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Multi-use of Community Energy Storage

Energy Services and their Compatibility with Increasing Self-consumption as Primary Service with a Focus on Germany

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Abstract—**Battery energy storages play an important role in the energy transition toward an energy system based on renewable resources. Today, batteries on a household and community level in Germany are primarily used to increase consumption of self-produced electricity. However, batteries used solely for increasing self-consumption are neither profitable yet from an economic point of view, nor is the same battery capacity needed at all times when used only for self-consumption. At a considerable time of the day, the battery is either empty or fully loaded and could be used for other services. Community energy storages show several advantages compared to home storages and might also help to explore possibilities of using a battery for multi-use due to the size and simplification of control. Thereby, extra profits for a positive business case can be generated and a more efficient use of the battery is made possible.**

This paper investigates and structures possible services of community energy storages in Germany. It highlights the most promising services for multi-use and shows what prerequisites regarding the state of charge of the battery is necessary to perform the service. Moreover, a technical simulation of energy flows of a community with a variation in the number of households, photovoltaic capacity, and battery dimensions provides evidence that multi-use of community energy storage is even possible with only minor effects on self-consumption levels inside the community. For instance, the results show, that, on average, more than 30% of battery capacity can be used for additional services if the share of storage capacity used for self-consumption is adjusted monthly depending on the season and solar radiation.

Keywords— ***community energy storage, multi-use, collective self-consumption, energy services, energy prosumers, energy communities***

I. INTRODUCTION

Battery energy storages can play a significant role in the energy transition. By decoupling production and consumption battery storages are valuable in an energy system where a large share of production comes from fluctuating renewable energies. In the residential sector investments in battery energy storage are primarily motivated by increasing self-consumption [1]–[6]. However, using battery storage solely for increasing self-consumption is not yet profitable, nor is the battery used efficiently [2], [3]. For a large part of the day, the battery is empty since there is no surplus of electricity to be stored or the battery is fully loaded, and surplus energy has to be fed into the grid. Previous studies showed that for increasing profitability and efficiency the battery needs to be used for multiple services [7]–[9]. Community energy storages (CES), in this paper defined as battery energy storage system "sited in and serving the power demands of a community within a spatially bounded, organizationally defined area or region" [10] shows several advantages compared to home storages. Advantages include a higher self-consumption ratio compared to a community with the same amount of storage capacity in individual storages [11]–[13] or the possibility to include more actors on an individual level [14]. Higher participation is important to strengthen the acceptance of energy transition [5], [10], [14], [15]. Besides, CES might also help to explore the possibilities of using a battery for multi-use due to the size and simplification of control [10], [13], [16]. Even though existing literature gives some examples of services that battery storages can facilitate [9], [10], [17]–[22], there is neither a comprehensive compilation of possible services CES can provide nor on the potential feasibility of multi-use when increasing self-consumption is considered to be the primary service that should not be significantly compromised. This paper closes this research gap and provides an extensive overview of services CES can comprise in Germany gathered through a variety of methods. In addition, a business case is analyzed in depth where storage capacity is flexible allocated to different services throughout time highlighting most promising services to combine with increasing self-consumption. For

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evaluating the potential of flexible allocation, a simulation provides evidence that secondary services can be applied without compromising the primary service of self-consumption significantly.

II. THEORY

Batteries in the residential sector are mainly used for increasing self-consumption [1]–[6]. Hence, for finding the optimal storage capacity, earlier research focused primarily on optimizing the battery capacity according to battery costs, demand and electricity production from photovoltaic (PV) [5], [6]. Hereby taking into account that PV production depends on solar radiation and thus, varies over time. Also household's electricity demand fluctuates throughout the day with peaks in the morning and the evening [6], [7], [14]. Moreover, with increasing electrification of other sectors, e.g., electric vehicles in the mobility sector and heat pumps in the heating sector, demand will fluctuate even more, leading for instance to higher demand in the cold months and less demand in the warm months of the year [5]–[7], [14], [15]. These developments lead to increasingly inefficient use of the battery as the full battery capacity is not used during large parts of the day due to multiple causes [23] (cf. also Fig. 3, in chapter IV.B):

