Business models for the integration of electric vehicles into the Austrian energy system

R. Rezania, and W. Prüggler

***Abstract*--From the energy sector's point of view, the integration of EVs must be realized with optimal technical solutions following the basic principles of economical frameworks. Therefore, the aim of this work is the definition and economic analysis of business models in the timeframe of 2020 and beyond. The business models are divided into a controlled charging strategy as Grid to Vehicle (G2V), which describes the participation of EVs in the Austrian control energy market, Vehicle to Grid (V2G) as well as a second life of lithium-ion batteries. Overall results indicate low positive contribution margins (from -7.32 to 63.94 €/vehicle/month) for V2G and G2V applications, even if costs for needed equipment as well as dispatch probability for providing of control energy are neglected. Thus, an economic realization of these concepts cannot be recommended at currently existing Austrian market conditions. The reuse of batteries after their automotive lifetime on the contrary can be recommended for a simultaneous participation on the energy exchange and control energy markets. Compared to a reference technology the minimum remaining lifetime of those reused Li-ion batteries must be more than four years.**

Index Terms*—Battery second life, Business models, Control energy market, Electric vehicles, Energy storage, Grid to vehicle, Vehicle to grid.

I. INTRODUCTION

THE system integration of electric vehicles (EVs) is related to new technical, economical and regulative challenges, which partly can be overcome by adequate business models (BMs). Generally, BMs reflect the interaction between participating stakeholders and have to meet the mobility needs of the drivers (consumers, mobility users). The comparison between the revenues and expenses of each stakeholder, involved in a BM, leads to a depiction of the realization potential of a certain business idea. The BMs for e-mobility could be based on the provision of different grid services like

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control energy (primary, secondary and tertiary control). The control energy availability can be ensured in a control area due to appropriate control energy markets. The needed control energy reserves will be realized with power plants which are contracted e.g. by the responsible transmission system operator (TSO) [1]. A deviation in system frequency (50 Hz +/- 20 mHz) leads to activation of primary control, which attempts to stabilize the system within seconds.. A further deviation of 180 mHz leads to activation of the whole primary reserve. The secondary reserve, will be activated (automatically) at least within seconds to 15 minutes to restore the frequency to its origin value before the deviation, frees the primary reserves for possible further irregularity [2] and reestablishes the planned cross border power flows [1]. If the frequency deviation holds on in the control area, the tertiary control will be activated. It releases the secondary control and restores the frequency value before the incident. The frequency deviations are caused due to imbalance between electricity generation and consumption in a certain time period. A higher generation or a lower consumption level causes an increase in system frequency. Thus, the system can be stabilized with counteractions like decreasing/ increasing of generation/ demand. Because of control-related reasons, deviations occur also between the target and the actual values during the exchange of energy between neighbouring electricity grids. This so called unintentional deviation (Inadvertent Exchange) in a control area is the volume of energy that the control area accidentally takes from or supplies to the transmission grid of the RGCE (Regional Group Continental Europe). According to ENTSO-E, the excess volumes of energy that were taken or supplied must be redelivered in the following week on the basis of pre-defined times (no monetary compensation).

The economic potential of EVs due to their contribution for providing control energy has been evaluated in different control areas with dissimilar assumptions. Reference [3] analyzed the mentioned economic potential of plug-in hybrid vehicles in Germany and Sweden by using historical data on called control energy. The method obtained a positive contribution margin in the range of 30 to 80 €/Vehicle/Month (consideration of battery degradation cost) for vehicles in Germany, whereas negative margins were calculated for the case study of Sweden. The different results for the both countries are derived from various market characteristics (e.g. there is no power price in Sweden for provision of control energy) and generation capacity mixtures. Even more, Plug-in hybrid vehicles may qualify for a positive margin of about 18 €/Vehicle/Month by providing secondary and tertiary control energy in Portugal [4]. Reference [5] derives a profit of about 6-160 €/Vehicle/Month in Denmark. In general, these results depend on charging and discharging capacities and do not consider the additional costs such as e.g. communication and charging infrastructure.

Another possible BM considering EVs is the reuse of Li-ion batteries after their automotive retirement. Reference [6] mentioned that the battery second use has the potential to become a common component of future battery BMs.

In this regard, this paper is focused on the definition and assessment of vehicle to grid (V2G, controlled charging and discharging) and grid to vehicle (G2V, controlled charging) business models including the description of involved stakeholders. The V2G and G2V business models are designed for the participation of EVs in the Austrian control energy markets. Furthermore, the reuse of Li-ion batteries after automotive retirement builds up the second focus of this paper. In this context, the 2nd life BM considers a combined participation of refurbished batteries in the energy exchange and control energy market.

