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Competition effects of simultaneous application of flexibility options within an energy community

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Abstract—**As part of an increased diffusion of decentralized renewable energy technologies, an additional need for flexibility arises. Studies indicate that operating battery storage systems for multiple uses as community electricity storage system (CES) promises superior benefits. This seems decisive, since cheaper flexibility options such as demand response (DR) are more applicable and might further reduce the market size for storage facilities. This research paper aims to analyze the competition effects of CES with simultaneous application of DR. The optimization results of the synthetic case studies provide insights in the profitability level, the service provision and the flexibility potential. While even under requested legal circumstances a CES is only partially profitable, the economic situation improves in terms of an optimal storage utilization. This, however, is reduced through competition effects with DR.**

I. INTRODUCTORY REMARKS

As part of an increased diffusion of decentralized renewable energy technologies, an additional need for flexibility arises. Although electricity storage facilities can't yet compete with generation flexibility, load management and cross-sectoral synergies due to their high investment costs and efficiency losses [1], they remain popular.

The form in which flexibility options are integrated in the future energy system on a community level is currently not foreseeable. Nowadays, electric batteries are most commonly employed as household electricity storage systems (HES) that prosumers use to maximize their share of individual self consumption (SC) or autarky level. Studies indicate that operating battery storage facilities for multiple uses such as community electricity storage system (CES) promise a higher profitability [1], [2]. Compared to a HES, a CES can be realized with economies of scale due to its size, and exhibit a higher utilization degree, leading to a smaller storage capacity [3].

The assessment of flexibility options requires an integrated consideration of changing energy system conditions. The simultaneous application of different flexibility options in particular might lead to unexpected behavior patterns. Cheaper flexibility options such as demand response (DR) might reduce the market size for storage applications as CES [3].

In view of the mentioned uncertainties, this research paper aims to investigate the competition effects of CES with the simultaneous application of DR in Germany. For a systematic evaluation, the following research questions are assessed: (i) Which operating conditions shape the flexibility options at community level? (ii) Which effects are visible in terms of profitability and utilization at different energy system conditions? While the first question is answered by reviewing literature, the second question is investigated by applying a scenario based analysis.

Section II sketches the foundations of flexibility solutions. Subsequently, Section III introduces the applied optimization model IRPopt. Furthermore, case studies are presented. Section IV evaluates the results of the model based analysis. Finally, Section V summarizes the results and outlines future work.

II. COMMUNITY FLEXIBILITY

A. Flexibility Options

Similar to a HES, a CES is a power bank that stores excess energy generated by decentralized energy systems of individual prosumers in a central electrical storage to bridge the temporal and quantitative gap of renewable electricity supply and energy demand. Each participating household is located in spatial proximity to the CES and connected via the public grid on the distribution level. Every participant is assigned an account tracking how much electricity they fed in or withdrew from the system. The CES system is managed by an operator.

While the prosumers main strategy is to maximize their self consumption, application strategies from the perspective of the operator include electricity generation improvements, energy arbitrage services, renewable energy integration and reserve tendering services [3].

Since other flexibility options could reduce the market size for storage applications [3], participating households also have the possibility to apply DR. The concept of DR is defined as the changes in electricity consumption in response to changes in the price [4]. Thereby, only load shifting, temporary load reductions that are compensated for by load increases in other time periods, is adopted in this research paper.

B. Legal Framework

Since storage solutions can only be affordable when having a competitive advantage over grid consumption (GC), i.e. the taxes, fees and levies for storage feed-in and consumption don't exceed the difference between GC and the electricity feed-in tariff, their legal treatment is imperative for their economic feasibility [5].

In contrast to HES however, CES systems fail to meet the legal criteria for SC according to § 3 No. 19 EEG, and are thus treated as final consumer while charging and as a generation unit during discharge (according to § 5 No. 33 EEG and § 5 No. 1 EEG respectively), potentially causing a double burden. While article § 61k EEG lifts the double burden of the EEG surcharge for charging, the exemptions from fees remains partly vague [6], [7]. While no grid fees occur for charging the storage, the Bundesnetzagentur argues that an exemption from the grid fees by § 118 EnWG does not include the exemption from grid related levies [8].

