Business Models and Grid Impact of Energy Storages and Controllable Loads for PV-Self-Consumption at Prosumer Level

Basem Idlbi
idlbi@hs-ulm.de
Technische Hochschule Ulm
Ulm University of Applied Sciences
Ulm, Germany

David Stakic
stakic@hs-ulm.de
Technische Hochschule Ulm
Ulm University of Applied Sciences
Ulm, Germany

Matthias Casel
casel@hs-ulm.de
Technische Hochschule Ulm
Ulm University of Applied Sciences
Ulm, Germany

Dietmar Graeber
d.graeber@hs-ulm.de
Technische Hochschule Ulm
Ulm University of Applied Sciences
Ulm, Germany

Gerd Heilscher
heilscher@hs-ulm.de
Technische Hochschule Ulm
Ulm University of Applied Sciences
Ulm, Germany

Martin Fiedler
martin.fiedler@swu.de
SWU Stadtwerke Ulm/Neu-Ulm GmbH
Ulm, Germany

***Abstract*— Many countries are experiencing rapidly increasing distributed generation (DG) of renewable energy sources (RES). Electricity self-consumption is currently replacing feed-in-tariffs (FIT) as one main driver of this development. A prosumer, who is a consumer and producer of energy through his own DG, like photovoltaic (PV), can save costs through the self-consumption of his PV energy. The attractiveness of this business case is mainly based on the decreasing levelized cost of energy (LCOE) of PV systems as well as the difference between the decreasing FIT and the increasing costs of electricity consumption from the public grid. Utilizing local energy storages like batteries or power-to-heat (PtH) can increase both self-consumption and earnings. Noticing this tendency, electricity suppliers and industrial manufacturers offer new business models, in which small local storages of prosumers can be substituted with district storages or even virtual storages.**

This contribution presents an economic comparison and grid impact analysis of different self-consumption business models (i.e. home storages, PtH, district storages, virtual storages), considering the perspectives of prosumers as well as electricity suppliers. For realistic results, assumptions have been made based on the data of a real grid area near the city of Ulm.

The results show that home storages, district storages as well as PtH systems are currently significantly less profitable for prosumers compared to pure PV-systems, if only self-consumption is targeted as a business case. District storages are not attractive as a business model as well, whereas cloud storages can yield a quite good return at least for the electricity suppliers. However, an analysis of a future scenario indicates a better economic potential for storage business models. The grid impact analysis demonstrates a possible reduction of load and voltage through storages. Yet, for an efficient use of storage systems in regard to the electricity grid, financial incentives are necessary to support a grid-friendly operation of storages.

Keywords—Home Battery Storage, District Battery Storage, Power-to-Heat, Self-Consumption, Business Models, Grid Impact

I. INTRODUCTION

To compensate the shutdown of conventional plants, which is necessary to achieve the upcoming aim of the German government of reducing greenhouse gases [1], PV systems as well as other DG should be further installed. The German government has offered FIT for PV systems to support their installation. To finance the FIT, levy were added to the electricity consumption tariff. Currently, the FIT is reduced year by year by the government to limit the cost burden on levy payers. Consequently, the business case of PV-self-consumption in combination with energy storage or controllable loads like PtH has been attractive for prosumers in Germany, as well as in other countries, especially when taking into consideration the decreasing FIT as well as the financing programs and subsidies offered by the government e.g. [2]. Accordingly, more than 50,000 PV-storage systems were installed in Germany until the end of 2016 [3]. Considering the investment cost reduction of such systems, this number has been doubled until the end of the summer of 2018 [4]. Similarly, electrical heating systems have been installed increasingly during the past years [5], [6]. Noticing the high installation numbers of home battery storages, electricity suppliers and industrial manufacturers offer new business models, in which small home storages of prosumers can be substituted with central district storages or even virtual storages.

On the other hand, an aim of grid operators is to control the consumption and feed-in of prosumers based on the surrounding grid conditions, like voltage and loading of grid components, in order to increase grid resilience (e.g. [7], [8]). Through self-consumption, energy can be supplied quite close to the consumption. In other words, self-consumption has the potential to stabilize the system and reduce also transmission costs because of the close balancing of load and generation [9].

Post FIT scenarios deliver a number of arguments that are relevant for self-consumption. This paper will focus on self-consumption of PV systems under current regulations and also for post FIT conditions. Therefore, home battery storages (HBS) as well as other alternatives for maximizing self-consumption will be analysed based on their economic effectiveness and impact on the grid. This paper is structured in four sections. Section I presents a background to the topic based on the regulatory framework and a literature review. Section II describes the approaches followed to perform the analysis of this contribution. Section III shows the results of the performed simulations, whereas sections IV and V focusses on the conclusions and the outlook.

A. *Regulatory Framework in Germany*

Self-consumption is a major focus point of the German "Energiewende" (transformation of the energy system). Especially in the industry and various business sectors, self-consumption has been a common method to stabilize energy costs and increase independency for many years. The private sector increases self-consumption on the basis of the privilege for self-consumption defined in the German Renewable Energy Law (EEG) 2014 [10].

Self-consumption in Germany works under specific regulatory conditions. PV systems with a nominal power lower than 10 kWp are nearly free of taxes and free of fees, levies and grid charges. This makes the use of the electricity of PV systems in self-consumption interesting under economic aspects. Autarky and independency is also an important reason to conduct self-consumption for the private sector [11]. However, these aspects are hard to quantify economically and will therefore be neglected in this paper.

B. *Home Storages as Flexibility for Renewable Energy*

In an ongoing transformation process of the energy system, flexibility is getting more and more important. Flexibility is one of the most important answers to tackle volatility. The increasing number of decentral volatile electrical generation systems makes it necessary to activate an increasing number of flexible load systems. The most popular technologies in Germany today are PtH and HBS. However, the prosumer is part of the public grid and also is in need of it for a reliable electrical supply at any time. The potential flexibility of PtH and HBS have to gain a higher value for the surrounding electrical grid and allow, also under economic conditions, a more social operation of the prosumer flexibility. There are e.g. minimal incentives for prosumers to do peak load shaving in the current regulation of the German government. The factor "energy per year" is still the most important one in the private sector [10].

C. *State of the Art*

Due to their importance for the future energy system, PV systems combined with HBS are investigated in numerous studies, which are published in various papers. Good profitability of such systems is essential, since it presents the main motivation for their installations. Several papers showed that the HBS systems do not show such a high profitability due to their high investment costs. Since the prices are expected to decrease continuously in the future, several authors expected that such systems will be profitable in the near future, e.g. [12], [13]. District battery storages are also discussed in several papers showing their technical advantages and possible use cases, but they also showed that DBS systems are not profitable [14], [15]. In order to improve the utilization and feasibility of storages, several authors discussed different use cases other than self-consumption, e.g. [16], [8] and [17]. Considering the low profitability of physical storages, new business models are developed in the market including cloud storages, e.g. [18]. In the German market, several business models based on cloud storages are already being offered, e.g. [19]. PtH systems have been under the focus of several papers. For example, [7] demonstrated a good technical and economic potential for grid support through PtH systems. Considering the variability of available models in the market and the numerous factors affecting their profitability, there is still a need for an economic comparison of these models. Grid impact should be also analysed, since it is important for grid operation. This contribution will analyse the effect of the investigated battery storage models on the distribution grid based on a grid simulation of a real test area, which is a village near Ulm.