The remainder of this paper is organized as follows: the next 2 sections provide an overview of the developed business models and their related use cases. The selected methodology and used data for the assessment of described business models is presented in the fourth chapter. The fifth section describes the results. Conclusions will be drawn in the last section.

II. BUSINESS MODELS FOR V2G AND G2V APPLICATIONS

This chapter describes the BMs considering the participation of EVs in the control energy markets. The BMs are divided on the one hand in three use cases depending on the charging station's location and on other hand to provide positive or negative control energy. The negative control energy will be provided with a controlled charging (G2V) application, which can be realized with controllable charging stations as well as a bidirectional communication solution (not necessarily in real-time for providing tertiary control energy) between the services provider (aggregator) and charging station operator.

In addition to that positive control energy can be provided with controlled discharging strategies (V2G). Again a bidirectional communication infrastructure is needed. Furthermore, the requirement of a V2G inverter (integrated e.g. in the vehicle) for feeding energy back into the grid is a major difference between V2G and G2V applications. Based on that, this chapter focuses on a more detailed description of possible V2G use cases, depending on the charging station location. These use cases are also valid for G2V application except the above-mentioned differences.

The V2G use cases can be realized at in-house (home), public and semi-public (office) charging stations. Even more the V2G use cases are enabled by an aggregator, who controls the mentioned charging stations. The ownerships of the needed equipment for the specific use cases can be described as follows (see also [7], [8]):

- Charging at home or office: The charging stations (except their smart meters) for e-mobility solutions are owned by the building owners.
- Charging at public charging point: It is assumed, that the local distribution system operator (DSO) owns and is responsible for the installation and distribution of the stations.
- Communication infrastructure: An adequate communication system (e.g. GSM) will be needed to provide V2G applications. The discharging signal will be send to the smart meter which is part of the charging points. In the next step, the charging station undertakes the communication with the vehicle's on-board controller and enables or disables

discharging activities. The infrastructure can be owned e.g. by a telecom company

- Energy management system (server including software): This system provides the ability for the aggregator to implement controlled charging and discharging strategies. In this case the communication infrastructure needs a bidirectional connection. The aggregator is the owner of the described energy management system.

Fig. 1 shows the V2G use case for feeding energy into the grid from home charging stations considering the data flow, ownership of equipment (smart meter, V2G-Inverter, energy management system and on-board controller) as well as the overall system integration of the mentioned equipment. The second V2G use case for feeding energy into grid is applicable for office charging stations and has equal definitions/constraints as the first one. The main difference between those use cases lies in the higher number of EVs at an office (company) parking area.

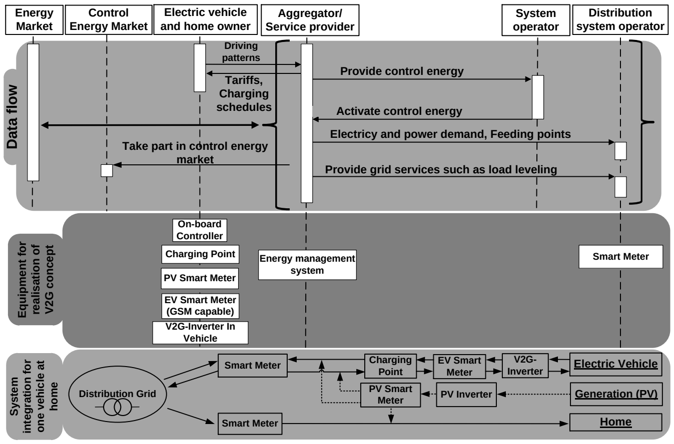

Fig. 1. V2G use case for feeding energy into the grid at home stations

Fig. 2 describes the third V2G use case for feeding energy into the grid from a public charging station illustrating the assignment of charging stations to the local DSO. The data flow sections of Fig. 1 and Fig. 2 shows that the EV-user holds an exclusive business relationship to the aggregator (service provider). Thus, the aggregator takes over all interactions with other involved stakeholders in all described use cases. The responsibilities of before-mentioned aggregator could be assigned to an advanced retailer considering the current Austrian energy system rules. In this context, it has to be ensured that the DSO still is responsible for a reliable operation of the electricity grid.

