that there is a rather large gap with respect to p_{DW}, so UPs here are rather profitable themselves). In case H, $max(S_2)$ is reached almost for the same bid prices as in case D (p_{DW} = 10 €/MWh and p_{UP} = 350 €/MWh) but it is around 101%, i.e. much higher than in case D. In case D, due to the rather small power for recharge (P_n = 2 kW), the energy exchanges for the BS (Q_{DW} = 0.218 MWh and $|Q_{UP}|$ = 0.644 MWh) are not very large if compared to $Q_{DAM,bnc}$ (2.057 MWh); in case H, power for recharge is much larger (P_n = 12 kW) than in case D, so larger energy exchanges are carried out: as compared to $Q_{DAM,bnc}$ (3.591 MWh), Q_{DW} = 2.171 MWh and, especially, $|Q_{UP}|$ = 3.374 MWh are not small, so, although the downward service implies some more costs as compared to case D, much more economic benefits from the upward BS are obtained.

TABLE III
STUDY CASES [10]

	Domestic Recharge	Non-Domestic Recharge
V1G without Recharge Program	A	E
V1G with Recharge Program	B	F
V2G without Recharge Program	C	G
V2G with Recharge Program	D	H

TABLE IV
MAIN TECHNICAL PARAMETERS OF THE STUDY CASES AND ASSUMED VARIABLE COMPONENTS OF CHARGES, EXCISE DUTIES, VAT [10]

	Domestic Recharge	Non-Domestic Recharge
Maximum recharging power P_n [kW]	2	12
Daily internal energy recharge ΔE_{rech} [kWh]	7.5	13
Recharge program power P_{prg} [kW]	2	4
BESS nominal energy E_n [kWh]	40	
Round-trip eff. $\eta_{round-trip}$ [%]	85	
$T_r = [t_{ini}, t_{end}]$ without/ with recharge program	[19:00, 06:00]/ [18:00, 06:00]	
p_{on}: price of total charges [€/MWh]	99.732	74.877
p'_{on}: price of system charges + network & metering charges [€/MWh]	77.832	59.307
VAT on energy purchases [%]	10	22
p_{ex}: price of excise duties [€/MWh]	22.7	12.5
R_{cap}: price of capacity remuneration [k€/MW/yr]	30	

TABLE V
INVARIANT RESULTS

	$Q_{DAM,bnc}$ [MWh] ($p_{DAM,bnc}$ [€/MWh])	C_1 [€]	$Q_{DAM,prg}$ [MWh] ($p_{DAM,prg}$ [€/MWh])
A	2.057 (48.94)	387.81	0 (-)
B	2.057 (50.18)	390.51	1.512 (63.90)
C	2.057 (48.94)	387.81	0 (-)
D	2.057 (50.18)	390.51	1.512 (63.90)
E	3.591 (48.97)	597.42	0 (-)
F	3.591 (50.22)	602.82	3.024 (63.90)
G	3.591 (48.97)	597.42	0 (-)
H	3.591 (50.22)	602.82	3.024 (63.90)

VI. CONCLUSIONS

For each of the considered study cases (which differ, in particular, as to the maximum recharging power, the energy to be recharged on each simulated day, the service direction), regions in the (p_{DW}, p_{UP}) plane exist for which the service is profitable in that the related bill (even without subsidies and without any additional capacity remuneration) is lower than or equal to the benchmark bill. Maximum profitability is achieved, in the considered study cases, for small downward bid prices, around 10 €/MWh, and higher upward bid prices, around 80 or 350 €/MWh, so that costs for the energy bought on the BM are small enough and revenues for the energy sold on the BM are high enough. This way maximum savings between around 7% and 113% can be reached with respect to the benchmark bill. If downward bid prices are much higher

TABLE VI
SAVING S_i [% OF C_1] WHEN $C_i \leq C_1$: N_i; $min(S_i)$ AND $max(S_i)$ (WITH THE RELATED BID PRICES (p_{DW}, p_{UP}) ([€/MWh], [€/MWh]) IN BRACKETS), $\mu(S_i)$ AND $\sigma(S_i)$. FROM TOP TO BOTTOM, $i = 2, 3, 4$