1. High state of charge (SOC) throughout the day when stored electricity from overproduction during the day is not consumed at night
2. Full battery during large parts of the day when production considerably exceeds demand and battery is fully charged quickly
3. Low maximum SOC when production only slightly exceeds demand for short periods of the day
4. Empty battery during large parts of the day when demand exceeds production considerable and the battery is discharged quickly

Due to these reasons, the optimal battery capacity needed to increase self-consumption varies over time, and temporarily some of the capacity could be used for secondary services. This paper investigates how much capacity could be used otherwise and how different approaches would affect self-consumption.

III. MATERIALS AND METHODS

A. Services

In a first step services applicable for CES were identified using a model for the development process of services created at Fraunhofer IAO [24]. First, ideas for potential services were collected through a literature research on services already offered in the German market and through workshops with domain experts, in which creativity techniques and innovation methods such as brainstorming, the 6-3-5 method [25] or group discussions were used. Second, stakeholders from the business community were interviewed for further ideas. The identified service ideas were then concretized by formulating the specific value proposition and assessing the feasibility and potential of the respective service. This assessment was made from various perspectives through guided interviews with stakeholders from industry and academia. For this purpose, an evaluation form was prepared and distributed to the participants. The participants were questioned about criteria such as the potential of the respective service, possible obstacles (e.g. during implementation) or regulatory framework conditions.

To achieve a business case with economic viability and use the battery more efficient, a combination of several services is required in a multi-use application. The focus in this paper was set on a business model that flexibly adapts the storage capacity to the current needs of the respective user, thus reserving only a part of the total capacity for the primary use self-consumption at a time. The concept behind this flexible storage capacity is to counteract the inefficient use of batteries described in chapter II. The storage capacities or power reserves not required at a given time can be bundled and used secondarily for other applications.

Hence, as part of the development of a business case based on flexible storage capacity, the previously identified services were again evaluated by mentioned stakeholders in terms of their compatibility for multi-use within the frame of the current legal and technological framework also taking the current market conditions into account.

B. Compatibility of multi-use with increasing self-consumption

For analyzing from a technological point of view the compatibility of different services in a multi-use application a simulation is used to determine at what times during the day and year the storage is not used for increasing self-consumption and therefore could be used otherwise. The simulation is a technical bottom-up simulation of energy flows in a household or community, run on a minute basis. This allows the illustration of isolated effects, e.g., shading by clouds or simultaneity in electricity demand. The model incorporates various household appliances, all used at certain times of the day, with specific load profiles and a permutation in usage across days according to statistical surveys [26]–[29]. The model is designed to represent different household sizes and efficiency classes of average German households [30]. The PV production is based on radiation data from Lindenberg being one of the few locations in Germany where minutely data was openly available [31]. The conversion to electricity with PV-modules is based on Sauer [32].

1) Simulated use cases

In this study, two different communities are simulated, based on pilot projects located in Köln-Widdersdorf and Groß-Umstadt. Both have implemented CES, and real data was available to validate the results. These two communities were selected to reflect two different settings:

1. Multi-family house community (MFH-Community) including 75 apartments with a centralized heat (heat pumps), and centralized PV production (225 kWp) and total electricity demand of 508 MWh
2. Single-family houses community (SFH-Community) consisting of 16 single-family houses with decentralized heat (heat pumps) and PV production (total of 103 kWp) and total electricity demand of 119 MWh

The size of the installed batteries varies in both communities with a rather high battery capacity of 115 kWh and 250 kW power in the SFH-Community and a rather small battery capacity of 84 kWh and 18 kW power in the MFH-Community, considering that literature suggests approximately one kWh storage capacity per MWh electricity demand per year [33]. The reason for the installation of the rather large battery in the SFH-Community was to meet requirements of the balancing energy market where in the MFH-Community the focus was on increasing self-consumption.