Moreover, while § 9 StromStG provides an exemption from the electricity tax for the case of spatial proximity of storage and generator systems, the definition is unclear, and its applicability remains uncertain [6].

The legal framework can thus be read differently for an economic assessment. In the unfavorable reading, grid related levies and electricity tax also incur for charging the CES, while in a favorable reading they only apply for consumption from the system. In order to not put the community solution worse off than the household solution, the BVES (German Energy Storage Association) requests to exempt CES systems for self consumption from both the EEG surcharge and electricity tax altogether. The BVES claims CES systems are eligible for reduced grid fees when they are operated in a way that relieves the distribution net in question. Hereinafter, this is designated as requested case.

In terms of DR, energy utilities are required to offer electricity tariffs to end consumers that give them an incentive for energy savings (§ 40 EnWG), in particular load-variable or time-variable tariffs, if this is technically feasible and economically acceptable. However, the general obligation for energy utilities to charge customers according to the standard load profile impedes the wide-scale introduction of variable electricity tariffs [9]. Thereby, also no exemptions of fees and levies are possible since the end-consumers in the course of DR cover the load by grid-consumption. Thus, the same price components as in GC are prescribed.

Figure 1 shows the fees and levies CES systems incur in favorable and unfavorable interpretation of the legal framework, as well as the case requested by the BVES, in contrast to GC or DR.

C. Economic Foundation

A CES provides a number of economic advantages over a HES, due to decreasing cost per kWh for increasing battery capacity and lower maintenance costs [1]. Currently, HES systems cost roughly 1500-2500€ per usable kWh, whereas costs of CES are estimated to be around $800\,€/\mathrm{kWh}$ to $1000\,€/\mathrm{kWh}$ [10].

Revenue potential for a CES includes energy arbitrage (approx. $17.7\,€/\mathrm{kW}$ p.a. [11]), optimization of self consumption and reserve market offerings (approx. $156\,€/\mathrm{kW}$ p.a. for primary, $170\,€/\mathrm{kW}$ p.a. for secondary, and $57\,€/\mathrm{kW}$ p.a. for tertiary control reserve [2]). [1] concludes that the highest revenues can be achieved through a combination of spot market and reserve market participation, with the bigger share stemming from the latter.

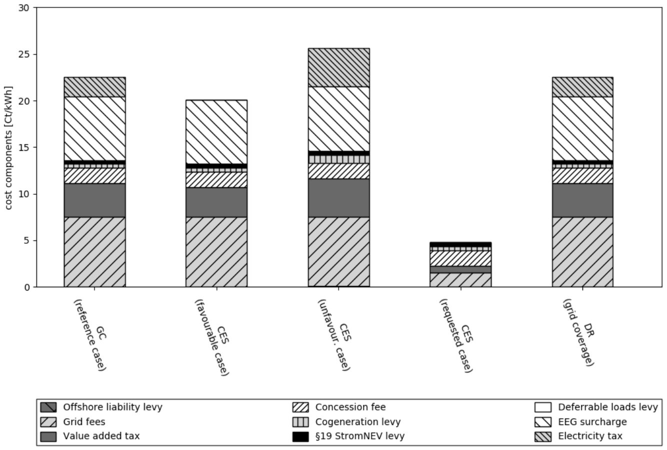


Figure 1. Cost components (ct/kWh) of electricity from CES under different interpretations of the legal framework, with grid-related levies & fees and electricity tax (unfavorable), without grid-related levies & fees and electricity tax (favorable),

Taking the investment costs, the legal framework and the revenue potential together, it is apparent that a CES is clearly not competitive if the current legislation is interpreted unfavorably. In the favorable interpretation levies, fees and taxes are the same as for GC. This would leave a margin of roughly the amount of the generation cost. However, the feed in tariff as well as the investment costs needs to be taken into account as well. Consequently, the prosumer would be already better off feeding the excess electricity into the grid for the remuneration. Thus, only the requested legal interpretation requires a precise assessment.