For the economic assessment the V2G application combines the described use cases before the first daily drive (parked at home), after the last daily drive (parked at home) and during the day (parked in public area or office). The contribution margins are then calculated for specific customer driving patterns, charging strategies, battery characteristics, the amount of called control energy and its intensity (number of calls) by considering the tendering process of the Austrian control energy markets.

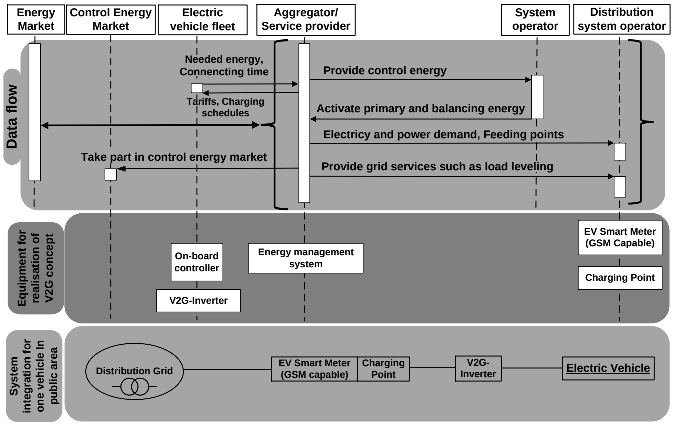

Fig. 2. V2G use case for feeding energy into the grid at public charging stations

III. BUSINESS MODELS FOR SECOND LIFE APPLICATIONS

The aim of stationary battery usage lies in storing energy and releasing it at more beneficial time periods. The reuse of batteries after their automotive retirement thus could contribute to lower e-mobility cost. The reason can be found in an added disposal value of the used battery reducing initial battery prices of EVs. The mentioned disposal value depends on the battery lifetime after automotive retirement and its application purpose. Therefore, an hourly sequentially linear optimization model has been developed which derives the maximum contribution margin of Li-ion batteries (employed in second use application) taking part in the Austrian energy exchange and control markets.

IV. METHODOLOGY AND DATA

This chapter describes the methodology for the assessment of BMs for V2G, G2V, second life applications as well as the used data (energy and control power prices).

A. Assessment of business models for V2G and G2V applications

As mentioned in the BMs descriptions, the information about the main charging strategy, driving patterns, battery characteristics, the daily called control energy and prices on the energy exchange and control market build up the needed data for the calculation of the economic potential for the involved stakeholders of the BMs.

The analysis refers to battery electric vehicle groups of 94, 36 and 28 vehicles which have a battery capacity of 16, 24 and 48 kWh. The driving patterns are an outcome of an Austrian travel survey for the federal state of Salzburg in 2004 [9]. The main charging strategy is based on a linear optimization with the target function to minimizing the charging costs considering Li-ion battery charging characteristics [10]. Because of different daily electricity price curves during winter and summer, the assignment of low cost charging points is performed. Therefore, typical price curves from 2009 were selected and adapted to an average electricity price of about 80.82 €/MWh in 2020 [11]. The constraints for the optimization consist of a maximum charging/discharging power of 10.5 kW, charging and discharging efficiency of about 95 %, and the used range of battery capacity. In this context, the battery is operated between 10 and 90 % of its nominal capacity in order to reduce the negative impacts of overloading or deep discharging on capacity losses.

The simulation of control energy demand/call refers to historical data of the APG control area and an add-on modeling of daily control energy demand, which is based on the outcomes of descriptive statistical analyses of historical data from 2006 to 2010. This modeling consists of 3 main steps:

- Step 1, analysis of the amount of called control energy: The aim of this step lies in the assignment of an appropriate probability density function to each time interval within a day. The database consists of called control energy in the APG control area from 2006 to 2010 with a 15 minutes resolution. Fig. 3 shows the absolute frequency of called positive secondary control energy in the APG-control area. A normal distribution function in this case has been implemented for each time interval as the concentration of the called control energy lies in the interval from 15 to 30 MWh. The low level spikes have been neglected due to their small share compared to the whole called control energy. Generally, the same characteristic has been found and selected for tertiary control. However, for example Fig. 4 shows another characteristic for called positive unintentional deviation in the APG-control area. The selected distribution function is a generalized extreme value distribution function because the called events concentrate on low energy levels up to 20 MWh. Again, the spikes at the lowest levels were neglected.
- Step 2, the number of control energy calls (absolute frequency) within a day including an appropriate distribution function: A normal distribution function is assumed for the number of control energy calls within a day. Accordingly, an average value and a standard deviation of the mentioned normal distribution function have been derived based on various historical data.
- Step 3, using of a random generator for selecting of times and associated amounts of control energy calls: An acceptance-rejection method [12] is selected to derive total amounts of control energy calls. The calling times are randomly distributed and at least one of them occurs in an one hour time block (four successive time periods (15 minutes resolution)).