	N_2	$min(S_2)$	$max(S_2)$	$\mu(S_2)$	$\sigma(S_2)$
A	8	0.84 (70, -)	8.06 (10, -)	4.97	2.51
B	216	0.00 (40, 280)	7.20 (10, 80)	2.16	1.79
C	902	0.03 (110, 610)	24.10 (10, 350)	7.88	5.11
D	1385	0.02 (130, 910)	23.46 (0, 350)	5.12	4.19
E	5	6.07 (40, -)	19.71 (10, -)	14.68	4.94
F	127	0.02 (30, 340)	11.60 (10, 80)	3.42	3.07
G	826	0.24 (80, 890)	113.48 (10, 350)	43.24	26.39
H	1639	0.03 (200, 930)	101.17 (10, 350)	26.96	20.78
	N_3	$min(S_3)$	$max(S_3)$	$\mu(S_3)$	$\sigma(S_3)$
A	15	0.93 (140, -)	16.15 (10, -)	9.32	4.87
B	514	0.01 (10, 840)	13.32 (10, 80)	3.44	2.94
C	1515	0.02 (190, 580)	35.40 (10, 350)	12.33	7.41
D	1982	0.00 (210, 940)	29.41 (10, 350)	6.60	5.10
E	10	5.11 (90, -)	46.20 (30, -)	30.97	13.76
F	435	0.00 (10, 980)	32.86 (30, 70)	6.76	7.18
G	1272	0.08 (130, 800)	152.95 (20, 350)	61.90	36.15
H	2074	0.01 (260, 970)	122.53 (10, 350)	33.09	25.19
	N_4	$min(S_4)$	$max(S_4)$	$\mu(S_4)$	$\sigma(S_4)$
A	15	0.93 (140, -)	16.15 (10, -)	9.32	4.87
B	514	0.01 (10, 840)	13.32 (10, 80)	3.44	2.94
C	1697	0.00 (170, 990)	43.05 (10, 350)	13.92	8.68
D	2644	0.01 (410, 380)	40.93 (10, 350)	9.31	7.48
E	10	5.11 (90, -)	46.20 (30, -)	30.97	13.76
F	435	0.00 (10, 980)	32.86 (30, 70)	6.76	7.18
G	1307	0.21 (130, 800)	168.42 (10, 350)	64.66	38.65
H	2329	0.03 (230, 810)	149.07 (10, 350)	38.96	30.67

TABLE VII
SAVING S_{iR} [% OF C_1] WHEN $(C_i - R_{cap}P_{prg} \cdot 1yr) \leq C_1$, $i = 2, 3, 4$: N_{iR}; $min(S_{iR})$ AND $max(S_{iR})$ (WITH THE RELATED BID PRICES (p_{DW}, p_{UP}) ([€/MWh], [€/MWh]) IN BRACKETS), $\mu(S_{iR})$, $\sigma(S_{iR})$

	N_{2R}	$min(S_{2R})$	$max(S_{2R})$	$\mu(S_{2R})$	$\sigma(S_{2R})$
B	3776	0.01 (390, 810)	22.57 (10, 80)	7.62	4.67
D	4153	0.00 (570, 520)	38.83 (0, 350)	11.93	7.46
F	1498	0.00 (160, 430)	31.51 (10, 80)	10.65	6.45
H	2398	0.00 (340, 510)	121.08 (10, 350)	35.17	24.52
	N_{3R}	$min(S_{3R})$	$max(S_{3R})$	$\mu(S_{3R})$	$\sigma(S_{3R})$
B	4494	0.00 (460, 790)	28.68 (10, 80)	9.03	5.57
D	4773	0.01 (640, 500)	44.78 (10, 350)	13.61	8.48
F	1987	0.01 (200, 620)	52.76 (30, 70)	14.34	9.10
H	2839	0.01 (370, 680)	142.44 (10, 350)	41.39	28.95
	N_{4R}	$min(S_{4R})$	$max(S_{4R})$	$\mu(S_{4R})$	$\sigma(S_{4R})$
B	4494	0.00 (460, 790)	28.68 (10, 80)	9.03	5.57
D	5457	0.00 (710, 480)	56.29 (10, 350)	15.91	10.46
F	1987	0.01 (200, 620)	52.76 (30, 70)	14.34	9.10
H	3087	0.00 (390, 890)	168.98 (10, 350)	46.88	34.06

TABLE VIII
ANNUAL ENERGY EXCHANGES [MWh] CORRESPONDING TO $max(S_2)$ IN TABLE VI

	Q_{DW}	Q_{UP}	$Q_{in,tot}$	$Q_{out,tot}$	$Q_{UP,prred}$	$Q_{DAM,prg,act}$	$Q_{DAM,res}$
A	0.403	0	2.054	0	0	0	1.650
B	0.307	-1.017	2.054	0	-1.017	0.495	1.252
C	0.563	-0.416	2.543	-0.416	0	0	1.980
D	0.218	-0.644	2.739	-0.577	-0.066	1.445	1.075
E	2.370	0	3.609	0	0	0	1.239
F	1.572	-2.034	3.609	0	-2.034	0.990	1.047
G	3.911	-3.033	7.177	-3.033	0	0	3.266
H	2.171	-3.374	7.422	-3.241	-0.133	2.891	2.360

(tens or few hundreds of €/MWh), very high upward bid prices (hundreds of €/MWh, up to around 900 €/MWh) are still able to yield profitable economic results, but the related bill is very close to the benchmark bill, so the saving is minimal.