2) Calculation of available storage capacity for secondary use

To analyze available storage capacity for secondary use, in a first step the SOC and depth of discharge (DOD) of the battery is simulated when the battery is only used for increasing self-consumption. Afterwards, the storage capacity that could be assigned to secondary services without compromising self-consumption is calculated, using different time slices (e.g., minute, day, week, month) with following equation:

$$CAP_{S_N} = (CAP_{BAT} - \max SOC_N + \min DOD_N) / CAP_{BAT} \quad (1)$$

where CAP stands for capacity, S for secondary services, BAT for battery and N for the time slice applied.

In addition, for time slices of weeks and months, two subsequent simulations are applied to calculate the effect of a reserved amount of the battery for a secondary use on self-consumption. The first simulation is done as before, to determine the daily maximum SOC and minimum DOD. Subsequently, for weeks and months ten percentiles (e.g. 10%, 20%...100%) of the daily SOC and DOD are derived. The simulation was then repeated for both weekly and monthly time slice another ten times ceteris paribus but with limiting SOC and DOD according to the SOC and DOD calculated beforehand. Hence, part of the capacity is reserved for secondary services.

IV. RESULTS

A. Services

CES can be utilized for a variety of applications, allowing a range of power-related services to be linked to them. In total, using mentioned methods (cf. III.A) about 30 service ideas have been identified (cf. Fig. 1). The collected services were divided based on discussions with experts of the energy field into the following seven categories where boundaries are not always distinct: energy management, monitoring, storage capacity trading, power trading, cross-sector services, grid stability and self-sufficient systems. Based on consultation with the experts, the service concepts were prioritized with respect to their overall potential and realistic implementation horizon. This paper will highlight six services that experts evaluated as currently or in the future most promising to be suitable for a multi-use combination with the primary application of increasing self-consumption. Other services are either not suitable for multi-use (e.g. emergency power supply) or experts believe that these services are not feasible or economically viable in the near future (e.g. island network). The information in the descriptions of services is derived from the literature research and the interaction with domain experts and stakeholders specified in Chapter III-A. It relates to the findings in Schnabel and Kreidel (2019) [34] and Schnabel (2020) [23]. In these two reports also an extensive description and evaluation of all services is provided.

1. Direct marketing of power

In principle, this service can be useful in the case of highly fluctuating electricity prices in order to compensate higher costs for electricity storage and storage losses. However, since levies are incurred, direct marketing via today's systems is estimated to be very expensive by the stakeholders. For this reason, the utilization of excess current is currently still more commonly associated with power-to-X processes. In the future, however, marketing without levies can become exciting in the interaction between households and businesses consumer. An interplay between self-consumption and direct marketing is particularly promising if a load and generation forecast can be used to predict well when the CES will have free capacity left for power trading. It must be clarified whether the service is also economically viable with small quantities of power. In the longer term, this could give rise to new business areas for energy utilities.

2. Intraday-trading

The interregional balance between generation and consumption enables additional income to the primary use self-consumption without significantly limiting it. Indeed, no large profits are currently expected and there is a certain additional expense for the necessary