The implementation of the mentioned approach results in different control energy scenarios differing in the amount of called control energy (energy scenarios) and the number of daily called time intervals (call scenarios, intensity). Each energy scenario (high and mean energy scenario) is characterized by three different call scenarios, which describe its intensity. Hence, this method results in 6 scenarios for each kind of control energy. Fig 6 provides an overview of the scenarios for each kind of control energy type (primary, secondary or tertiary control energy).

The combination of different driving patterns (number of vehicles) with the control energy scenarios will build up a result range for each vehicle category for the economic assessment of the V2G and G2V applications. Particularly, the comparison between the charging costs of a low cost charging optimization approach on the one hand and the charging costs of the G2V business models on the other hand, will be performed.

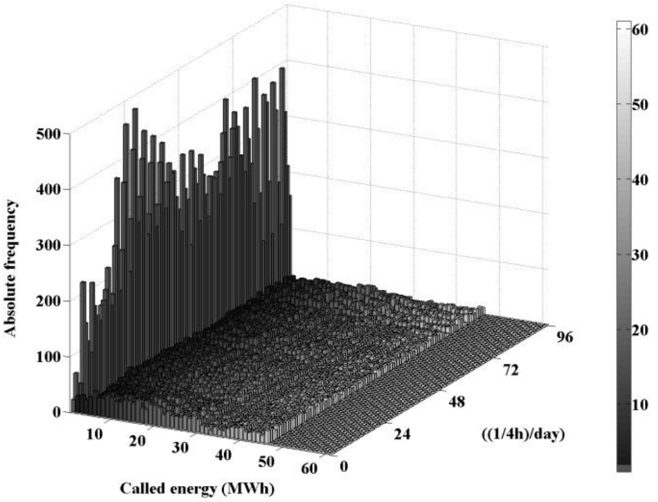

Fig. 3. Number of calls of positive secondary control energy per time period (15 minutes resolution) in the APG control area from 2006 to 2010

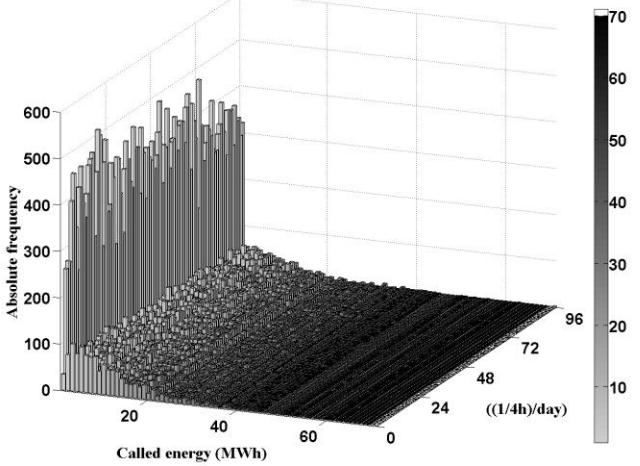

Fig. 4 Number of calls of positive unintentional deviation per time period (15 minutes resolution) in the APG control area from 2006 to 2010

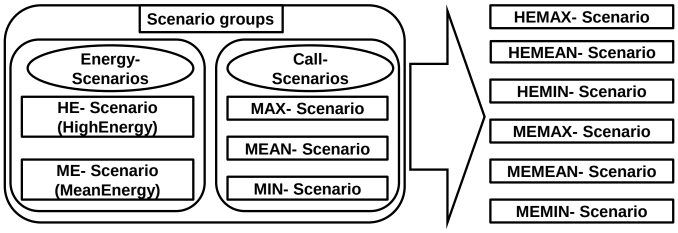

Fig. 5. Combination of energy and call scenarios for each kind of control energy type

B. Assessment of business models for second life applications

For EV battery 2nd applications battery capacity losses during automotive lifetime will be calculated as a function of driving patterns and its degradation due to driving [13] (in this case without the V2G application). Therefore, if the battery losses are less than 20 %, the battery still can be used as electricity energy storage (EES) to fulfill different applications. The contribution margin of each stationary application then gives the information about an achievable disposal value of the battery for a certain second use application. The analyzed EES application in this context realizes a combined EES contribution to the energy exchange (e.g. the EEX market) and control energy markets (tertiary and secondary control).