II. METHODOLOGY

This section describes the investigated business models, analysis approaches and assumptions followed to perform the study of this contribution.

A. *Business Models:*

This contribution presents an analysis of several business models at prosumer level which aims at increasing the self-consumption of their PV systems. The following business models have been designed based on the German electricity market.

1) *PV system:* This is the reference model, which other storage models will be compared with in this contribution. The business case here depends on the avoided costs of electrical energy through self-consumption as well as the income through FIT when feeding the excessive energy in the grid. For the economic analysis, several sizes of PV systems will be considered. Based on an analysis of 2800 PV systems in the grid area of Ulm, the average size of PV systems at normal customer level is found to be 5.78 kWp, hence 6 kWp will be assumed as the main size under focus in the analysis.

2) *Home battery storage (HBS) combined with a PV system:*

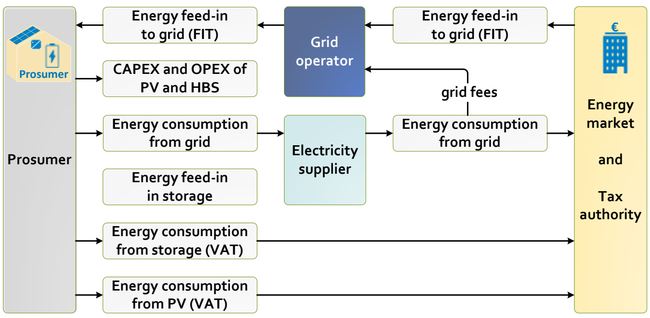

Fig. 1. Cost flows of a HBS combined with a PV system

This represents a small storage as flexible load and generation aiming at increasing the prosumer self-consumption. Usually HBS are installed in the property of prosumers who are also responsible for its operation.

Therefore, the prosumers undertake the capital and operation expenditures (CAPEX and OPEX). OPEX includes the maintenance costs and battery losses. The cost flows of this business model is illustrated in Fig. 1.

3) Power-to-heat (PtH) combined with a PV system and possibly with HBS: The mechanism of PtH consists of an electrical water heating system for space heating and domestic hot water. This represents a controllable load, which offers significant flexibility for self-consumption.

4) District battery storage (DBS): This represents a large battery system, which can be installed and operated by an electricity supplier or other industrial parties. This storage is operated as an energy bank where prosumers can rent some capacity in order to store their excessive energy and consume it later. The DBS can be installed in the public low voltage (LV) grid close to a local area transformer. In this business model, the service provider undertakes the CAPEX and OPEX of the DBS and receives a monthly rent for a contractual battery capacity.

5) DBS in a private areal grid (DBS-PAG): This is similar to a DBS model, however, the service provider does not pay for grid fees and taxes that apply for a public grid. It is assumed that costs for the prosumer in this model are similar to the costs of DBS, as it is offered by the same service provider, and in order to be able to compare the two models when they have a similar income.

6) Virtual district battery storage (DBS-cloud): which does not include any physical storage but rather a virtual one that leads to similar cost flows between the involved parties. Therefore, the energy flows in this model are similar to the case of no storage, while the energy stored virtually in the storage is sold in the energy market. This is a product offered by several energy supplier and other industrial manufacturers in Germany (e.g. [19]), since it can yield some earnings for the service provider. While the prosumers do not have to buy a storage system and reserve a suitable room for it. It is assumed that costs for the prosumer in this model as well are similar to the costs of DBS, as it is offered by the same service provider.

B. *Modelling and Assumptions of Economic Analysis*

In a first step, the business models described in the previous subsection are compared economically. The economical comparison is mainly based on the investment costs, avoided costs through self-consumption and the income from FIT. For the calculation of the yearly amounts of the consumed energy from grid, energy consumed from the PV system, energy consumed from the analysed model (e.g. HBS), fed-in energy in the grid and energy fed in the storage, a tool to analyse yearly profiles with the resolution of 15 minutes is developed. The database for this analysis is prepared in cooperation with the local municipal operator (SWU) in order to obtain a database close to reality. In the calculation, different assumptions and limitations for the considered models in this contribution are supposed. The believed economic assumptions for the calculation and approaches for modelling are summarized hereinafter.

- *Economical comparison method:*

For the investigation of the feasibility of the involved alternative models, the net present value (NPV) comparison method is chosen in this contribution. The NPV of each model is calculated as described hereinafter.

$$NPV = \sum_i^N (INC_i - C_i).PWF_i \quad (1)$$

Where i is the number of year

N is the lifetime of the project, which is assumed to be 20 years in this contribution.

PWF_i is the present worth factor of the year, which can be calculated as follows.

$$PWF_i = (1 + WACC)^{-i} \quad (2)$$

$WACC$ (weighted average cost of capital) are the assumed capital cost of the private investors in DG (i.e. PV)

INC_i is the yearly incomes, including the avoided costs of heat and electrical energy through self-consumption and the gain through FIT.

$$INC_i = EC_{no\ PV} - EC_{PV+model} + INC_{FIT} \quad (3)$$

$EC_{no\ PV}$ is the yearly cost of heat and electrical energy for the case of neither PV nor self-consumption model is installed.

$EC_{PV+model}$ is the yearly energy cost for the case of a PV and possibly a self-consumption model is installed.

INC_{FIT} is the income through FIT

$$EC_{PV+model} = C_H + C_E + C_{los} + C_{SC} \quad (4)$$

C_H is the yearly cost of heat

C_E is the yearly cost of electrical energy

C_{los} is the cost of energy losses in a HBS (i.e. only for HBS models)

C_{SC} is the cost of energy self-consumption from the PV or the self-consumption model (e.g. HBS)

C_i is the yearly costs including CAPEX and OPEX of the systems (i.e. PV and the self-consumption business model), depreciation cost (linear), yearly credit repayment, interest of the credit, etc.

$$C_i = CAPEX + OPEX + C_{dep} + C_{cr} + C_{int} \quad (5)$$

C_{dep} is the yearly depreciation costs (assumed to be linear).

C_{cr} is the yearly sum of credit repayment

C_{int} is the yearly interest for the rest of credit

The general economic assumptions, which are necessary to calculate the NPV, are listed in TABLE I.

TABLE I. GENERAL ECONOMIC ASSUMPTIONS IN THIS CONTRIBUTION

Credit interest rate [%]	WACC [%]	Credit for CAPEX [%]	Credit repayment per year [%]
3	4.5	50	10

- *PV:* In this contribution, the PV systems are economically represented by the values in TABLE II. The feed-in tariff is regulated by the German law (i.e. EEG [10]). The value in this table is for PV systems with a nominal module power lower than 10 kWp and applies for February 2019. The FIT is decreasing in monthly intervals, but it will be fixed for the tariff at the date of installation [10]. The economic value of the energy from PV is published by the German transmission grid operators and describes the value at the energy market where electrical energy is common traded.

TABLE II. ECONOMIC ASSUMPTIONS REGARDING PV SYSTEMS

CAPEX [€/kWp]	OPEX [%]	Economic Life Time [years]	Feed-in Tariff [€/kWh]
1456 [20]	0.5	20	0.1135 [21]

- *HBS:* Based on an analysis of all battery systems in the area of Ulm including 133 battery systems, an average mean nominal power of 4.68 kW and a mean capacity of 7.45 kWh are calculated. However, the analysed systems are not only valid for domestic prosumers but also include large battery systems of some businesses for the private sector. The HBS model starts charging if PV surplus power is available after balancing PV generation (-) and household load (+). A schematic illustration of the HBS model is depicted in Fig. 2. It is assumed for the economic analysis that the nominal power of the HBS is high enough, so that the charging power of the battery is only limited by the availability of PV feed-in.