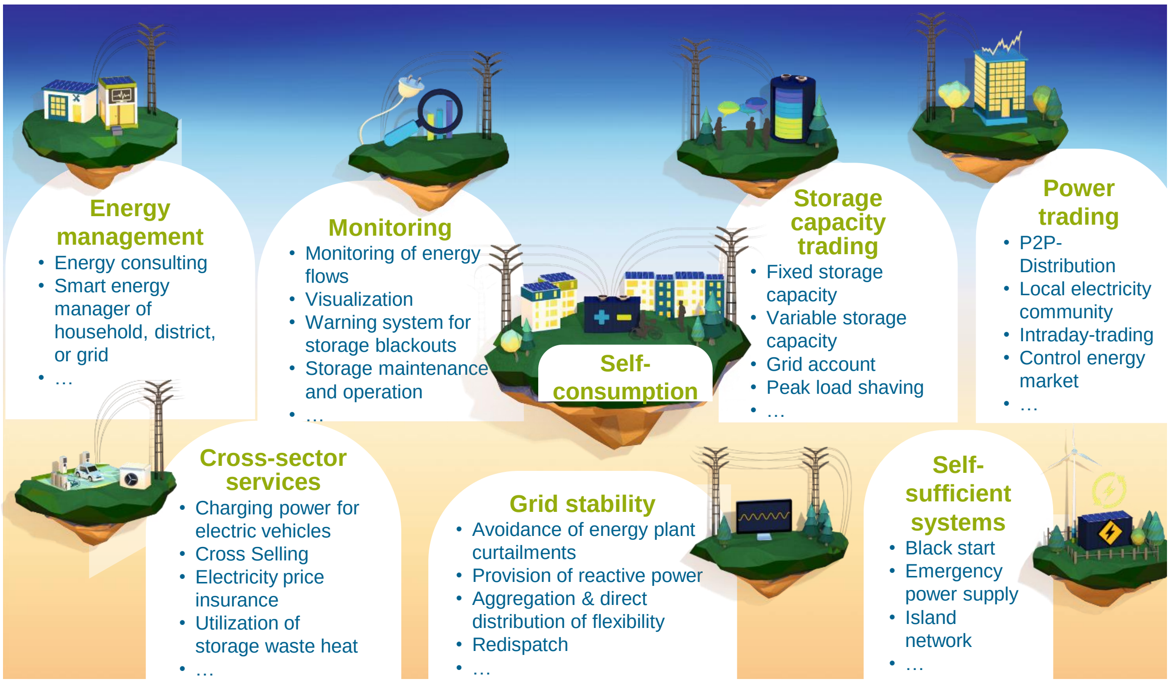

Fig. 1: Services of CES besides increasing self-consumption

connection with other storage facilities ("pooling"), in order to be able to achieve the required minimum volumes of power. On the other hand, the service can be used very flexibly and makes it possible to sell surplus electricity at short notice.

3. Charging e-vehicles

The significant advantages of this service from an energy perspective are, on the one hand, that CES enables high charging capacities without having to expand the infrastructure (e.g. transformer stations) for this purpose. On the other hand, very large amounts of energy are also drawn off in the summer months when electricity generation is high and there are otherwise few consumers. In this way, a higher proportion of the self-generated PV electricity can be used and the advantages of the CES become more visible to the residents of the community. The usage rate of the storage increases due to constant charging and discharging procedures. E-vehicle charging also complements well temporally the normal consumption profile of private households, as the majority of vehicles are charged at night.

4. Peak load shaving

Today, peak load shaving is only relevant for consumers who bear different grid connection costs according to their peak load consumption, i.e. pay a demand charge per kWh. This is currently not the case for private households and smaller companies. However, in the medium term, it is expected that performance-based network charges (dynamic or based on peak loads) will also be introduced here. Depending on the level of these charges, it remains to be seen whether this service will also become economically viable for smaller services in the future. In the longer term, however, this could create new business areas for energy utilities.

In special cases, peak load shaving can already be an economically very attractive area of application for CES. Whether the scale of storage is sufficient for self-consumption and additionally load capping of very large consumers is questionable. In addition, the service is very consumer-oriented and therefore not very flexible.

5. Peer-to-peer-power trading

Currently, there is no implemented market for peer-to-peer-power trading at the community level. On the one hand, this is due to the unclear situation as to whether and how the circumstances of peer-to-peer trading can be reconciled with the existing legal framework. In the near future, the defined market roles and their responsibilities do not seem to be adapted to the introduction of peer-to-peer trading. On the other hand, the necessary market organizational challenges, such as transactions via blockchain, have also not been fully resolved.

In principle, however, a prosumer with a PV system and CES could sell electricity from both systems to other prosumers. In this way, surplus electricity can be optimally utilized. Within a community, the service can become interesting if the community has an area grid and no or only low grid fees and other charges would be associated with the electricity supply. Otherwise, with small trading volumes, the achievable profit compared to a (still) guaranteed buy-back price appears to be low and associated with high administrative expenses.

Due to the direct connection to the other residents of the community, a high level of identification can be expected from the service. One argument against the secondary service peer-to-peer trading in the community is that often all of the residents of the community have a surplus of electricity simultaneously. However, peer-to-peer trading does not always necessarily have to be regionally limited. Overall, peer-to-peer trading offers the potential to change existing business models of established market players to a far-reaching extent in the long term.

