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Exploiting Potential Gross Economic and Environmental Benefits of 2nd-Life Battery Energy Storage Systems by Mechanisms Allowing Operators to Share in the Value Creation

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Abstract

Suitable operation of decentralised battery energy storage systems (BESS) can create a value for the power sector 2-3 times the costs by reducing renewable electricity generation curtailment and fossil power generation. This goes along with environmental benefits, notably greenhouse gas emission abatement, which overcompensate the environmental impact of the BESS production. These effects are enhanced if BESS with 2nd-life batteries are used which are extracted from electric vehicles after their capacity has fallen below a specified threshold after some years of operation, and which are subsequently used for stationary applications instead of being recycled straightforwardly. Even for a low electrification rate of the vehicle fleet, the technical potential of such 2nd-life BESS is tremendous: the entire need for frequency response and reserve could be provided more or less as a side effect and the power sector's flexibility could be raised significantly, thus ensuring stable grid operation even at a high penetration rate of fluctuating renewable power generation. The existing regulatory framework puts obstacles if not impedes operators to share in the value they can create for the power sector. As a result, BESS operation is not optimised with regard to system value creation and environmental benefits and less BESS are installed due to lacking business opportunities. This work gives an overview of the technical potential of 2nd-life BESS for the power sector and their potential environmental benefits, and outlines mechanisms allowing operators to share in the value creation. It is based on results obtained in the EU-H2020 projects ELSA and GOFLEX.

Keywords: 2nd life batteries; gross economic value; environmental benefits; regulatory framework; business models

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1. Number, capacity and power of 2nd-life batteries available from electric vehicles

The number of 2nd-life batteries which are available for stationary battery energy storage systems (BESS) is given by (1), where $n_{vehicles}$ denotes the number of vehicles in the considered region, e.g. the EU, a_{2nd} the 2nd-life availability rate, defined according to (2) as the product of r_{el}, the rate of electrification of the vehicle fleet and r_{reuse}, the rate at which used batteries extracted from electric vehicles are further used in stationary BESS, t_{1st} the average time of use in the vehicle, and t_{2nd} the average time of use for the stationary application. The total energy storage capacity of the available batteries is given by (3) and their total power by (4), where *e* denotes the average guaranteed capacity and *p* the average guaranteed power of the batteries during their 2nd life. For the purpose of the following calculations, the vehicle stock is defined to be 100 % electric if, on the average, each vehicle has a battery whose guaranteed capacity equals *e* in case it is reused for a 2nd life. This might be realized by a stock of vehicles comprising fully electric, hybrid and even a few fossil-fueled vehicles with batteries of different size.

(1) $N = n_{vehicles} \cdot a_{2nd} \cdot \frac{t_{2nd}}{t_{1st}}$

(2) $a_{2nd} = r_{el} \cdot r_{reuse}$

(3) $E = e \cdot N$

(4) $P = p \cdot N$

Taking for $n_{vehicles}$ the number of vehicles in the EU, 300 million in 2016 [1], assuming 50 % for r_{reuse}, and taking the values of the BESS developed in the EU-H2020 project ELSA for the other parameters: 10 years for t_{1st}, 5 years for t_{2nd}, 11 kWh for *e*, and 12 kW for *p*, the number, capacity and power of permanently available 2nd-life batteries as a function of the vehicle stock electrification, respectively, 2nd-life availability rate is as shown in Table 1. If only 5 % of the EU vehicle fleet is electric and half of the batteries are reused, these batteries have a power of 45 GW, the same as all EU pumped hydro power plants together had in 2011 [2] which are presently the most important storage technology in the power sector. [3] BESS with the characteristics assumed here are called ELSA-type BESS in the following.