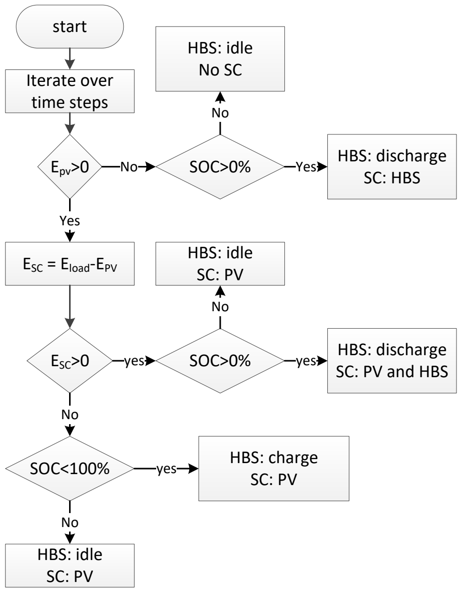

Fig. 2. Logic of the HBS model. SC means self-consumption, e.g. SC: PV means self energy consumption from the PV system. E_{PV} the feed-in of the PV, E_{load} is the energy consumption of the load

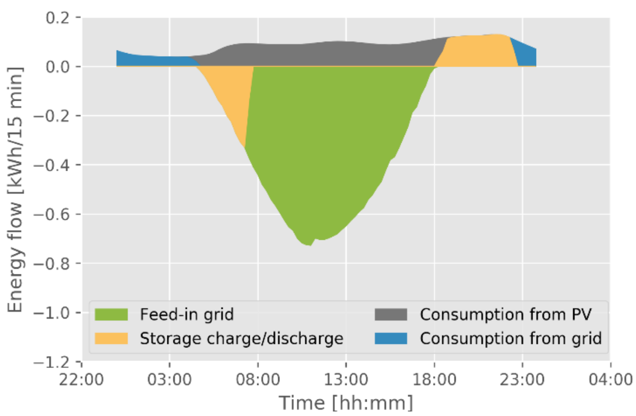

Fig. 3. Exemplary energy distribution on 18.05.2017 at prosumer level with a PV-storage system. PV system has a nominal power of 4 kWp, and the home storage has a capacity of 2 kWh

For a better understanding of this business model, Fig. 3 depicts the energy flows between systems of this business model on an exemplary day.

- *HBS including governmental subsidy:* The HBS started in Germany many years ago in the household sector, because the government launched also several subsidy programs e.g. [2]. The feasibility of the HBS models is investigated in this contribution, considering no subsidy as well as considering a subsidy program.

The cost assumptions that represent a common HBS system are listed in TABLE III. System 1 in the table means the present installation of HBS, whereas System 2 represents the second installation after the first system is depreciated. The lifetime of a battery is dependent mainly on the number of charge cycles, so that the higher number of cycles per year means a lower lifetime. Some exemplary analyses of the developed model of HBS are performed and show that less than 300 cycles per year are expected. This number can increase if the simulations have a higher resolution. In addition, the lifetime batteries can be affected by other factors (e.g. temperature), which are not considered in this contribution. For simplification, a lifetime of 10 years is assumed in this contribution for HBS and DBS.

TABLE III. ECONOMIC ASSUMPTIONS REGARDING HBS SYSTEMS

CAPEX [€/kWh]	OPEX [%]	Lifetime [years]	Battery losses [%]	Exemplary Subsidy program [2]
System1: 1000 System2 (in 10 years): 600 [22]	1	10	10	- 200 €/kWh - min 400€ - subsidized kWh min. relation 1.2kWp:1kWh - systems between 10 & 14kWp 400€ extra -max. feed-in 50% of kWp

- *DBS:* The CAPEX per kWh is significantly lower at DBS compared to HBS. This is an advantage of the DBS for the operator. And for the prosumer, the rent of a specific capacity in the DBS is an important economic factor. This model is relatively easy to be implemented by the prosumers since it does not require CAPEX, and thus reduces the economic risk for the prosumers. A disadvantage of DBS compared to HBS is that the public grid is always involved to deliver the electrical energy to the households and this fact heightens taxes, fees and levies on the business case on top and as a consequence reduces the advantage of the lower invest costs for the service provider. Cost assumptions related to DBS are listed in TABLE IV. The amount of 10 €/kWh/month is assumed for this analysis based on discussion with the SWU. The energy flows between systems in this business model are theoretically similar to the ones presented in Fig. 3. However, since the self-consumed energy flows through the public grid, grid fees and other taxes are due. These taxes are assumed to be paid by the service provider, since they are not supposed to be paid directly by the prosumers in an equivalent HBS system.

- *DBS in a private distribution areal grid (DAG):* If the DBS is installed in a private grid, which belongs to the private sector, taxes and grid fees are not due. Therefore higher profitability is expected for the DBS operator with this model (i.e. service provider). In the economic analysis of this contribution, the service operator must pay 0.0679 €/kWh for the energy withdrawal from the DBS-DAG whereas he must pay 0.2037 €/kWh for the energy withdrawal from the DBS.

TABLE IV. ECONOMIC ASSUMPTIONS REGARDING DBS

CAPEX [€/kWh]	OPEX [%]	Lifetime [years]	Battery losses [%]	Rent for prosumers [€/kWh/month]
System1: 800 System2: 400 [22]	1	10	10	10

- *DBS-cloud:* The owner of this model (i.e. service provider) does not have to buy a DBS system, which means he does not undertake high CAPEX or OPEX. It is assumed that 200 €/prosumer are paid by the service provider to cover the software and personal costs of this model. The energy inserted in the virtual HBS will be sold according to FIT, while the energy withdrawn from the virtual DBS will be actually withdrawn from the grid for the normal electricity tariff. In addition, the service provider offers this service for the rent of 10 €/kWh/month.

- *Electrical load:* The load profile utilized for the economic analysis is based on a standard household profile for the year 2017 (data from the SWU). The standard load profile is then scaled based on the annual consumption of 3207 kWh [23]. The German electrical price for the private sector is strongly influenced by the government. More than 50% of the price consists of taxes, levies and fees. The self-consumption use case gains advantage for the prosumer at these costs. Therefore it is also important to look at these issue in order to evaluate the costs of the different systems and approaches. It should be taken into consideration that self-consumed electrical energy is taxed by the value added tax (VAT). In addition, the prices of CAPEX presented in this contribution do not include VAT. The average price per kWh in the year 2014 was 29,53ct/kWh, which is one of the highest prices in the European Union [24]. To create realistic results, and to compare them as close as possible to the real situation of a prosumer in the city of Ulm, tariffs of the SWU are used. It should be taken into account that each invoice for the consumption of electrical or heat energy has basic fees for the energy supplier. These fees are not considered in this contribution since they apply for all models and thus do not affect the economic comparison. The assumed electrical energy prices are listed in TABLE V.