6. Balancing energy

Participation at the balancing energy market with a CES requires prequalification by the transmission system operator responsible for the respective control area. This and the required minimum power volumes will usually necessitate a bundling of storage facilities beyond a single community. In principle, the size of the individual storage facilities is arbitrary, but CES with a larger capacity are more economical, since the one-time costs of connection are independent of the capacity. To participate in the market, it is necessary to specify a fixed capacity, which must be provided. However, this can vary at different times, so this service can be a useful complement to buffering self-consumption. In the balancing energy market, battery power plants with a total of 230 MW of capacity have already received prequalification for the provision of balancing energy in 2018. On the one hand, this shows the attractiveness of this market so far, but on the other hand, it has led to a sharp drop in prices. Still, a forecast of the balancing energy market attractiveness for the next years is extremely uncertain.

Of great importance when identifying the potential of services for multi-use is whether the service requires an empty or full storage. Tab. 1 indicates for identified services whether empty or full storage is required for the provision of this service.

Tab. 1: Secondary Services and their application possibilities

Secondary service	**Can be used when the storage is…**	
	…empty	**…full**
Direct marketing of power	-	X
Intraday-trading	X	X
Charging e-vehicles	-	X
Peak load shaving	-	X
Peer-to-peer-power trading	X	X
Balancing energy	X	X

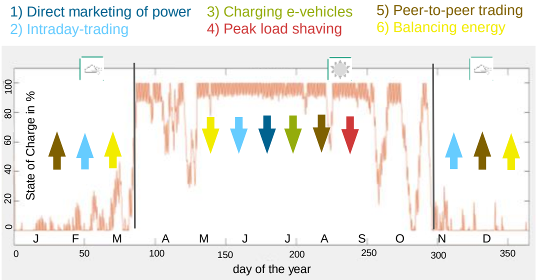

Fig. 2: Combination of different services with self-consumption

The described prerequisites on the SOC vary across the year. This becomes clearer in Fig. 2, which shows the simulated SOC of CES over one year. It is evident that in winter months, much of the self-generated PV energy is consumed directly and the storage is hardly used, while in summer months the storage capacity is often too low to absorb even more PV electricity. The direction of the arrow symbolizes how the utilization of the storage can be optimized by combining other services, such as using the storage for peak load shaving or for the balancing energy market. A detailed calculation of possible capacities will be performed in the following section.

B. Compatibility of multi-use with increasing self-consumption

The previous sections identified possible services and business models for secondary application. In this section the possible capacities for secondary applications due to a more efficient use of the battery is calculated using a simulation of energy flows inside of two exemplary communities (cf. III.B.1).

Fig. 3 shows the results of two exemplary days of the simulation (cf. III.B) of a SFH-Community displaying electricity demand and production as well as the amount of self-produced electricity that is consumed directly, stored in the battery, and fed into the grid. Identified possibilities of inefficient use (cf. chapter II) are all displayed in the example.

For identifying possible periods where battery capacity could be used for secondary services the simulation was used to identify periods where the storage is either completely full or empty. In addition, the average SOC was calculated. The results in Tab. 2 show that the battery is for large parts of the year – e.g., in sum 274.4 days in the MFH-Community and 209.3 days in the SFH-Community - either fully loaded or empty. Both of these conditions bear the potential to be exploited for secondary services according to prerequisites as described in IV.A.