Besides, DR has the potential of providing flexibility at lower costs. Even though, its impact is limited by the amount and type of loads which can be deferred, the economic feasibility of CES could be affected [3].

D. Optimal utilization

Due to the variability of individual households' load profiles, the capacity of a CES can be dimensioned smaller than the aggregated capacity of HES systems whilst keeping the self consumption rate constant [12]. This is because a diverse prosumer structure leads to an increased harmonization of electricity supply and demand, translating into lower common storage needs.

Additionally, CES for multiple uses on the distribution grid level increases the utilization ratio [2]. While the utilization ratio is $62\,\%$ for the multi-tasking system, it is only $1.64\,\%$ (reducing load) and $26\,\%$ (storing surplus PV) for the single-tasking applications.

III. OPTIMIZATION SYSTEMATIC

A. Integrated modeling

The optimal matching of the energy flows between energy sources and energy demand is determined using the model IRPopt [13], [14]. This bottom-up techno-economic numerical optimization model, implemented in GAMS/ CPLEX, allows for solving mixed-integer problems in a quarter-hourly resolution for perennial periods. The implemented modular model structure enables the configuration of actors, components, connections and transactions under uncertain market developments and undetermined policy interventions if deemed important to the problem at hand. The major objective is to maximize the total profit of individual actors.

In the framework of this paper, the model works with an actor related two-step optimization systematic. The model firstly optimizes from an aggregated customer perspective, determining the residual energy demand and excess energy supply with all components the customers have regulative access to. With respect to the first optimization step (prosumer optimization), the tariff scheme as well as the variable costs of decentral energy systems are decisive. In the subsequent step, the model optimizes all other energy and financial flows from the utilities' perspective, considering all residual energy demand and supply. A regional energy deficit might be balanced by storage systems, by generation plants activities and by spot market trading. Additionally, operating reserve can be pooled and offered. With respect to the second optimization step (organization optimization), the market prices as well as the variable costs of the central and decentral energy systems are decisive. Thus, the applied operation strategy in this research can be summarized as follows:

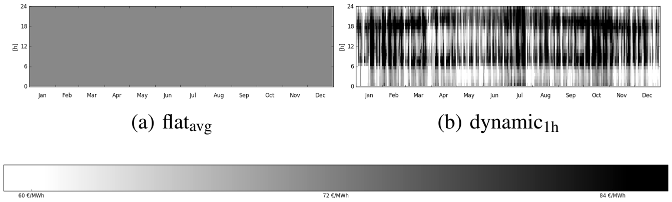
- DR is applied to optimize the electricity consumption with regard to the tariff scheme and the decentralized generation,
- self consumption is maximized by electrical load coverage with respect to CES participants and their tariff scheme,
- charging and discharging behavior of CES participants is considered by the CES-system operator,
- storage utilization is maximized by spot market trading and balancing system service offerings with respect to CES-system operator, as well as
- residual energy demanded is provided by minimizing the provisioning costs of the operator

B. Case studies

To explore competition effects, this research deploys a scenario based analysis at community level, considering different market actors, system processes and system relations. Historical data of 2015 as spot, reserve and fuel market prices set some of the boundary conditions for the assessment. Additionally, an interest rate of 4 % and a value added tax of 19 % is applied.

The community consists of six individual residential customers. The prosumers demonstrate slightly differing electrical load profiles (EL) based on the highly-resolved profile set of [15]. The average energy consumption per year of the households varies between 2900 kWh_{el} and 4500 kWh_{el}. The heating load profiles (HL) are derived on the basis of the Hellwig methodology [16]. The assumed average demand per year between the households varies from 15300 kWh_{th} to 18300 kWh_{th}. Since DR is associated with a level of discomfort, it is assumed that a maximum of 40 % of residential load can be shifted for 4 h (DR_{max}). A realistic average share of shiftable load (DR_{avg}) is given by 20 % for 2 h [17]. No DR possibility is expressed by $DR_{n.a.}$.