Fig. 6 shows the EES operation schedule by participating at the energy exchange and tertiary control market. For a fair comparison of the results the same operation schedule would be used in the case of participation of EES at the energy exchange and secondary control market. The figure shows the number of calls of tertiary power per time period in 2010. The called positive control energy represents an incremental characteristic matching the increase in electricity demand between 08:00 to 12:00 and 16:00 to 20:00 o'clock. The decrease in demand between 00:00 and 04:00 o'clock shows itself by increases of called negative control energy. Hence, the mentioned time blocks, called control blocks, with consideration of adapted battery charging/ discharging profiles build up the time periods where the battery ensures the delivery of a certain power (maximum value) as control power, if it is needed. If the EES (or EES operator) does not get a signal (automatically) or a phone call (manually) for delivering of control power in the mentioned control blocks (for each hour one signal), the battery is able to take part in the energy exchange market.

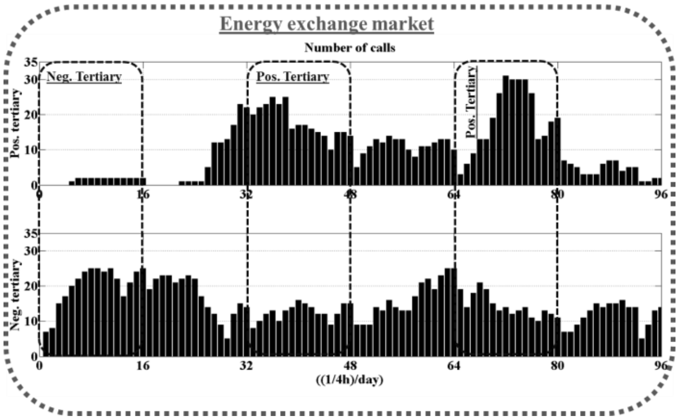

Fig. 6 Battery operation schedule based on historical market information-participating in energy exchange and control energy market

The other time blocks (04:00 to 08:00, 12:00 to 16:00 and 20:00 to 24:00 o'clock) define areas in which EES takes part in the energy exchange market and can provide its capacity for the beginning of the control blocks.

By assuming the same charging and discharging efficiencies for the 2bd Life application as were used for V2G and G2V applications (from grid to battery η_{G2B} or from battery to grid η_{B2G}) the following formulas introduce a sequential linear optimization model. The goal of the optimization is the maximization of EES (or EES operator) contribution margins (revenues) due to its participation on the energy exchange and control market. Equation (1) describes the calculation of the battery state, which will be computed from the previous state and charging/ discharging power as a function of the previous state. The state of charge, as shown in (2) can be varied between 10 and 80 % of the whole battery capacity. Equation (3) describes the variation range of charging and discharging power, whereby the maximum charging power is equal to maximum discharging power. The maximum charging power could get two values: 3.5 or 10.5 kW. Even more, a battery with a maximum charging/ discharging power must be able to fulfil the conditions of participation in the control energy market. Those conditions like a minimum bid of 10 MW power e.g. can be ensured by a pooling of small EES including their management through an aggregator (EES operator). Therefore, it must provide the maximum charging/discharging power for the whole time of mentioned control blocks in Fig. 6. For example a battery with a capacity of 24 kWh will be operated between 2.4 (24*0.1) and 19.2 kWh (24*0.8) with an operation range of 16.8 kWh Thereby, the maximum charging/discharging power is 3.5 kW, because charging or discharging the battery at 10.5 kW for 4 hours would exceed the operation range of 16.8 kWh. Equations (4) and (5) therefore depict the condition of the battery state at 00:00, 08:00 and 16:00 o'clock due to a successful participation in the control energy market.

$$S_{Li}(t+1) = S_{Li}(t) + P_{Charg,\,t+1}(S_{Li}(t)) * \eta_{G2B} * h - P_{Disch,\,t+1}(S_{Li}(t)) * h \qquad (1)$$

S_{Li}: State of battery (kWh),
h: Time factor (h)
$P_{Charg,t}$: Charging on a certain time (kW)
$P_{Disch,t+1}$: Discharging power on a certain time

$$0.1 * C_{Li} \le S_{Li} \le 0.8 * C_{Li} \qquad (2)$$

C_{Li}: Maximum capacity (kWh)

$$\begin{aligned} 0\,kW &\le P_{Char,\,t}(S_{Li}(t)) \le Max\_Charg\_power \\ 0\,kW &\le P_{Disch,\,t}(S_{Li}(t)) \le Max\_Disch\_power \\ Max\_Charg\_power &= Max\_Disch\_power \end{aligned} \qquad (3)$$

