ATLANTIS PRESS
Atlantis Highlights in Engineering, volume 4
13th International Renewable Energy Storage Conference (IRES 2019)

Common battery storage for an area with residential houses

Eberhard Waffenschmidt,
Technische Hochschule Köln,
Cologne, Germany
Correspond to:
eberhard.waffenschmidt@th-koeln.de

Till Paulzen,
Technische Hochschule Köln,
Cologne, Germany

Alexander Stankiewicz
Rheinenergie AG
Cologne, Germany

***Abstract*—In this publication the technical benefits of a mutual battery storage compared to a solution with three individual battery storages is investigated. This has been done in the context of the EU funded project "GrowSmarter" in collaboration with Rheinenergie in the living area Stegerwaldsiedlung in Cologne.**
In the project area each of the three buildings has its own battery storage (size varies by building). This publication investigates the options for 3 buildings connected by a private residential grid instead of a public grid, with a central battery storage and the chance of energy self-consumption. This part consists of 3 houses with 167 apartments arranged around a common yard. The roofs are covered with photovoltaic modules with an installed power of 202,5 kWp. For this area Li-Ion batteries are installed in separate containers. They have a combined capacity of 200 kWh (130, 60 and 10 kWh) with varying maximum power (30, 20 and 5 kW). It is primarily used to optimize the use of the PV power. As a result, the grade of autarky can be improved from 41 % to 45% by use of a common battery storage.

Keywords—battery, residential area, residential grid, Li-Ion, common use, photovoltaic, autarky

I. Introduction

The mutual use and operation of decentralized renewable energy sources and storages is a trend which may lead to an optimized use of renewable energy. In addition, it may allow the participation of citizens to benefit from a decentralized energy structure. Here, we focus on the mutual use of a battery storage in a residential power grid.

One option is to operate a mutual storage by the grid operator. This is possible in smaller cities in Europe, where grid operators are allowed to operate generation facilities and storages due to the "De Minimis" rule [1]. In this case, the operation of a mutual storage in a related grid gives the opportunity of an islanding operation in case of an emergency. Examples for such applications are the project IREN2 [2][3] or the project in the community of Bordesholm [4]. In this case the relation between grid operator and customers does not change.

Another examples allows and requires the involvement of the customers. In the project "Strombank" [5], performed by University of Stuttgart and energy providers in Mannheim, 20 different customers are interconnected by a mutual storage. In this case, the customer were households, small industrial companies. As a requirement, each customer had to provide at least a photovoltaic (PV) generator. The customers were given a trading account (similar to a bank account), which allowed them to trade electricity among each other. Since the concept requires the ownership of a PV system, it excludes citizens, which are not able to operate a PV system, like e.g. tenants.

A further project in Germany is the mutual storage and energy grid „Quartierspeicher Weinsberg" [6], located in the town Weinsberg close to Heilbronn. It connects 23 apartment units and includes a 150 kWh electrical battery storage as well as an 20000 Liter heat storage. A mix of PV, combined heat and power (CHP) generation and heat pumps connected by an electric grid and a heating grid provides electrical and heat power. The project could demonstrate islanding operation and grid releasing operation of the system.

An example for a field trial in other countries than Germany is the project in Alkimos Beach, Australia, by the company Synergy [7]. A mutual LiIon battery with an energy capacity of 1.1 MWh connects 100 houses, which are equipped with PV systems. The aim is to investigate, how to integrate PV systems in existing power grids. The project runs from 2014 to 2020. As an intermediate result, the inhabitants can save up to 40 Australian Dollars per year due to the mutual storage.

In addition, new business models are being developed for mutual battery storages [8], and legal frame conditions are analyzed in detail in an article by Reiner Lemoine Institut [9], which also includes the additional operation as provider for primary reserve power.

In the EU-project "GrowSmarter" in cooperation with several partners, including RheinEnergie AG, the City of Cologne has set itself the task of integrating energy, mobility and information and communication technology into urban planning. This is to be implemented in the "Stegerwaldsiedlung" in Cologne-Mülheim. As illustrated in Fig. 1, in this context, 16 buildings were or are being renovated in terms of energy efficiency, equipped with photovoltaic modules, heat pumps and battery storage devices and networked via a central, intelligent energy management system.