In terms of GC a flat and a dynamic tariff are applied as shown in Figure 2. For every time step, with the flat tariff customers pay 28.81 Ct/kWh_{el} to the sales side, grid side and political side, with proportions depending on fees and levies (as illustrated in Figure 1). After deducing statutory fees and levies, the competitive pricing elements remain. Given a mean spot market price of 3.16 Ct/kWh_{el} in 2015, another 3.96 Ct/kWh_{el} of the sales cost component are added as the utility margin. In contrast, the variable electricity tariff has next to the same utility margin a variable hourly price component according to the spot market price. Additionally, the feed-in remuneration for photovoltaic energy is given with 12,4 ct/kWh_{el}.



(a) $flat_{avg}$ (b) $dynamic_{1h}$

Figure 2. Applied electricity $tariffs_{el}$ of the year 2015 (competitive pricing elements only)

Table I
TECHNOLOGY SPECIFICATIONS FOR CASE STUDY ASSESSMENT

	PV	HP	ES	NGB	CHP
Cap.	0-30 m^2		0-10 kWh_{el}		
Power		9 kW_{th}	0-10 kW_{el}	9 kW_{th}	4,5 kW_{el}
Effic.	18 $\%_{el}$		90 $\%_{el}$	95 $\%_{th}$	48 $\%_{el}$
Coeffic.		3,9			0,5

Table II
CASE STUDY PLANNING FOR FLEXIBILITY ASSESSMENT

	$\#1_{flat}$	$\#1_{dynamic}$	$\#2_{flat}$	$\#3_{flat}$
Prosumer	PV, EG, FG, NGB	PV, EG, FG, NGB	PV, EG, HP	PV, EG, HG
Operator	CES	CES	CES	CES, CHP
Sensitivities	PV size (0-30 m^2) and CES capacity (0-10 kWh_{el}), DR possibility ($DR_{n.a.}$,$DR_{avg.}$,$DR_{max.}$)			

The prosumers are equipped with different technologies and are connected to a CES facility via the public grid. Various assumptions about required technologies for the photovoltaic system (PV), the heat pump system (HP), the electrical storage system (ES), the natural gas boiler system (NGB) and the combined heat and power system (CHP) are outlined in Table I. The given data is broken down to one single customer. Additionally, while the local electrical grid (EG) and the fossil grid (FG) posses an efficiency of 100 %, the local heating grid (HG) has an efficiency of 95 %.

Taking into account flexibility options under consideration as well as the technical processes, different community structures

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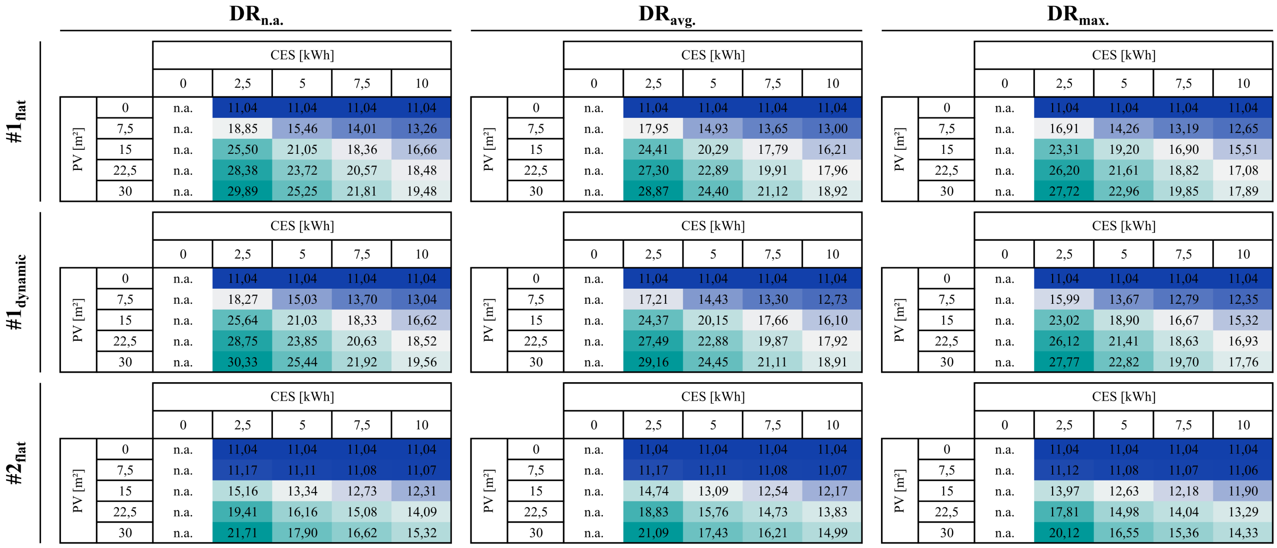