TABLE V. ECONOMIC ASSUMPTIONS REGARDING ELECTRICAL ENERGY PRICES

Electricity tariff [€/kWh]	Cost of self-consumption (VAT) [%] component of electricity tariff	Grid operator fees [€/kWh]
0.29	19	0.0748

- *PtH:* This is designed based on the technical conditions of a product (EGO - Smart Heater [25]) that is commonly available on the market for solar electrical heating systems. These PtH systems provide a maximum power of 3.5 kW and can be operated between 0 and 3.5 kW in 0.5 kW steps. It has to be considered that the PtH system cannot randomly operate. There are break times between start and stop orders which have to be respected during operation. However, these break times can be neglected, because they are much shorter (i.e. 110 s to 230 s) than the 15 minute resolution assumed for the analysis of this contribution. The model to calculate the actual power of the PtH considers the iterative operation of the system in 0.5 kW. In addition, the calculation of daily heat demand of the prosumer is described in a next step. The PtH starts heating if PV surplus power is available after balancing PV generation (-) and household load (+). A schematic illustration of the PtH model is depicted in Fig. 4.

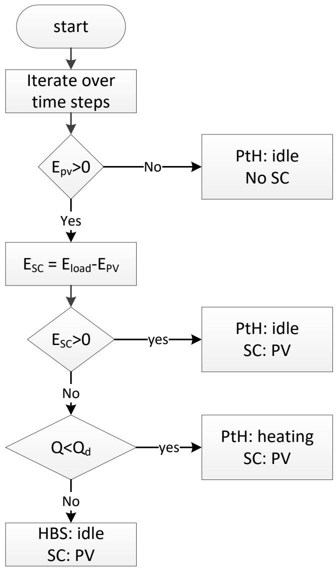

Fig. 4. Logic of the PtH model in a similar illustration like Fig. 2. Q_d is the daily heat demand. Q is the accumulated heat of the day through the PtH

- *The combination between PtH and HBS:* This is also considered as a business model in this contribution. Before the modelling of this combined model, several analyses were conducted in order to define the logic for the battery charge and the heating of the PtH system. The analyses showed a better feasibility when the HBS charges first (fully). Then the electrical energy can be converted to heat. This conclusion is realistic when considering the high costs of electrical energy compared to heat energy. For better understanding of the logic of the aforementioned business models, Fig. 5 depicts the energy flows between systems of this business model for an exemplary day.

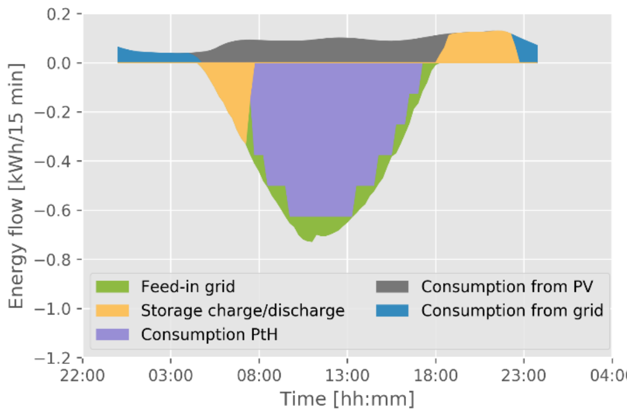

Fig. 5. Exemplary energy distribution on 18.05.2017 at prosumer level with a PV-HBS-PtH system. PV system has a nominal power of 4 kWp, and the home storage has a capacity of 2 kWh. The heat demand on this day is 19.57 kWh, which allows nearly a full cunsuption of the PV power in this exemplary day

The CAPEX of the PtH was calculated based on the installed system at Ulm University of Applied Sciences. The CAPEX includes the costs for investment and a common price for the installation of the system. It is assumed that the analysed prosumer type already owns a thermal storage and a primary heating system, which both are necessary to provide the space heating and the domestic hot water. Therefore, the costs for both of them is not considered in the CAPEX of the PtH business model.

TABLE VI. ECONOMIC ASSUMPTIONS REGARDING PTH SYSTEMS

CAPEX [€] 3.5 kW	OPEX [%]	Lifetime [years]
932	1	20

- *Heat load:* The heat demand depends on the outdoor air temperature. Therefore, a Sigmoid calculation approach for the load profile is utilized. In this contribution, the standard load profile of gas is used to calculate the daily energy values of heat demand [26]. This assumption is suitable because gas is used in the household sector only to provide heat for space heating and domestic hot water. The shape of the Sigmoid function relates to the physical behaviour of the building, characterized by the dependencies of the energy consumption from the outdoor conditions (convection, conduction through the walls and air infiltration). For the air temperature, the test reference year (TRY) from the German weather service is used, and then average values per day are calculated (T_t) [27]. The following equations describe the calculation approach:

Equation for the rated air temperature (ϑ):

$$\vartheta = \frac{T_t + 0.5 \cdot T_{t-1} + 0.25 \cdot T_{t-2} + 0.125 \cdot T_{t-3}}{1 + 0.5 + 0.25 + 0.125} \quad (6)$$

T_{t-1} : Air temperature of the day before
T_{t-2} : Air temperature of two days before
T_{t-3} : Air temperature of three days before

Equation for Sigmoid Function ($h_{(\vartheta)}$):

$$h_{(\vartheta)} \frac{A}{1+(\frac{B}{\vartheta-40})\cdot C} + D \quad (7)$$

Coefficients of a multifamily house (W24) [28].
A = 2.507817
B = -35.0367363
C = 6.2430159
D = 0.1025195

Equation for the day at week factors (W24):

$$h_{Wo} = F(d) \cdot h(\vartheta) \quad (8)$$

$F(d)$ = 1

Equation for the consumer value (KW):

$$KW = \frac{Q_N}{\sum_i^N (\vartheta_{Wo})} \quad (9)$$

Q_N : Annual energy consumption

Equation for daily heat energy consumption ($Q_{(d)}$):

$$Q_{(d)} = KW \cdot \vartheta_{Wo} \quad (10)$$

- *Heat and gas price:* The gas price is not affected so severely by taxes, levies and fees compared to the electrical energy prices, so they sum up at approximately 25%. This unbalance on energy sectors is a difficulty to empower business use cases in the field of hybrid energy approaches. Self-consumption gains no advantage on the heating (gas) sector currently [29]. Gas is one of the most common fuels to generate heat in the private sector in Germany. Therefore, the gas price is used to assume the costs for heat, which includes space heating and domestic hot water. To generate a regional character, the tariffs of the SWU are used. The price consists of two points: a basis and an energy price. This calculation was also used for a common demand of one year at the analysed area (14,356 kWh/a). It results in a price of 0.075€/kWh for the standard tariff of the SWU [30].

- *Metering:* Prosumers must pay for the corresponding metering system, which is necessary to record the energy feed-in as well as consumption. For the DBS model, the maximum limit for this cost as defined by the government is assumed [31]. The assumed metering costs are listed in TABLE VII.