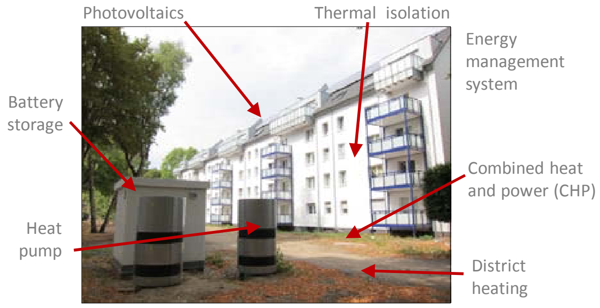

Fig. 1: Stegerwaldsiedlung

The district is supplied additionally with heat by the local district heating network of RheinEnergie AG in order to cover the peak load of the heat demand. These arrangements are intended to reduce the primary energy consumption of the settlement by up to 60 % and also reduce greenhouse gas emissions by 60% to 70%.

In this publication the technical benefits of a mutual battery storage compared to a solution with three individual battery storages is investigated. In the project area each building has its own battery storage (size varies by building). This publication investigates the options for 3 buildings connected by a private residential grid instead of a public grid, with a central battery storage and the chance of energy self-consumption. This publication is based on the bachelor thesis of the co-author Till Paulzen [10].

II. CONSTRAINTS

Fig. 2 shows a map of the Stegerwaldsiedlung (left) and the considered area for the investigations (right). The relevant area consists of three building blocks with apartments: The block on Deutz-Mühlheimerstraße (DM), the block on Gaußsstraße (GA) and the block on Sonnenscheinstraße (SO). They are arranged around a common yard. Fig. 3 shows a photograph of this yard. All buildings are owned by a company, which rents the apartments to in total 167 tenants. This company also owns and operates the energy infrastructure including the battery storages. The total yearly energy demand of the households is 250 MWh/a

Each building block has a photovoltaic (PV) System on its roof. As the buildings are differently oriented, also the PV systems have different orientations. The total installed PV power is 203 kWpk with an annual energy generation of 167 MWh/a. This is less than consumed in the area, such that full autarky cannot be achieved.

To each PV system a battery storage is related. The batteries are not placed inside the buildings but in external containers of different sizes. Fig. 4 shows a photograph of a small size container. The doors are made from glass, such that the neighbors and visitors can always have a look at the technique. The batteries are Li-Ion batteries of different sizes. Fig. 5 shows a photograph of the inside of such a container. The total capacity is 200 kWh with an inverter power of in total 55 kW. They have a very high efficiency of 98% and the inverters have an efficiency of 96%.

The batteries are used to optimize the grade of autarky and the PV self-consumption of the houses. To make a better use of the PV power, also the heat pumps are operated preferably on PV power and on energy stored in the batteries.

Detailed numbers about the buildings, the PV systems and the batteries are listed in Table I.

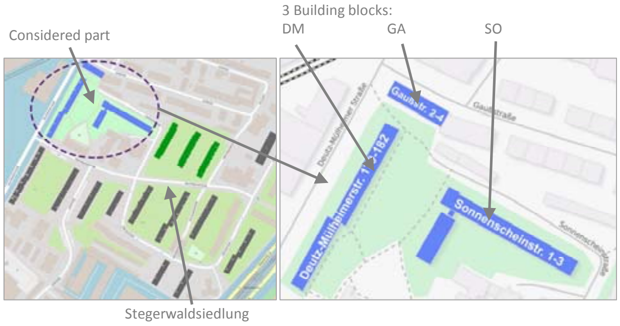

Fig. 2: Map of the considered area (Map: open street map)

Fig. 3:Photgraph of the common yard between the houses as well as one of the battery containers.

Fig. 4: Photograph of a battery container (small container version).

Fig. 5: Photograph of the battery racks inside the container (large container version).

TABLE I: DATA OF THE CONSIDERED AREA.

	DM	*GA*	*SO*	*Sum*
Number of tenants	65	20	82	167
Living area before refurbishment / m²	3059	1080	4797	8936
Living area after refurbishment/ m²	3792	1266	4797	9855
PV-Orientation	East/West	South	East/West	-
PV-Angle / deg	45	45	12	-
PV-Power / kWp	99.55	9.88	93.6	203.03
PV-Generation / kWh/a	76184	9536	81446	167166
Spez Generation kWh / kWpk	765.28	965.18	870.15	823.36
Consumption households / kWh	84477	28864	137362	250703
Consumption heat pumps / kWh	126807	41904	158241	326952
Battery capacity / kWh	130	10	60	200
Battery power / kW	30	5	20	55

III. METHODOLOGY

The existing three battery containers are arranged as illustrated in Fig. 6. The batteries for Building DM and GA are located in the same container, but are not interconnected. Instead, each battery is connected individually to each its related building. Fig. 7 shows the assumed arrangement of a common storage for all buildings. For the investigations, it is assumed to have the same total capacity and power rating of 200 kWh / 55 kW and a round trip efficiency of 92%.