Future work includes looking for profitable bid price time profiles; they could be obtained, e.g., by analyzing more deeply the historical (accepted) prices on the BM. Starting from such price profiles, then, an optimization of the energy bids for the service could also be carried out. Of course, battery cycling aging has to be taken into account and inquired carefully, because the energy exchanges for the service can increase charge-discharge cycles to a great extent with respect to the ones related to EV driving and to benchmark recharge.

Finally, attention should be moved from single EVs to EV aggregates, to analyze service supply from three interacting points of view: the end user's one (which has been considered here), the grid operator's one and the BSP's one. A BSP, e.g., needs to know both the BESS parameters and recharge needs of the EVs in its portfolio and the energy quantity and unit price signals in the ancillary service market, in order to optimize EV coordination both for technical and for economic purposes.

REFERENCES

[1] ENTSO-E, Supporting document for the Network Code on Operational Security, 2nd Ed. Final, 24 September 2013. [Online]. Available: https://www.entsoe.eu.

[2] H. Holttinen, J. Kiviluoma, N. Cutululis, A. Gubina, A. Keane, and F. Van Hulle, Ancillary services: technical specifications, system needs and costs, REserviceS Project, Deliverable D2.2, November 2012. [Online]. Available: https://www.reservices-project.eu.

[3] D. Greenwood, K. Lim, C. Patsios, P. Lyons, Y. Lim, and P. Taylor, "Frequency response services designed for energy storage," Appl. Energ., vol. 203, pp. 115-127, 1 October 2017.

[4] H. Jia, X. Li, Y. Mu, C. Xu, Y. Jiang, X. Yu, J. Wu, and C. Dong, "Coordinated control for EV aggregators and power plants in frequency regulation considering time-varying delays," Appl. Energ., vol. 210, pp. 1363–1376, 15 January 2018.

[5] Y. Shi, B. Xu, Y. Tan, D. Kirschen, and B. Zhang, "Optimal battery control under cycle aging mechanisms in pay for performance settings," IEEE Trans. Autom. Control, vol. 64, no. 6, pp. 2324–2339, June 2019.

[6] A. Rossi, M. Stabile, C. Puglisi, D. Falabretti, and M. Merlo, "Evaluation of the energy storage systems impact on the Italian ancillary market," Sustainable Energy, Grids and Networks, vol. 17, pp. 100178, 2019.

[7] B. Vatandoust, A. Ahmadian, M. A. Golkar, A. Elkamel, A. Almansoori, and M. Ghaljehei, "Risk-averse optimal bidding of electric vehicles and energy storage aggregator in day-ahead frequency regulation market," IEEE Trans. Power Syst., vol. 34, no. 3, pp. 2036–2047, May 2019.

[8] LAZARD, Lazard's levelized cost of storage analysis - Version 4.0, November 2018. [Online]. Available: https://www.lazard.com.

[9] ARERA (formerly AEEGSI), Authority Decision 300/2017/R/EEL. In Italian. [Online]. Available: https://www.autorita.energia.it/, 5 May 2017.

[10] S. Canevese, D. Cirio, M. Gallanti, and A. Gatti, "EV recharge for the supply of balancing services in Italy: preliminary techno-economic evaluations," in 7th Int. Conf. on Clean Electrical Power (ICCEP 2019), Otranto, Italy, 2-4 July 2019.

[11] M. Benini, S. Canevese, D. Cirio, and A. Gatti, "Participation of battery energy storage systems in the Italian Balancing Market: management strategies and economic results," in 2018 IEEE Int. Conf. on Env. and Electr. Eng. and 2018 IEEE Ind. and Comm. Power Systems Europe (EEEIC / I&CPS Europe), Palermo, Italy, 2018, pp. 1422-1427.

[12] GME website. http://www.mercatoelettrico.org.

[13] ARERA (formerly AEEGSI), Regolamento recante le modalità per la creazione, qualificazione e gestione di unità virtuali abilitate miste al mercato dei servizi di dispacciamento - Regolamento UVAM MSD, 25 September 2018. In Italian. [Online]. Available: http://download.terna.it.