Table 1: Number, capacity and power of 2nd-life batteries for a reuse rate of 50 % and different vehicle stock electrification rates

vehicle stock electrific. rate, r_{el}	0.33%	1.0%	2.0%	5.0%	10%	20%	50%	100%
2nd-life availability rate, a_{2nd}	0.2%	0.5%	1.0%	2.5%	5%	10%	25%	50%
available 2nd-life batteries, N (mill.)	0.25	0.75	1.5	3.75	7.5	15	37.5	75
total available batt. capacity, E [GWh]	2.75	8.25	16.5	41.25	82.5	165	412.5	825
maximum power from batt., P [GW]	3.0	9.0	18	45	90	180	450	900

2. Frequency response and reserve provided as a side effect

Among the presently most interesting business cases for BESS are provision of frequency response and reserve [4]. Operators of BESS can respond themselves or via aggregators on the respective tenders at national level. However, the technical potential for frequency response and reserve of 2nd-life BESS is so huge, that these grid services might in future be provided in addition to another service more or less as a side effect. For illustrating this potential, the range of the state of charge (SOC) has been calculated in which all BESS participating in primary reserve (PR) provision must stay on the average, in order to ensure that all the PR presently needed in the European Network of Transmission System Operators (ENTSO-E) zone, that is $\pm$ 3,000 MW for up to 30 minutes [5], can be provided by them. This calculation has been made for ELSA-type BESS for different values of the 2nd-life availability rate. The results are shown in Fig. 1.

The upper curve displays the maximum SOC and the lower curve the minimum. If the BESS are operated in such a way that their SOC is on the average always between both curves, respectively returns in this range within 2 hours after PR has been provided, all the PR needed in the ENTSO-E zone can always be provided. At a 2nd-life availability rate of 0.17 %, the minimum and maximum SOC are both 50 %. This means that up to that 2nd-life availability rate the total BESS capacity is too small for providing all the PR needed in the ENTSO-E zone. Yet, a fraction of it could be provided. Going to higher values of the 2nd-life availability rate, all the PR can be provided if the SOC remains on the average in a certain range. This range of suitable SOC is quickly enlarged as the 2nd-life availability rate increases. As it can be assumed that all the BESS are with a high probability within a SOC range that reaches from a few percent up to little less than 100 %, all the PR needed in the ENTSO-E zone can be provided with a very high probability as a side effect even for a 2nd-life availability rate up from a few percent.

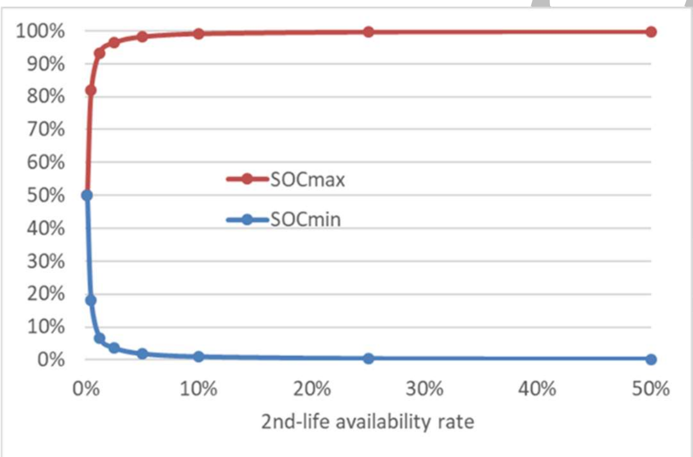

Fig. 1. Maximum (upper curve) and minimum (lower curve) value of average SOC required for providing all the PR needed in the ENTSO-E

In the very rare event that the maximum PR, or a significant part of it, will effectively be needed, this will modify the SOC of the BESS in such a way that they might exceptionally not be able to fully serve their original purpose. Hence, it must be ensured that this restriction is not detrimental to the original purpose or it must be adequately compensated. A remuneration paid to the BESS operator as a compensation can however be lower than the remuneration needed for BESS operated exclusively for PR provision, because the BESS is mainly refinanced by its original purpose.