The existing batteries are operated in a mode to improve the PV self-consumption. If the PV generates excess energy, it is first stored in the batteries. If the batteries are completely charged, excess power is fed into the power grid. Correspondingly, the batteries are first discharged, if there is more power demand than generation. If the batteries are empty, power is taken from the grid. This operation mode is also assumed for the simulations of the common battery storage.

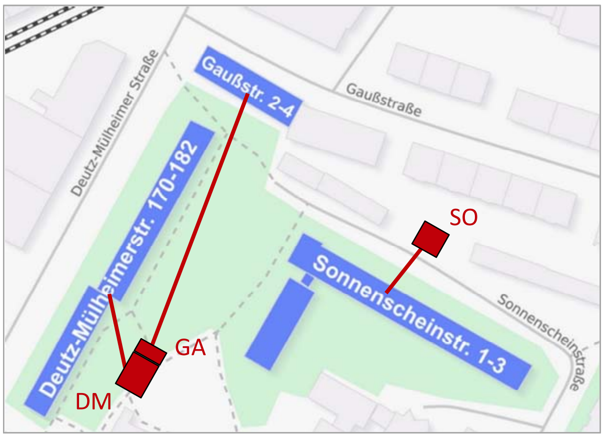

Fig. 6: Map of the houses with the existing individual batteries. (Map: open street map).

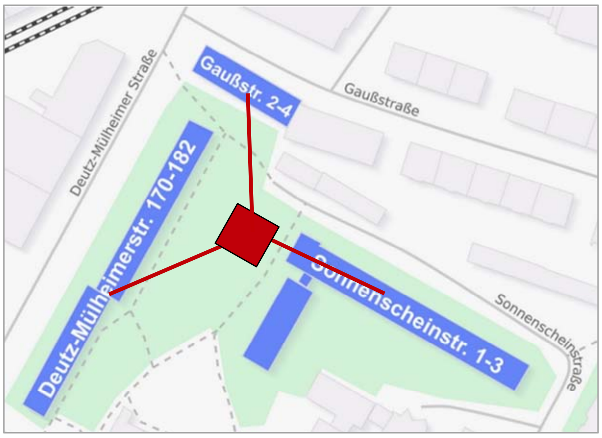

Fig. 7: Map of the houses with the assumed common battery storage. (Map: open street map).

As figures of merit for the investigation the PV self-consumption and the grade of autarky are used. In this context, autarky is defined according to [11] as the amount of energy, which can be provided at each point of time from PV and battery. It is *not* based on summed-up yearly energy. The figures of merit are discussed here for the whole area in total. Some individual results for the buildings (in case of three individual batteries) can be found in Table II.

In the course of the project, profiles of the power flow are measured with a resolution of 1 h for at least one year. This includes individual PV generation, load demand, heat pumps and battery charging and discharging. Fig. 8 shows exemplary profiles for one specific day of the year. The figure of merits of the existing solution with three battery storages can be directly derived from the measurements.

The grade of autarky is calculated from the measured data as follows: For each 1 h time step the residual power P_r, which is imported from the public grid is calculated from the sum of all related consumed power P_c, subtracted by the all power delivered by the battery P_{bat} and by the PV systems P_{PV}. Only positive values are considered, such that feed-in is not considered:

$$P_r(t) = \max [\Sigma P_c(t) - \Sigma P_{bat}(t) - \Sigma P_{PV}(t), 0] \quad (1)$$

The residual energy E_r is calculated by numerical integration of the residual power over the investigated period of time:

$$E_r = \int P_r(t)\, dt \quad (2)$$

The consumed energy E_c is calculated similarly from the numerical integral of the consumed power over the investigated period of time:

$$E_c = \int \Sigma P_c(t)\, dt \quad (3)$$

Finally, the grade of autarky g_a is calculated as the ratio of residual energy E_r and consumed energy E_c:

$$g_a = E_r / E_c \quad (4)$$

The PV self-consumption is calculated from the fed-in energy which is calculated similar to (1) as follows. Here, only the negative values are considered as fed-in power P_f, and then negated to achieve a positive number:

$$P_f(t) = - \min [\Sigma P_c(t) - \Sigma P_{bat}(t) - \Sigma P_{PV}(t), 0] \quad (5)$$

The fed-in power is subtracted from the generated PV power to obtain the internally used PV power P_{use}.

$$P_u(t) = \Sigma P_{PV}(t) - P_f(t) \quad (6)$$

The used PV power P_u and the generated PV power P_{PV} are numerically integrated over time to achieve the used PV energy E_u and the annual generated PV energy E_{PV}. Finally, these two values are divided by each other to obtain the grade of PV self-consumption:

$$g_{PV} = E_u / E_{PV} \quad (7)$$

All calculations are performed using the spreadsheet calculation tool Excel.