Max_Charg_power: Maximum charging power
Max_Disch_power: Maximum discharging power

$$S_{Li,\,control,\,negative} \le 0.8 * C_{Li} - 4 * Max\_Disch\_power \qquad (4)$$

$S_{Li,control,negative}$: Battery state at 00:00 o'clock

$$0.1 * C_{Li} + 4 * Max\_Disch\_power \le S_{Li,\,control,\,positive} \le 0.8 * C_{Li} \qquad (5)$$

$S_{Li,control,positive}$: Battery state at 08:00 and 16:00 o'clock

The difference between revenues and cost build up the contribution margin, which must reach a maximum value due to the hourly sequentially linear optimization approach and its constraints, defined by (2)-(5).

In the model the contribution margin will be calculated based on the time of the called control energy (2010 values), assumed energy price curves for the energy exchange market in 2020 and assumed power and energy prices for providing control energy in 2020.

C. Data

The assumed price curves for the low cost charging points for V2G/ G2V use cases and described second life applications in 2020 are illustrated in Fig. 7. The energy price curves during the summer periods are characterized with a maximum energy price at 12 o'clock. The winter prices during a day show itself with 2 local maximums in the early morning and evening.

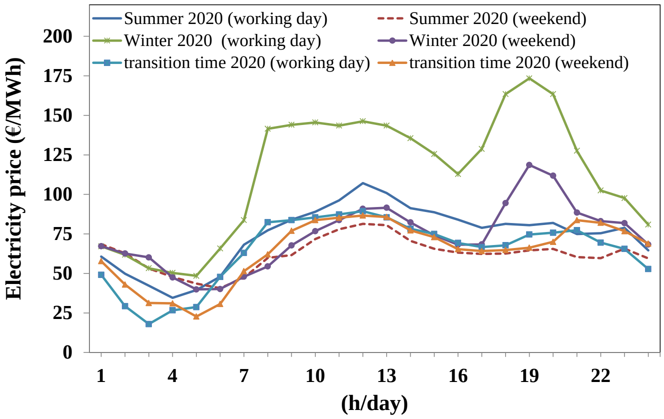

Fig. 7 Assumed electricity prices for 2020 based on typical price curves in 2009

Table I depicts the used energy and power prices for the Austrian control energy market in 2020 which have been calculated based on historical control energy market conditions as described in [14]-[16].

TABLE I
AVERAGE CALCULATED AND ASSUMED VALUE OF ENERGY AND POWER PRICES FOR AUSTRIAN CONTROL MARKET IN 2020

	Positive (V2G)		Negative (G2V)	
	Power price €/MW/h	Energy price €/MWh	Power price €/MW/h	Energy price €/MWh
Primary control	53.6		53.6	
Secondary control	26	116.90	26	73.1
Tertiary control	2	176.75	10	73.1

V. RESULTS

A. EVs participation in control energy market in the APG-control area

Fig. 8 shows the results of the G2V application (providing of negative control energy from home, office and public charging station) and shows the difference (average value) between the charging costs due to a cost optimal charging strategy (not participating at control energy market) and the G2V application (combined charging at energy and control markets). The shown results refer to the vehicle category with a battery capacity of 48 kWh. The X-axis indicates the variation of power and energy prices for the tertiary and secondary control market. The charging costs in the G2V use case (tertiary market) are higher than the low cost charging strategy on the point 100 % (energy price = 73.10 €/MWh , power price = 10 €/MW/h). The reason lies in the concentration of called tertiary energy between 06:00 and 20:00 o'clock. Therefore, the vehicle must be charged with higher energy costs compared to the low cost charging strategy (charging in the early morning or late evening). The power price cannot compensate the mentioned gap (still negative contribution margin). A positive gap can be reached by energy price reduction of about 30 % from the main point with an energy price of 73.10 €/MWh. This energy price will be paid by the aggregator due to EV charging.

Charging the vehicles on the secondary market results in lower charging costs and therefore positive margins compared to the low-cost charging strategy can be achieved due to a higher number of secondary calls, their distribution over all time periods and higher prices. Based on the discussed main point in Fig. 8, the contribution margins due to participation of EVs on negative control market (tertiary and secondary) obtain a spread of margins between -87.6 and 70.80 €/vehicle/yr (-7.32 and 5.9 €/vehicle/month).