3. Technical potential to provide power in case of supply shortfall

If power supply is increasingly provided by volatile renewable power plants, there might be periods in which BESS have to contribute to security of supply. For illustrating the technical potential of 2nd-life BESS to do this, again ELSA-type BESS have been used as an example and the duration has been calculated for which the average, respectively, peak power demand of the EU can be provided by fully charged BESS. The calculation has again been done for various values of the 2nd-life availability rate and under the assumptions mentioned above. The results are shown in Fig. 2.

For low 2nd-life availability rates the EU power demand can be fully met by the available BESS for a few minutes, if sufficiently charged, providing a significant potential to bridge short blackouts and to support black start of power plants after a blackout. For medium 2nd-life availability rates, e.g. if half of the vehicle stock is electric and most batteries are collected for 2nd-life use, the EU power demand can be met for about one hour by sufficiently charged BESS. The slight bend downward of the curves reflects the increase of the electricity demand with increasing electrification of the vehicle stock.

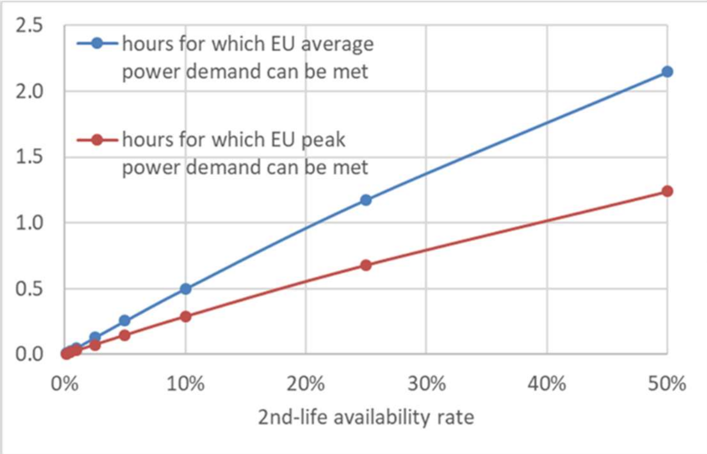

Fig. 2. Number of hours for which the average (upper curve) and peak (lower curve) power demand can be met in the EU

4. Technical potential for 100 % RE supply

Further calculations have been made to assess the technical potential of ELSA-type BESS to provide a substantial contribution to the energy storage needed for 100 % renewable energy supply of the EU + Norway + Island + Switzerland + Balkan Countries + Ukraine + Turkey. In such a case BESS with a capacity of 3,320 GWh are needed [6]. If all vehicles in the EU are electric and all the batteries are reused in 2nd-life BESS, the then available storage capacity corresponds to 50 % of the required battery storage in the mentioned region, respectively, more than 50 % of the battery storage required in the EU.

5. Costs of decentralized 2nd-life BESS and value for the power sector

ELSA-type BESS are assumed to be sold at 580 €/kWh in the beginning, to have a life-time of 10 years, a replacement of the battery after 5 years at costs of 151 €/kWh, and 58 €/kWh operational costs per year. Considering weighted average cost of capital of 15 %, the total annual costs are 189 €/kWh or 173 €/kW. The annual costs have been put in relation with results obtained for the United Kingdom on the optimum BESS deployment and the generated value creation for the power sector as a function of the BESS annual costs [7]. According to these findings, 4.3 GW of decentralized BESS represent the gross-economic optimum for reaching the target of average power generation emissions of 130 gCO_2/kWh in 2030 mainly by extending renewable power generation. This corresponds to 4 % of the UK's vehicle stock being electric and 50 % of the batteries being reused (or 2 % of the vehicle stock being electric and 100 % of the batteries being reused). The value created, essentially by avoided curtailment of renewable power generation and avoided generation in gas power plants, is 404 €/kW annually, that is 2.4 times the total annual costs.