$\#1_{\text{flat}}$

PV [m²]	$DR_{n.a.}$ CES [kWh] 0	2,5	5	7,5	10	$DR_{avg.}$ CES [kWh] 0	2,5	5	7,5	10	$DR_{max.}$ CES [kWh] 0	2,5	5	7,5	10
0	n.a.	11,04	11,04	11,04	11,04	n.a.	11,04	11,04	11,04	11,04	n.a.	11,04	11,04	11,04	11,04
7,5	n.a.	18,85	15,46	14,01	13,26	n.a.	17,95	14,93	13,65	13,00	n.a.	16,91	14,26	13,19	12,65
15	n.a.	25,50	21,05	18,36	16,66	n.a.	24,41	20,29	17,79	16,21	n.a.	23,31	19,20	16,90	15,51
22,5	n.a.	28,38	23,72	20,57	18,48	n.a.	27,30	22,89	19,91	17,96	n.a.	26,20	21,61	18,82	17,08
30	n.a.	29,89	25,25	21,81	19,48	n.a.	28,87	24,40	21,12	18,92	n.a.	27,72	22,96	19,85	17,89

$\#1_{\text{dynamic}}$

PV [m²]	$DR_{n.a.}$ CES [kWh] 0	2,5	5	7,5	10	$DR_{avg.}$ CES [kWh] 0	2,5	5	7,5	10	$DR_{max.}$ CES [kWh] 0	2,5	5	7,5	10
0	n.a.	11,04	11,04	11,04	11,04	n.a.	11,04	11,04	11,04	11,04	n.a.	11,04	11,04	11,04	11,04
7,5	n.a.	18,27	15,03	13,70	13,04	n.a.	17,21	14,43	13,30	12,73	n.a.	15,99	13,67	12,79	12,35
15	n.a.	25,64	21,03	18,33	16,62	n.a.	24,37	20,15	17,66	16,10	n.a.	23,02	18,90	16,67	15,32
22,5	n.a.	28,75	23,85	20,63	18,52	n.a.	27,49	22,88	19,87	17,92	n.a.	26,12	21,41	18,63	16,93
30	n.a.	30,33	25,44	21,92	19,56	n.a.	29,16	24,45	21,11	18,91	n.a.	27,77	22,82	19,70	17,76

$\#2_{\text{flat}}$

PV [m²]	$DR_{n.a.}$ CES [kWh] 0	2,5	5	7,5	10	$DR_{avg.}$ CES [kWh] 0	2,5	5	7,5	10	$DR_{max.}$ CES [kWh] 0	2,5	5	7,5	10
0	n.a.	11,04	11,04	11,04	11,04	n.a.	11,04	11,04	11,04	11,04	n.a.	11,04	11,04	11,04	11,04
7,5	n.a.	11,17	11,11	11,08	11,07	n.a.	11,17	11,11	11,08	11,07	n.a.	11,12	11,08	11,07	11,06
15	n.a.	15,16	13,34	12,73	12,31	n.a.	14,74	13,09	12,54	12,17	n.a.	13,97	12,63	12,18	11,90
22,5	n.a.	19,41	16,16	15,08	14,09	n.a.	18,83	15,76	14,73	13,83	n.a.	17,81	14,98	14,04	13,29
30	n.a.	21,71	17,90	16,62	15,32	n.a.	21,09	17,43	16,21	14,99	n.a.	20,12	16,55	15,36	14,33