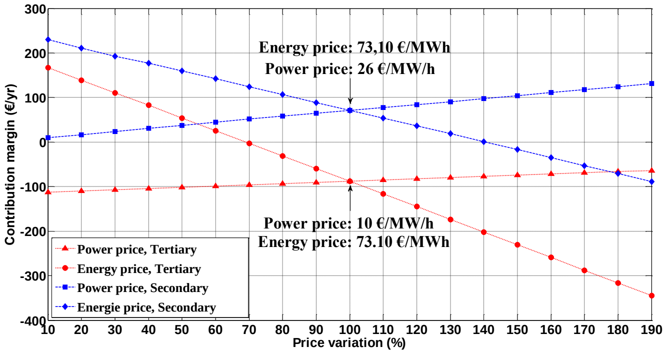

Fig. 8 G2V contribution margin for the EV category with a battery capacity of 48 kWh

Positive margins can be achieved at battery investment cost lower or equal to 500 €/kWh due to lower battery degradation costs. The spread of margins for providing of positive secondary power lies between 270.72 and 767.28 €/vehicle/yr (22.56 and 63.94 €/vehicle/month) (battery investment costs = 500 €/kWh). The same analysis has been conducted for providing of positive tertiary resulting in margins from 63.49 to 198.1 €/vehicle/yr (5.29 to 16.51 €/vehicle/month) (battery investment costs = 500 €/kWh).

The mentioned margins indicate the maximum contribution margins for each vehicle because of neglecting the dispatch probability in Austrian control area. The control power reserves in Austria are about +/-200 MW for secondary [17] and +280/ -125 MW for tertiary [18] control. The called control power data, which will be provided by the balancing group coordinator, indicates dispatch probabilities of about 17 % (18 %) for positive (negative) secondary and 0.4 % (1.35 %) for positive (negative) tertiary control energy in 2010. The probabilities correlate with those from control markets in Germany [19]. However, the consideration of dispatch probabilities (see Fig. 9) reduces the contribution margins for V2G application (secondary) in a range between 46.02 and 130.44 €/vehicle/yr.

Fig. 10 depicts the battery capacity losses due to automotive use for all analyzed vehicle categories (automotive lifetime is 10 years.). The batteries with 16, 24 and 48 kWh show average capacity losses of about 12, 9 and 6 % related to their installed capacity (without consideration of environmental parameters such as outdoor temperature). Generally, the results indicate the remaining capacity range for second life usage. Because of uncertainty in the battery lifetime, the results for a second life application were calculated taking into account lifetime variations.

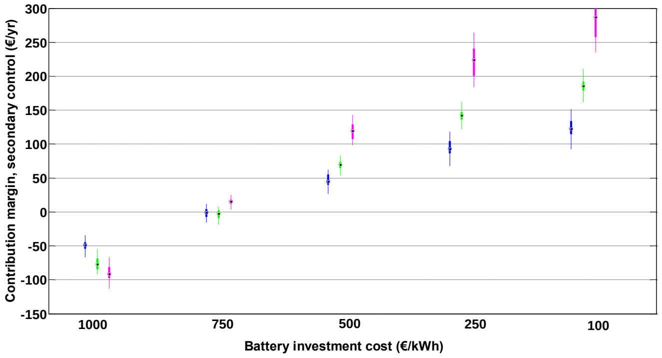

Fig. 9 EVs contribution margin due to their participation on control energy market (It exits for each value on Y-axis 3 boxplots. They refer from left to right to EVs with 16, 24 and 48 kWh battery capacity)

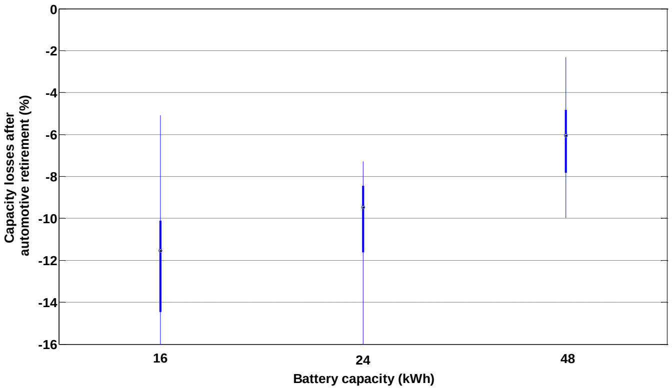

Fig. 10 Capacity losses due to automotive use (assumed vehicle lifetime is 10 years)

B. *Second life usage due to providing of control energy*

Fig. 11 illustrates the calculated contribution margins of Li-ion batteries (investment costs: 1,000 €/kWh) in the described second life application (participation on energy exchange and control markets see chapter IV). As expected, the margins due to a participation of the batteries on the energy exchange and tertiary market are lower than those in the secondary control market case (lower number of tertiary calls and more attractive prices on secondary market).