Tab. 2: Average SOC, days fully loaded and days fully empty

	Ø SOC	**At >95%**	**At <5%**
MFH-Community	16.2 %	18.3 days	256.1 days
SFH-Community	37.8 %	60.7 days	148.6 days

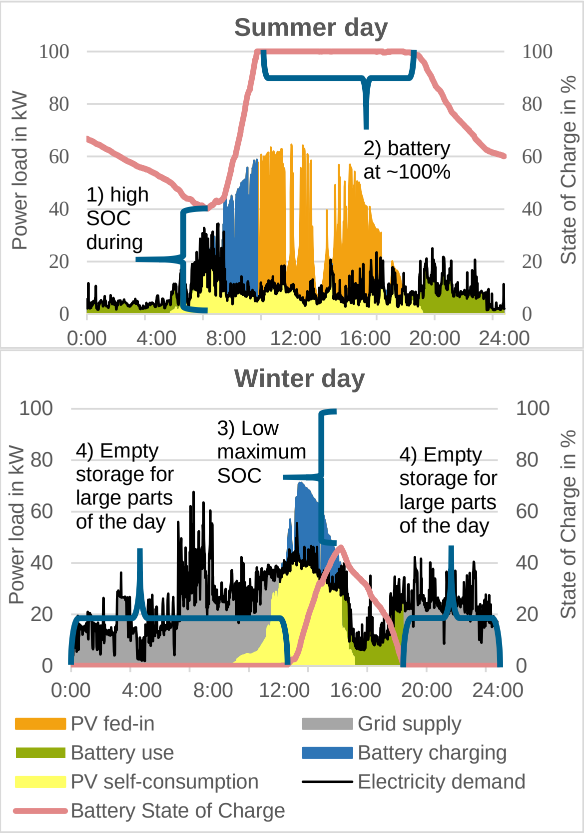

Fig. 3: Exemplary load profiles of simulation for summer and winter day showing varieties of inefficient use of CES

Besides situations where the battery is empty or full there are periods where only part of the capacity is needed because SOC does not drop below or go higher than a certain SOC. Potentials for exploiting these situations are analyzed by assuming flexible storage capacities where capacity is allocated for increasing self-consumption and for secondary use as described in IV.A. First, it was calculated how much storage capacity could be used for secondary services without compromising amount of self-consumption (cf. III.B.2). Results in

Tab. 3 show that available storage capacities for secondary use are increasingly higher the shorter the time slices are. For time slices lasting several days, the assumption made is that capacity is only allocated to secondary services when storage capacity is not needed for increasing self-consumption in any of the days of the week, month, or year. This assumption results in low capacities for secondary services for monthly (1.4 % in the MFH-Community and respectively 1.8 % in the SFH-Community) and yearly (0 % in both communities) time slices.

Tab. 3: Theoretically available storage capacity for secondary use of total storage capacity without compromising self-consumption with different times-slices with perfect forecast of demand and production

	Minutely	**Daily**	**Weekly**	**Monthly**	**Yearly**
MFH-Community	83.8 %	45.6 %	16.5 %	1.4 %	0 %
SFH-Community	62.2 %	45.0 %	17.1 %	1.8 %	0 %

Assuming a greater complexity for the operator of CES with shorter time slices, the focus of further calculation was put on weekly and monthly time slices. Fig. 4 shows results that tolerated a part of self-consumption being lost for increasing shares for secondary services (cf. III.B.2). Results show that for both communities and both time slices the capacity available for secondary services next to increasing self-consumption can be increased to more than 30 % without reducing self-consumption more than two percentage points compared to reference self-consumption shares (reference self-consumption rates without allocation of storage capacities for secondary services are at 70.3 % in the MFH-Community and 69.6 % in the SFH-Community). Fig. 4 also illustrates that weekly allocations only slightly increase possibilities to increase available storage capacity for secondary services compared to monthly time slices.

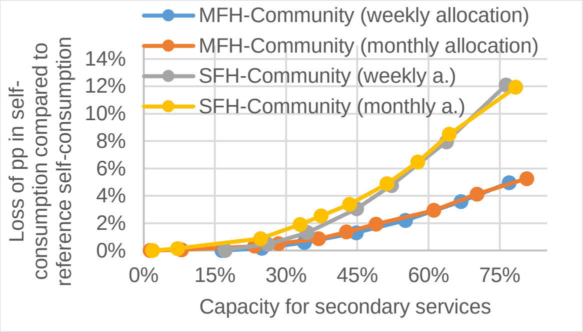

Fig. 4: Loss of pp in self-consumption vs. capacity for secondary services with monthly and weekly allocation