Figure 3. Average sum of customer and operator flexibility potential per annum [€/(kWh) p.a.] resulting of the application of CES without and with DR on the basis of the requested legal framework. Each of the cases $\#1_{\text{flat}}$, $\#1_{\text{dynamic}}$ and $\#2_{\text{flat}}$ has been optimized by different PV sizes and CES capacities. Additionally to the case of no $DR_{\text{n.a}}$, load shifting has been possible by taking into account $DR_{\text{avg.}}$ and DR_{max}

are conceivable. All six residential prosumers are arranged in the same way. An overview of applied scenario cases is outlined in Table II. In case $\#1_{\text{flat}_{\text{avg}}}$ using flat tariffs and $\#1_{\text{dynamic}_{1\text{h}}}$ using variable tariffs, the prosumers are connected to the EG to cover their EL. The HL is satisfied by a NGB. Thus, a FG connection is necessary. In the other cases the sectors are coupled. For case $\#2_{\text{flat}_{\text{avg}}}$, the NGB is replaced by a HP and case $\#3_{\text{flat}_{\text{avg}}}$ implements a CHP on the operators side. The heating load of the prosumers is covered by a HG. In all cases CES capacity is provided by the operator. Various sensitivities are applied with respect to the PV and the CES capacity and the ability to perform DR. While the operator is only able to trade on the spot market in the regular cases #1-3, case $\#1_{\text{flat}_{\text{avg}}}$ is additionally optimized by taking both spot market trading and reserve market offerings into account.

IV. RESULTS EVALUATION

The optimization results of the flexibility potential are displayed in Figure 3 for $\#1_{\text{flat}}$, $\#1_{\text{dynamic}}$ and $\#2_{\text{flat}}$. Results of $\#3_{\text{flat}}$ are almost identical to $\#1_{\text{flat}}$. The optimized values are broken down to the mean value across the prosumers. Competition effects of DR and CES have been investigated under the circumstances of the requested legal framework. A CES would not be utilized in terms of the favorable or unfavorable legal specifications as stated in Section II-C.

The flexibility potential consists of additional expenditures and revenues of a prosumer and the operator without considering investment costs of the CES. The results rather show the available financial resources regarding an investment. Cost savings on the prosumer side accrue from the utilization of the CES instead of purchases from GC. Budgetary surplus on the operator side can be achieved by spot market trading of the available CES capacity. The highest flexibility potential is always evident in terms of the greatest PV area as well as the largest CES capacity. While the flexibility potential varies significantly between the cases, the application of DR has a similar negative effect in all cases. By considering the annual investment costs of the CES of approximately 74 €/kWh$_{\text{el}}$ p.a., it can be stated, that none of the displayed flexibility potentials is able to cover the corresponding costs. The maximum cases are able to cover costs to more than 50 % for $\#1_{\text{flat}}$, $\#1_{\text{dynamic}}$ and for $\#3_{\text{flat}}$ and 39 % for $\#2_{\text{flat}}$. The best results can be achieved by the smallest CES capacity and the greatest PV size. In contrast, by taking both spot market trading and reserve market offerings into account the CES costs can be covered as calculated for $\#1_{\text{flat}}$. Additionally, the flexibility potential of the CES decreases with simultaneous application of DR in $\#1_{\text{flat}}$, $\#1_{\text{dynamic}}$ and $\#3_{\text{flat}}$ by around 1-2 % in $DR_{\text{avg.}}$ as well as by around 3-4 % in $DR_{\text{max.}}$. In contrast, reductions are smaller in $\#2_{\text{flat}}$ since the CES offers a lower flexibility potential even in the best cases.