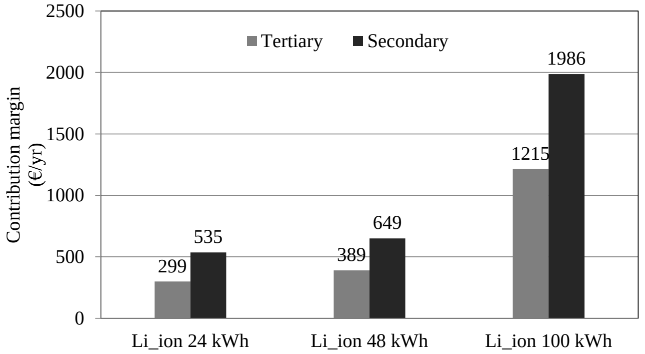

Fig. 11 Contribution margin for analyzed EES application in the first year

Based on those results, the disposal value of a Li-ion battery (original investment cost = 1,000 €/kWh) as a function of its lifetime has been compared to the present value of a lead acid battery which provides the same application (capacity: 100 kWh, operation range between 10 and 80 % of state of charge). The investment cost for lead acid batteries is between 50 and 100 €/kWh with a lifetime of 12 years [20]. The cost for an inverter has been neglected for both battery types. The dotted line in Fig. 12 presents the disposal value (present value) of the second use application based on the contribution margin in the year (2020), the battery lifetime and repurposing costs of about 250 € [6]. The solid line in the same figure represents the present value (interest rate = 7 %) of using the described lead-acid battery for the same purpose but with different investment costs (100 €/kWh or 50 €/kWh). The results conclude that the use of batteries after their automotive retirement might be reasonable if a lifetime of more than 4 or 8 years as a function of lead-acid battery investment costs can be achieved.

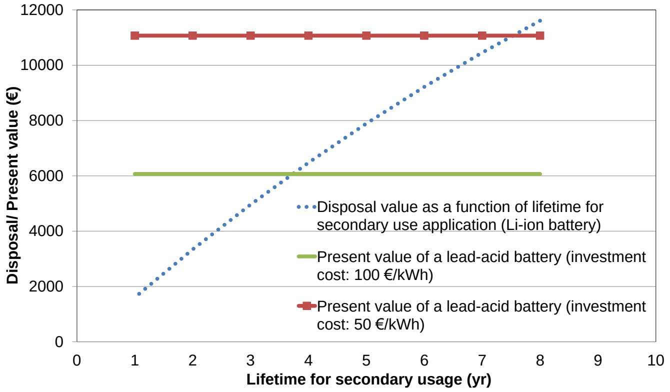

Fig. 12 Comparison of the disposal value of a vehicle battery in second use with the present value of a new battery for the same application (application: participation on the energy exchange and secondary control energy market)

Besides V2G and G2V applications, the dispatch probabilities in the 2^{nd} life use case were considered which results in more realistic outcomes.

VI. CONCLUSIONS

The calculation of G2V and V2G contribution margins doesn't consider the main costs like communication infrastructure, aggregator's energy management system and V2G inverter. Therefore, an economic realization of V2G (G2V) concepts (participation on the control energy market in Austria) with a maximum margin from -87.6 to 767.28 €/vehicle/yr (without consideration of costs and dispatched probability) cannot be recommended. The G2V application for participation on the negative secondary control market has a better economic potential compared to the V2G application. The reasons lie in a higher number of control energy calls and non-existing battery degradation costs.

In this context, other charging strategies like photovoltaic-oriented charging (at home or office) and discharging (covering the household demand or participation in the control energy market) can be considered as other kind of G2V and V2G applications, whereby the calculation of their economic potential will be analyzed in further project steps. This kind of charging strategy is expected to reduce the negative impacts of a high penetration of photovoltaic on a low voltage grid.

A reuse of EV batteries after their automotive lifetime for participation on the energy exchange and control energy markets thus can be recommended as a successful BM, if 2nd lifetimes higher than 4 years can be achieved. The reason lies in a positive and higher net present value of the reused batteries compared to new ones (same performance of lead acid batteries as those of reused batteries).

VII. References

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VIII. Biographies

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