TABLE VII. ECONOMIC ASSUMPTIONS REGARDING METERING

Cost for only PV [€/year]	Cost for HBS [€/year]	Cost for DBS-DAG [€/year]	Cost for cloud storags [€/year]
20	20	100	100

- *Assumptions regarding post FIT scenario:* The economic analysis considers the current situation based on PV and load profiles of the year 2017. In addition, a future scenario, after a possible inactivation of the FIT, considering the CAPEX values and energy prices of the year 2025, is analysed in this contribution. The income through grid feed-in is calculated based on the day-ahead market prices of the year 2017, which were provided by the SWU. The prices have the resolution of one hour. To represent the year 2025, the prices are scaled so that the average price is 0.05 €/kWh, according to [32]. However, it is assumed that the simulated model does not feed-in when the market price has a negative value, but it curtails the feed-in instead. The electricity tariff is assumed to increase at the same level of inflation rate [12]. The CAPEX of the PtH for the year 2025 is based on a reduced price, which is offered by the manufacturer for a high quantity. The costs for PtH installation are assumed not to change in this contribution. For the heat price an increase is assumed based on a similar analysis of the one in [33]. The cost assumptions for the post FIT scenario are listed in TABLE VIII.

TABLE VIII. ECONOMIC ASSUMPTIONS FOR POST FIT SCENARIO

CAPEX PV [€/kWp]	CAPEX HBS [€/kWh]	CAPEX PtH [€] 3.5 kW	Electricity tariff in [€/kWh]	Heat tariff [€/kWh]	Feed-in market price (Average) [€/kWh]
1200 [34]	System1: 600 System2: 300 [34]	788	0.346 [12]	0.0837	0.05 [32]

C. Modelling and Assumptions of Grid Impact Analysis

The business models of this contribution are based on cost flows between the involved parties, which are based on the costs of different energy flows as well as required taxes. An example of the energy flows in a HBS system combined with a PV system is depicted in Fig. 1. Additionally to the economic analysis, the increased self-consumption through storages will be investigated from the perspective of grid impact based on grid simulations. The setups and assumptions for the simulations are summarized hereinafter.

- *Simulation setup:* A quasi-dynamic simulation by means of the software PowerFactory is performed, considering the time resolution of 15 minutes [35].

- *Simulated scenarios:* Based on the availability of data, the simulation is based on the year 2015. Four exemplary days with high irradiation, corresponding to four seasons are simulated in this contribution (i.e. summer: 02.07.2015, winter: 26.02.2015, autumn: 09.09.2015, spring: 18.05.2015).

- *Simulated grid:* For this analysis, a real low voltage (LV) grid data from a test area near Ulm (i.e. Hittistetten) are utilized. The grid is supplied through southern and northern local area LV-transformers [36].

- *Load profiles:* A standard household load profile provided by the SWU is utilized for the simulation of households in the grid. Also, standard business load profiles from the SWU are utilized to simulate the corresponding business loads in the grid. The profile of each load in the grid is scaled based on the billing information of 2015. The simulated grid includes 218 loads representing mainly households and also few businesses.

- *PV systems:* Measured irradiation profiles from the area of Hittistetten are utilized to generate PV feed-in profiles for the simulation. The feed-in profile of each PV is scaled based on the billing information of 2015. The simulated grid includes 46 PV systems.

- *HBS:* For each household or business having one or more PV systems a HBS system is installed (i.e. modelled) to show their impact on the grid. The optimal dimensioning of HBS is out of the scope of this contribution. As a simplification, it is assumed that the HBS capacity in kWh is equal to the kWp of the combined PV systems [31].

- *DBS:* For the simulation with a DBS, large storage is installed in the southern substation and connected to the LV side of the southern local area transformer. The energy flow of this transformer is equivalent to accumulated energy flows of all HBS systems described in the previous point.

- *Simulated models:* Three simulation cases are considered in this contribution to simulate these models;

- Only PV in the grid (i.e. not combined with storages)
- PV combined with HBS systems (i.e. HBS for each household or business having one or more PV systems)
- PV systems combined with one DBS system, which substitutes all HBS systems of the previous model.

From the grid point of view, the DBS and DBS-PAG are similar since they have the same energy flows. In addition, the simulation of only PV systems is similar to the case when the prosumers substitute their HBS systems with a DBS-cloud model, because the cloud does not affect the energy flows in the grid. A grid simulation with PtH systems is not considered and should be performed in future contributions.

III. Results

A. Economic Analysis

- *Feasibility of HBS compared to only PV*

To compare the business models economically, their NPV is calculated according to the aforementioned assumptions and illustrated as can be seen in Fig. 6. The results show that the PV model is more profitable without HBS than is the case when it is combined with HBS. Even when considering the exemplary subsidy program [1], the HBS model is less profitable. The increasing installation of PV-HBS systems in Germany can be justified by the desire of prosumers to have higher self-sufficiency or beyond that by other social reasons.

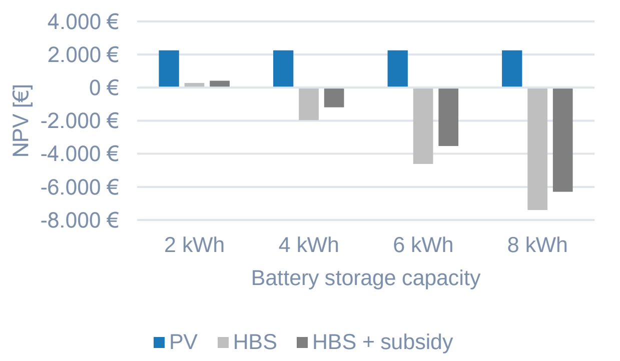

Fig. 6. Net present values for three business models for prosumers, corresponding to four battery sizes, considering the PV size of 6 kWp

- *Comparison of self-consumption business models*

Four business models to increase the prosumer´s self-consumption of PV energy are compared. The NPV of these models are calculated and depicted in Fig. 7. The results show that HBS can be profitable for small systems (e.g. 2 kWh), however, they are not practical for larger systems (i.e. negative NPV). This can be explained by the high CAPEX compared to the income occurring through the increased self-consumption. In addition, HBS systems show a better feasibility than the DBS and HBS+PtH based on the assumed prices. PtH systems do not proof as cost-efficient compared to the other models, which can be anticipated, since the heat energy price is lower than the FIT.

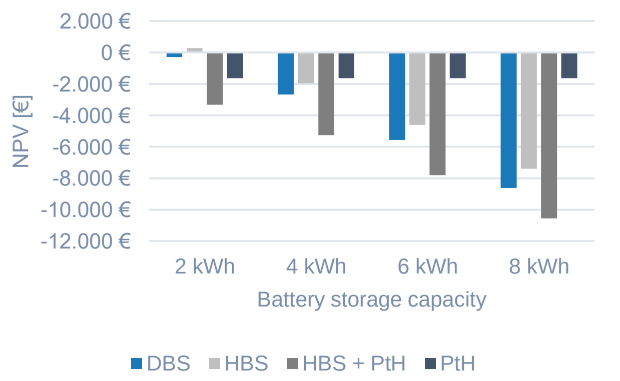

Fig. 7. Net present values for four business models for prosumers, corresponding to four battery sizes, one size of PtH model, considering the PV size of 6 kWp

- *Perspective of service provider: DBS-Models*

To analyse the profitability of DBS by electricity suppliers or other industrial service providers, three DBS models are compared in this contribution. The NPV of these models are calculated and illustrated in Fig. 8. The results show that physical DBS systems are not implementable as products because of their high CAPEX as well as because of the regulatory framework, which leads to several taxes, levies and fees for the DBS energy flows. Also, DBS-PAG systems can yield only slight profit, but their applicability is limited to private grids. On the other hand, cloud DBS are profitable as products, since they have a low CAPEX. Although cloud products are not cost-efficient for prosumers, they are already sold in the German market, which can be justified, as stated before, by the desire of the prosumer to have higher self-sufficiency or because of other services which are offered in combination with these products.