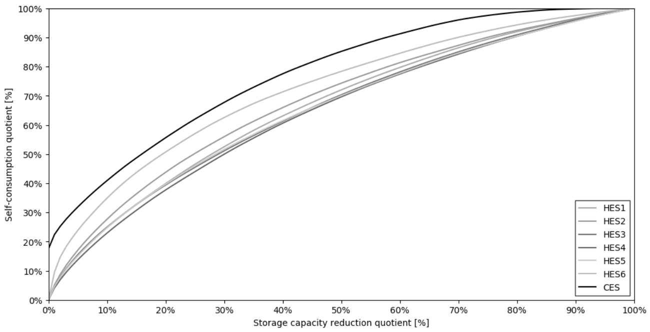

Figure 4. CES reduction potential for case $\#1_{\text{flat}}$ with $DR_{\text{n.a.}}$, a CES capacity of 2,5 kWh$_{\text{el}}$ and a PV size of 7,5 m^2 for each of the six residential prosumers

Due to varying load profiles, the optimal capacity of a CES can be smaller than the aggregated capacities of all individual

HES as outlined in Section II-D. This reduction might translate into lower CES investment costs. Figure 4 for $\#1_{\text{flat}}$ depicts a characteristic curve of the self consumption quotient linked to the storage capacity reduction quotient. The self consumption quotient represents the ratio of the self consumable energy in terms of the reduced storage capacity and the self consumable energy in terms of the initial storage capacity. The storage reduction quotient states the percentage share of the storage capacity of the initial storage capacity.

As illustrated, if the CES remains the initial capacity (100% of the capacity reduction quotient) the self consumable energy stays the same (100% of the self consumption quotient) both for the HES as well as for the CES system. The other way round, if the storage capacity is reduced to zero (0% for the capacity reduction quotient) the self consumable energy of the HES systems decreases to zero. For the CES, however, the self consumable energy only drops to 18%. This is because the stored energy of some prosumers can partly be used directly by other prosumers and thus is direct-marketed. Moreover, the relative state of charge of the CES varies with a lower frequency and a smaller amplitude compared to the state of charge of the HES systems since they do not vary synchronously. Due to these two aspects the self consumption as a percentage falls considerably more sharply in terms of a capacity reduction of a HES compared to a CES. Thus, in contrast to HES systems a moderate CES facility reduction has a far smaller effect on the customer benefit regarding self consumption. In concrete terms, in case $\#1_{\text{flat}}$ without $\text{DR}_{\text{n.a.}}$ an average reduction of 9,2 % of the storage capacity is possible without cutting any self consumption. DR_{max} even allows a reduction of 11,8 %. Case $\#2_{\text{flat}}$ allows a reduction of 18,8 % without $\text{DR}_{\text{n.a.}}$ and 24,4 % in terms of DR_{max}. This is also in line with the determined flexibility potential of the CES as described above. In contrast, $\#1_{\text{dynamic}}$ leads only to a reduction possibility of 3,75 % for $\text{DR}_{\text{n.a.}}$ and 4,9 % for DR_{max}. All in all, it can be stated that DR worsened the storage utilization and thus the flexibility potential. However, since CES allow a proper and flexible sizing various investment costs can also be saved.

V. CONCLUDING DISCUSSION

This research presents competition effects for simultaneous application of CES and DR at community level. It showed that DR slightly reduces the flexibility potential of CES and thus its profitability. The reason can be found in the lower utilization rate of the CES. This might lead to a different reduction potential and thus lower investment costs which again leads back to the profitability. Thus, if a CES system operator wants to implement an energy tariff regarding the discharging of the system, it is necessary to identify the optimal economic solution between the revenue regarding customer related discharging and the savings regarding the system related investment costs. Additionally, future optimization runs with respect to asymmetrical cases of the prosumer technologies should be taken into account in order to determine optimal flexibility and sizing potential.

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