About the same ratio of gross economic value creation to BESS costs applies if BESS costs are varied [7]. This implies that using BESS with 2nd-life batteries whose costs are lower than the costs of BESS with new batteries leads to a larger capacity of BESS installed and thus to higher gross economic benefits.

6. Environmental benefits

Avoided curtailment of renewable power generation and avoided generation in gas or other fossil power plants are also the main reasons for the environmental benefits which BESS can provide. A full Life Cycle Assessment (LCA) for ELSA-type BESS has been made. The environmental impact avoided by using an ELSA-type BESS instead of a BESS with a new battery is about 6.7 kg $CO_{2\text{-eq}}$/kW/yr with regard to the global warming potential, 0.04 kg $SO_{2\text{-eq}}$/kW/yr with regard to the acidification potential, and 104 MJ/kW/yr of non-renewable primary energy use. This effect is almost entirely due to the avoided battery production.

If the environmental impact of the production and logistics of the battery is accounted entirely to the 1st life in the vehicle and the impact of the remaining BESS components to the 2nd-life, and the ELSA-type BESS is operated such that 5 % PV curtailment is avoided in a scenario with local self-supply from PV of 43 % and an electricity mix similar to that in Germany (40 % renewable, rest carbon-rich) covers the residual demand, the net avoided environmental impact is 304 kg $CO_{2\text{-eq}}$/kW/year, 0.15 kg $SO_{2\text{-eq}}$/kW/year, and 2,506 $MJ_{\text{non-RPE}}$/kW/year. [8]

7. Mechanisms allowing BESS operators to share in value creation

The existing regulatory framework puts obstacles if not impedes operators to share in the value they can create for the power sector [4]. As a result, less BESS are installed due to lacking business opportunities and the operation of those BESS which are installed is not optimised with regard to system value creation and environmental benefits. Basically, mechanisms are required which let BESS operators share in part of the value they create for the system, thus (1) permitting more potential BESS operators to make a business, and (2) encouraging them to operate BESS in a way which serves the power sector as a whole.

The authors suggest to establish suitable mechanisms first for those system services which can merely be provided as a side effect by BESS installed primarily for another purpose, that are frequency response and primary reserve. For instance, operators who primarily use a BESS for optimising their own consumption, e.g. by peak shaving or by maximising their self-supply from renewable energies, might get a small remuneration for operating the BESS such that it participates in provision of frequency response and primary reserve. The remuneration paid for such micro-service provision as a side effect can be significantly less than the average price obtained by tenders. Nevertheless, such a regulation has the potential to increase the installed capacity of BESS. In a next step, such a mechanism might be extended to secondary and tertiary reserve and redispatch.

8. Conclusions

BESS with batteries which have been used in electric vehicles and are extracted from them to be used for stationary applications after their capacity has fallen below the minimum value needed for mobile use have a tremendous technical potential to provide services to the power sector worth 2-3 times the costs of the BESS. In addition, environmental benefits are created which overcompensate the environmental impact of the BESS production.

Gross economic value creation and environmental benefits go hand in hand and both depend on the way how BESS are operated. Essentially, both are a consequence of avoided curtailment of renewable power generation and avoided power generation of fossil power plants. If a renewables curtailment of a few percent and related fossil power generation are avoided, the environmental benefits overcompensate the impact of the BESS production. If in addition, 2nd-life batteries are used instead of new ones, this enhances the effect, but the benefits created by the BESS operation still dominate, notably with regard to the global warming potential.

Regulations allowing BESS operators to receive a small remuneration for participating in frequency response and primary reserve provision as a side effect might increase the scope for business opportunities and thus the installed capacity of BESS. If successful, such schemes might be extended to secondary and tertiary reserve and to redispatch. If only a few percent of the vehicle stock are electrified and half of the batteries are reused in 2nd-life BESS, the entire need for frequency response and reserve, and potentially also for redispatch, can be met with 2nd-life BESS alone. If these services are provided as a side effect in addition to another purpose, their cost might also be lower than prices achieved today for system services via tenders.

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