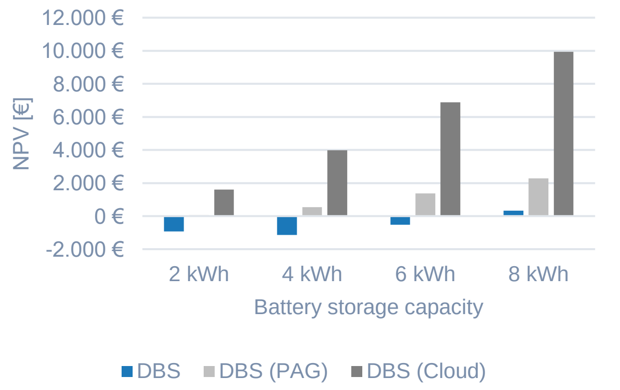

Fig. 8. Net present values for three business models for service provider, corresponding to four battery sizes, considering the PV size of 6 kWp

- *Post FIT scenario: Comparison of self-consumption business models*

Considering the aforementioned post FIT scenario, four business models are compared. The NPV of these models are calculated and illustrated in Fig. 9.

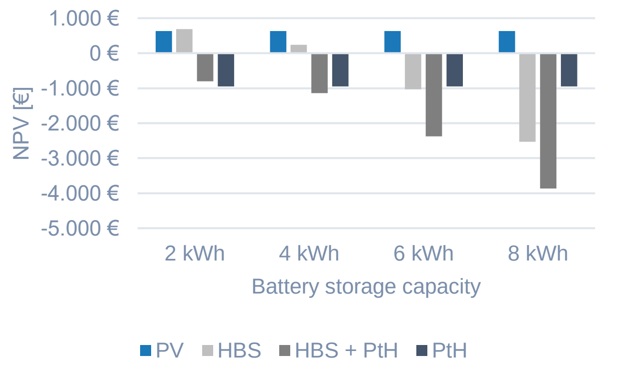

Fig. 9. Net present values for four business models for prosumers, corresponding to four battery sizes, one size of PtH model, considering the PV size of 6 kWp and the post FIT scenario. Assumptions for these results are listed in TABLE VIII.

It can be concluded that the HBS might be more profitable than only PV systems for small sizes of HBS (i.e. 2 kWh). Larger HBS systems are not cost-efficient compared to only PV systems because of their high CAPEX. PtH and HBS+PtH systems are not as profitable compared to the other models, since the assumed heat price is not much higher than the feed-in prices in the energy market. Hence the income via the increased self-consumption cannot compensate the CAPEX of the PtH systems. At this point, it is also indicated that the heat price includes much lower taxes, levies and fees compared to the electrical price for consumers. This fact leads to a low economic efficiency of PtH compared to storages. In addition, the heat demand is high in winter when the PV feed-in in Germany is low, which leads to slight increases of self-consumption.

- *Further results: different PV sizes*

For a comprehensive analysis, the self-consumption business models are compared considering several sizes of PV systems (i.e. from 2 till 10 kWp). However, the findings obtained from this comparison are similar to the ones presented in the previous sections (i.e. PV size of 6 kWp).

B. *Grid Impact Analysis*

The effects of HBS and DBS systems on the grid operation are estimated in this contribution based on grid simulations. The analysed effects include effects on voltage, loading of a local area transformer and loading of lines. The analysis is conducted utilizing real grid data of an LV grid (Hittistetten) close to the city of Ulm in cooperation with the SWU.

- *Impact on voltage*

The maximum and minimum voltage in the grid obtained through the simulation of only PV systems as well as combined with HBS systems or a DBS system are depicted in Fig. 10. It can be illustrated that the voltage deviation in the grid lies within the tolerance band of 3%. The simulation of HBS systems shows a possible reduction of the max. voltage, especially in the first half of sunny hours. This is a result of the local withdrawal of the PV feed-in when HBS systems charge. After most HBS have charged completely, the voltage reduction is very slight. On the other hand, the voltage in the simulation of a DBS is similar to the case of only PV systems, since the DBS do not affect the energy flows within grid lines.

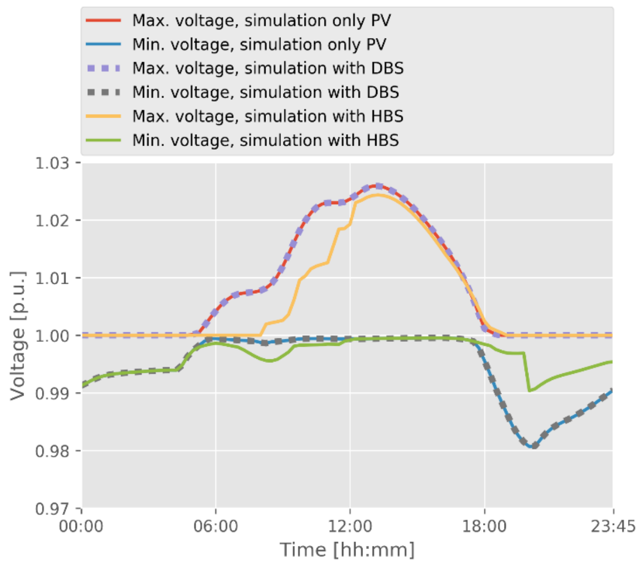

Fig. 10. Min. and max. voltage in the simulated grid (Hittistetten) in a summer day (i.e. 02.07.2015)

- *Impact on transformer loading*

The power flows that run through the southern transformer of the simulated grid in the aforementioned three simulation cases are depicted in Fig. 11. It can be seen that the power flows can be reduced through the HBS systems by the increased self-consumption, especially in the first half of the sunny hours because of the charge of the HBS systems. The power flow curve is shifted even further when simulating the DBS system. This is because it is installed at the southern transformer station, while it substitutes the HBS systems that belong to both southern and northern parts of the test area. However, the reduction of power flow and the corresponding relief for the transformer is not predictable, since it is dependent on the state of charge of the HBS systems.

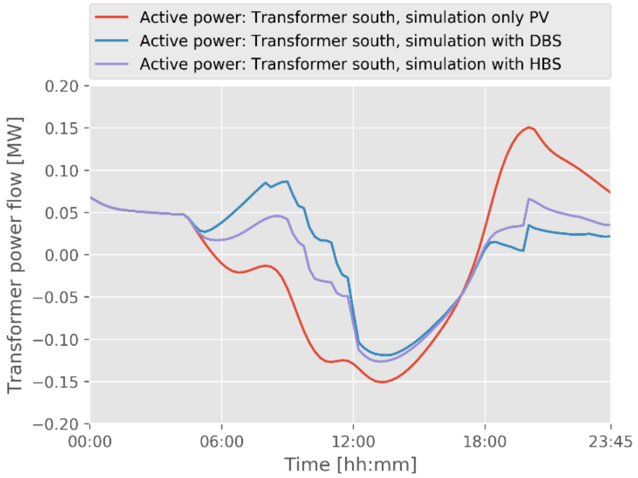

Fig. 11. Power flow through the southern transformer in the simulated grid (Hittistetten) in a summer day (02.07.2015)

- *Impact on grid components loading*

The differences between the max. loading in the grid when simulating only PV systems and loading when simulating them combined with HBS are depicted as boxplots in Fig. 12. Since the DBS system does not affect the energy flows within the grid, it also does not have an effect on the grid components loading, hence the results of this case are not considered in Fig. 12.