V. DISCUSSION

	Minutely	**Daily**	**Weekly**	**Monthly**	**Yearly**
MFH-Community	83.8 %	45.6 %	16.5 %	1.4 %	0 %
SFH-Community	62.2 %	45.0 %	17.1 %	1.8 %	0 %

The results of this paper are important in light of the expected increasing importance of shared storage. Today the regulatory framework in Germany leads to various taxes and levies when electricity is jointly stored. Burdens are especially high, when the electricity used to charge the battery has to pass through the public grid [10]. That might change in the future when directives of the “Clean Energy Package” adopted through European legislation in 2019 will be transposed to German law: First, the “Renewable Energy Drective II” (RED II, 2018/2001) states that a framework should be established where “jointly acting renewables self-consumers” are empowered “to generate, consume, store, and sell electricity without facing disproportionate burdens” and “renewable energy communities” should be able to “participate in available support schemes on an equal footing with large participants.” Second, the “Electricity Directive” (ED, 2019/944) states that “active customers” should be permitted to “provide several services simultaneously, if technically feasible” when owning an energy storage facility. Hence, it can be expected that the national framework might be more beneficial for CES in the future [10]. Moreover, the recently changed national framework might benefit multi-use in the future due to changes in §61 EEG 2021 that lifted additional burdens when CES are used for other services than storing own produced electricity [35].

The results of this paper add to existing research in the field of multi-use of battery storage with a focus on CES. First, this paper provides an extensive overview of possible services that can be carried out by CES with a focus on the German energy market and second, with the use of a simulation it was shown to what extend these services can be combined with the use of flexible storage capacity in form of a multi-use. While the research of services was performed for the German market, the identified services might also be relevant for most other countries with a similar regulatory framework. Moreover, results from the simulation of energy flows of two modeled communities is purely technical and hence, not country specific. However, the specific available capacity for secondary use varies for different settings of communities and the results displayed are solely for the two exemplary communities modeled. Still, since results showed certain similarities even though the two communities differed substantially, it can be assumed that results can be generalized to some extent. For instance results show that with flexible allocation of capacities on a weekly or monthly basis a significant share of the capacity can be allocated for secondary use (>30% of storage capacity) with only minor losses in self-consumption (<2 pp. less self-consumption compared to reference scenario). When implementing flexible capacity allocations the actual capacity available for secondary use or loss of self-consumption depends on the accuracy of the demand and production forecast. Thus, it might be lower than the calculated potentials that are based on an ex-post analysis. Since results suggest that the advantages of weekly allocation are only minor beneficial compared to monthly allocation, the realization of flexible allocations might be more promising with monthly allocations assuming that monthly allocation is less complicated compared to weekly allocations.

This paper focused on the technical potential of combing various services with increasing self-consumption as a primary service. Further research should be carried out to calculate the economic feasibility of these services and add to existing research that looked at the economic potentials of single services or a combination of only certain services [9], [34].

VI. CONCLUSION

In conclusion the results show that there are inefficiencies in battery capacity utilization when batteries are used solely for increasing self-consumption. Compared to home storages CES have an even greater potential to be utilized in a more efficient way due to size and simplification of control. A number of services (e.g. provision of balancing energy, peak load shaving, and providing e-vehicle infrastructure) could be applied in combination with increasing self-consumption resulting in multi-use of the battery even without compromising self-consumption substantially. This leads to less inefficiencies and could play a significant role in designing economically feasible business models. Still, performing multi-use is technically complex. The studies carried out demonstrate that flexible allocations of capacity throughout the year enables multi-use. Hereby, the results provide evidence that weekly allocations are only slightly beneficiary compared to monthly allocations. Therefore, complexity can be reduced by applying monthly allocations.

However, currently the regulatory framework in Germany does not benefit the multi-use in joint storages. Hence, in the process of the transposition of the directives of the Clean Energy Package joint storage and multi-use should be facilitated. This could lift the full potential of CES and result in a more important role of CES in the energy transition. In addition to needed changes in the regulatory framework, the research presented in this paper should be combined with previous research on revenue potentials of secondary services for deepening the knowledge on the feasibility of business models.

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