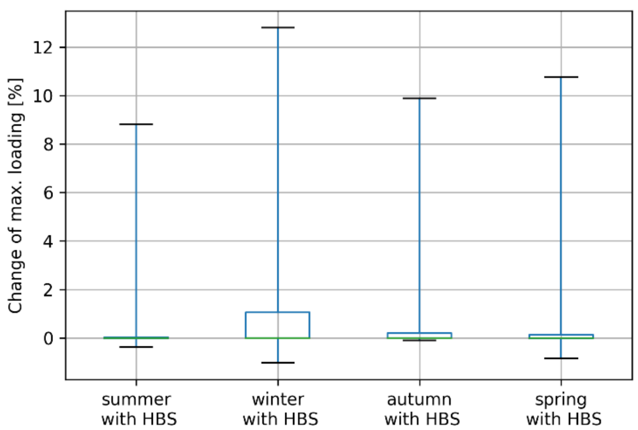

Fig. 12. Change of max. transformer/line loading in the simulated gird when simulating HBS systems compared to the simulation with only PV systems, considering exemplary days from four seasons. Summer: 02.07.2015, winter: 26.02.2015, autumn: 09.09.2015, spring: 18.05.2015

It can be seen that the HBS systems can reduce the max. loading at some times, but they might as well increase it in other times. This is because of the reduction of loading through self-consumption, especially when the HBS systems are in the charging mode. Therefore the reduction in winter is higher, since the HBS systems need more time to be fully charged. In general, HBS systems do not lead to a stable and reliable reduction of loading, when they are operated only to maximize the self-consumption.

IV. Conclusions

This contribution analyses the profitability of several business models which aim to increase the self-consumption of PV systems at prosumer level. In addition, the impact of HBS and DBS on the grid is analysed based on simulations of a real grid in a test area near Ulm.

The economic analysis, considering the cost assumptions made in this contribution, shows that HBS, DBS, PtH and HBS combined with PtH are not economically attractive when compared to the case when only a PV system is installed. The reason for the low profitability is their high CAPEX compared to the returns through the increased self-consumption. Governmental subsidy programs can improve the profitability of HBS system, nevertheless a pure PV system is more profitable. Apart from that, offering DBS systems as products by service providers does not show good profitability because of the current regulatory framework, which leads to several taxes, levies and fees for the DBS energy flows. Although the installation of PV-HBS systems in Germany is not profitable currently, they are installed increasingly. This can be explained by the desire of the prosumers to have higher self-sufficiency, consuming green energy or by other social reasons. PtH systems are currently not profitable compared to other models, as can be anticipated, since the assumed heat price is lower than the assumed feed-in tariff. Furthermore, the VAT paid by prosumers for self-consumed energy plays a negative role for the profitability of all analysed models.

A future scenario of post FIT is also simulated in this contribution. The results show that the HBS systems might be more cost-efficient than only PV systems, especially when these systems are optimally dimensioned. PtH systems are also not profitable in this scenario compared to the other models, since the assumed heat price is much lower than the assumed price for excess PV-electricity.

The grid impact analysis examined in this article shows that the local withdrawal of the PV feed-in through the charge of HBS systems can lead to a slight voltage reduction. This applies mainly to the first half of the sunny hours because of the charge of the HBS systems at this time. Additionally, the voltage in the simulation with a DBS is similar to the case of only PV systems, since the DBS do not affect the energy flows within the grid lines. In addition, the power flows on the analysed local area transformer as well as the grid lines can be reduced through the HBS systems, especially in the first half of the sunny hours, whereas DBS has a minor effect. In general, HBS systems do not lead to a stable and reliable reduction of loading or voltage, when they are only operated for maximizing the self-consumption. If the grid support is a target of these systems, they should have other control mechanisms than the one assumed in this contribution.

V. Outlook

To have a better profitability of the self-consumption business models, new business models should be developed in the market. These should include additional battery use cases next to self-consumption, such as grid support or the participation in the balancing market. Such a combination of use cases can increase the feasibility and lead to several profitable business models for both prosumers and service providers. In future contributions, further technologies will be considered in more detail with respect to the economic and grid operation analysis. This includes multi-functional storages systems, PtH, electro-mobility on prosumer level as well as public charging stations.

For a future renewable energy system, batteries are quite important as they offer flexibility. Therefore, the regulatory framework must be adapted to reduce constraints using batteries for more than one use case to increase the profitability of business models. This could avoid further subsidy programs for the flexibility needed in a pure renewable future.

Acknowledgment

This contribution presents the interim results of the project “Quartierspeicher”, which is funded by the unw “Ulmer Initiativkreis nachhaltige Wirtschaftsentwicklung“. This work is conducted in cooperation with the SWU “Stadtwerke Ulm/Neu-Ulm GmbH”. The methodologies and results of this contribution have been used and tested within the following projects:

- The project “C/sells” (Grant Agreement No.: BMWi 03SIN136) within the “SINTEG” funding program by the Federal Ministry for Economic Affairs and Energy.

- The collaborative project “InnoSÜD” within the framework of the federal states funding initiative “Innovative Hochschule”.

References

[1] Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit, “Klimaschutz in Zahlen: Sektorenziele 2030”, [Online] https://www.bmu.de/fileadmin/Daten_BMU/Download_PDF/Klimaschutz/klimaschutz_in_zahlen_sektorenziele2030_bf.pdf [Accessed on 05 March 2019]

[2] Subsidy programm BW (Baden-Württemberg) [online] https://um.baden-wuerttemberg.de/index.php?id=14033 [Accessed on 05 March 2019]

[3] J. Figgener et al., “Wissenschaftliches Mess- und Evaluierungsprogramm Solarstromspeicher 2.0”, Jahresbericht 2018, [Online] http://www.speichermonitoring.de/fileadmin/user_upload/Speichermonitoring_Jahresbericht_2018_ISEA_RWTH_Aachen.pdf [Accessed on 12 September 2018]

[4] PV Magazine, “100.000. Photovoltaik-Speicher in Deutschland in Betrieb genommen”, [Online] https://www.pv-magazine.de/2018/08/28/100-000-photovoltaik-speicher-in-deutschland-in-betrieb-genommen/ [Accessed on 11 September 2018]

[5] Magazine for technical building equipment, “Wärmepumpen-Marktanteil in Deutschland”, [Online] https://www.tga-fachplaner.de/Archiv/Heft-Archiv/article-818133-100248/waermepumpen-marktanteil-in-deutschland-.html [Accessed on 11 September 2018]

[6] PV Magazine, “PV-System mit Wärmepumpe ideal betreiben”, [Online] https://www.pv-magazine.de/archiv/pv-system-mit-wrmepumpe-ideal-betreiben/?tx_ttnews[backCat]=337&cHash=41a0bbdb79a7cbca6e3a2c7c2178e266 [Accessed on 12 September 2018]

[7] D. Stakic; F. Ebe; G. Heilscher; F. Meier; “Power to Heat für Prosumenten und Netzbetreiber in Niederspannungsnetze”, *3. Dialogplattform Power to Heat*, Berlin, Germany, 2017

[8] B. Idlbi, J. von Appen, T. Kneiske, and M. Braun, “Cost-Benefit Analysis of Battery Storage System for Voltage Compliance in Distribution Grids with High Distributed Generation”, *Energy Procedia*, vol. 99, pp. 215–228, Nov. 2016

[9] T. Benz, et al., “The Cellular Approach: The Basis of Successful, Cross-Regional Energy Transition”, VDE-Study; VDE Verband der Elektrotechnik, Elektronik, Informationstechnik e. V: Frankfurt, Germany, 2015.

[10] Bundesministerium für Justiz und Verbraucherschutz, “ Gesetz für den Ausbau erneuerbarer Energien (Erneuerbare-Energien-Gesetz - EEG 2017)”, [Online] https://www.gesetze-im-internet.de/eeg_2014/BJNR106610014.html [Accessed on 05 March 2019]

[11] Bundesnetzagentur, “Leitfaden zur Eigenversorgung, Juli 2016”, [Online] https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Energie/Unternehmen_Institutionen/ErneuerbareEnergien/Eigenversorgung/Finaler_Leitfaden.pdf?__blob=publicationFile&v=2 [Accessed on 05 March 2019]

[12] J. Moshövel, et al., “Analyse des wirtschaftlichen, technischen und ökologischen Nutzens von PV-Speichern”, Dec. 2015

[13] A. I. Nousdilis, G. C. Kryonidis, E. O. Kontis, G. K. Papagiannis, G. C. Christoforidis, and I. P. Panapakidis, “Economic Viability of Residential PV Systems with Battery Energy Storage Under Different Incentive Schemes”, in *2018 IEEE International Conference on Environment and Electrical Engineering and 2018 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe)*, 2018, pp. 1–6.

[14] E. Gaudchau, M. Resch, and A. Zeh, “Quartierspeicher: Definition, rechtlicher Rahmen und Perspektiven”, *Ökol. Wirtsch. - Fachz.*, vol. 31, no. 2, p. 26, May 2016.

[15] J. Sardi and N. Mithulananthan, “Community energy storage, a critical element in smart grid: A review of technology, prospect, challenges and opportunity”, *in 2014 4th International Conference on Engineering Technology and Technopreneuship (ICE2T)*, 2014, pp. 125–130.

[16] G. Fong, R. Moreira, and G. Strbac, “Economic analysis of energy storage business models”, in *2017 IEEE Manchester PowerTech*, 2017, pp. 1–6.

[17] L. Conrads, et al., “StromspeicherGeschäftsmodelle im aktuellenrechtlichen Rahmen”, Jan 2017.

[18] I. Ilieva and J. Rajasekharan, “Energy storage as a trigger for business model innovation in the energy sector”, in *2018 IEEE International Energy Conference (ENERGYCON)*, 2018, pp. 1–6.

[19] Innogy SolarCloud, product website, [Online] https://www.innogy.com/web/cms/de/3917572/fuer-zuhause/energie-selbst-erzeugen/photovoltaik-aus-sonne-wird-strom/photovoltaikloesungen-von-innogy/solarcloud/ [Accessed on 03 March 2019]

[20] Bundesverband Solarwirtschaft e.V. (BSW-Solar), “Photovoltaik-Preismonitor Deutschland”, [Online] https://www.solarwirtschaft.de/fileadmin/user_upload/BSW_Preismonitor_Q1_2016.pdf [Accessed on 05 March 2019]

[21] Photovoltaiksolarstrom, “Die Vergütung für eingespeisten Solarstrom 2019”, [Online] https://photovoltaiksolarstrom.com/einspeiseverguetung/#Anker1 [Accessed on 05 March 2019]

[22] Centrales Agrar-Rohstoff Marketing- und Energie-Netzwerk, “Marktübersicht Batteriespeicher - Informationsangebot”, [Online] https://www.carmen-ev.de/files/Sonne_Wind_und_Co/Speicher/Markt%C3%BCbersicht-Batteriespeicher_2018.pdf [Accessed on 05 March 2019]

[23] Average household, “Average Electricity Consumption”, [Online] https://www.musterhaushalt.de/durchschnitt/stromverbrauch/ [Accessed on 05 March 2019]

[24] Die Bundesregierung, “So setzt sich der Strompreis zusammen”, [Online] https://www.bundesregierung.de/breg-de/aktuelles/so-setzt-sich-der-strompreis-zusammen-268122 [Accessed on 05 March 2019]

[25] E.G.O., “EGO Smart Heater”, [Online] https://ego-shop.net/download/C3e6c8a8eX15a6ace9b61X3798/EGO_Smart_Heater_klein.pdf [Accessed on 05 March 2019]

[26] BDEW, VKU, GEODE, "Abwicklung von Standardlastprofilen Gas", Berlin, Jun 2016, [Online] https://www.bdew.de/media/documents/Leitfaden_20160630_Abwicklung-Standardlastprofile-Gas.pdf [Accessed on 05 March 2019]

[27] Deutsche Wetterdienst, "Testreferenzjahre (TRY)", [Online] https://www.dwd.de/DE/klimaumwelt/klimaforschung/spez_themen/try/try_node.html [Accessed on 05 March 2019]

[28] BDEW, VKU, GEODE, "Verfahrensspezifische-Parameter", [Online] http://www.encw.de/wp-content/uploads/2016/09/Verfahrensspezifische-Parameter.xlsx [Accessed on 05 March 2019]

[29] Bundesnetzabentur, "Informationen zu Strom- und Gaspreisen für Haushaltskunden", [Online] https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Verbraucher/PreiseRechnTarife/preiseundRechnungen-node.html [Accessed on 05 March 2019]

[30] Stadtwerke Ulm/Neu-Ulm GmbH, "Unsere Gasprodukte", [Online] https://www.swu.de/privatkunden/produkte-leistungen/gas/?tx_swuproductfinder_piproductfinder%5Baction%5D=list&tx_swuproductfinder_piproductfinder%5Bcontroller%5D=TarifData&cHash=547b879bcac4d6ec4bd2820caf8fb54b [Accessed on 05 March 2019]

[31] Bundesnetzagentur, "Moderne Messeinrichtungen / Intelligente Messsysteme", [Online] https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Verbraucher/NetzanschlussUndMessung/SmartMetering/SmartMeter_node.html [Accessed on 05 March 2019]

[32] EEX, "European Energy Exchange", [Online] https://www.eex.com/de/marktdaten/strom/futures/phelix-de-futures#!/2019/03/07 [Accessed on 05 March 2019]

[33] M. Reichmuth et al, "Entwicklung der Preise für Strom und Erdgas in Baden-Württemberg bis 2020", [Online] https://www.baden-wuerttemberg.de/fileadmin/redaktion/dateien/Altdaten/202/IE_Leipzig_Energiepreise_BW.pdf [Accessed on 05 March 2019]

[34] Energieheld, "Photovoltaik-Speicher - die richtige Größe finden", [Online] https://www.energieheld.de/solaranlage/photovoltaik/stromspeicher/groesse-dimensionierung#dimensionierung-groesse [Accessed on 05 March 2019]

[35] DIgSILENT PowerFactory, "Quasi-Dynamic Simulation", [Online] https://www.digsilent.de/en/quasi-dynamic-simulation.html [Accessed on 05 March 2019]

[36] Stadtwerke Ulm/Neu-Ulm Netze GmbH, "Testgebiete Smart Grids", [Online] https://www.ulm-netze.de/unternehmen/projekt-smart-grids/testgebiete.html [Accessed on 05 March 2019]