For the single mutual storage, the mutual profiles are used to calculate the residual load (see Figure 9 as example) and from this, the figures of merit are simulated using the described operation mode. In addition, the figures of merit are calculated for two additional cases: For the case without any storage and for the case with an infinite large common storage. So, in total 4 cases are investigated:

- No storage
- Single battery storages
- Common battery storage
- Infinite storage

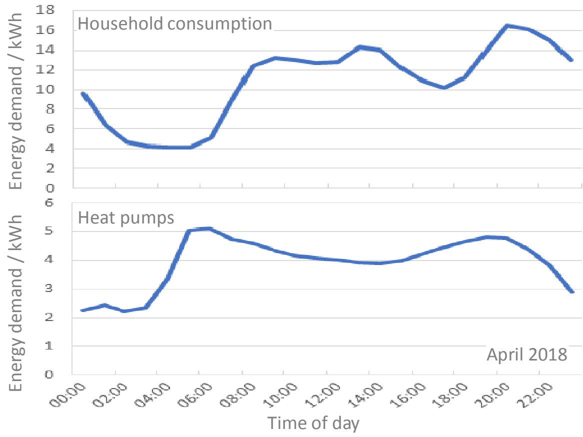

Fig. 8: Exemplary load profiles for household consumption and heat punps demand.

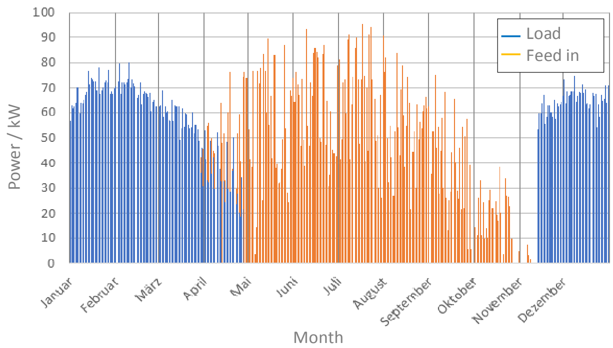

Figure 9: Residual load for infinite sized battery.

IV. RESULTS

The resulting figures of merit for the existing case with three individual batteries is shown in Fig. 10. The results are shown for each month of the year. As expected typically, one can observe a significantly higher demand of energy in winter and an opposing curve of PV generation with maximum generation in summer. The amount of PV self-consumption nearly matches the total consumption in summer, however due to timely mismatch the grade of autarky reaches a maximum in summer of only 85% of the generated PC energy. The yearly average grade of autarky is 41.1 %.

The corresponding results for the common battery storage are shown in Fig. 11. The consumption is the same by definition. In summer months, a slightly higher PV self-consumption can be observed. Apparently, the common battery storage helps matching the generation with the demand. Also the grade of autarky nearly reaches 100% in July. The total yearly average grade of autarky is improved to 45.1%.

The yearly results are summarized in Fig. 12, including the cases “No storage” and “infinite storage”. As intuitively expected, all figures of merit improve from “No storage” over “Individual storages” and “Common storage” to “Infinite storage”: The amount of energy delivered from the grid (“grid demand”) decreases from 190 MWh/a to 125 MWh/a. Correspondingly, the PV self-consumption increases by the same amount of energy from 100 MWh to 165 MWh and the grade of autarky improves from 34% to up to 58%. The difference in the grade of autarky between the common storage of 200 kWh to an infinite sized storage shows that the battery size could still be increased with technical benefit. The figure also shows the improvement of the figures of merit from individual storages to a common storage of the same size. It is indicated by the gray and red ovals: The grid demand reduces from 172 kWh/a to 160kWh/a by 7%, and the grade of autarky improves from 41.1% to 45.5%. The PV self-consumption improves from 120 MWh/a to 131 MWh/a by 11 MWh/a, corresponding to 9.7%.

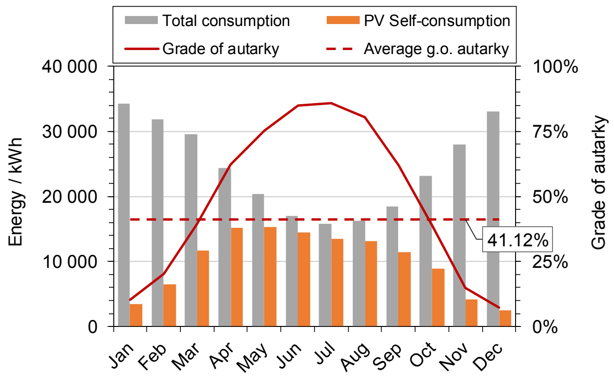

Fig. 10: Grade of autarky and PV self consumption for the existing case of three individual batteries.

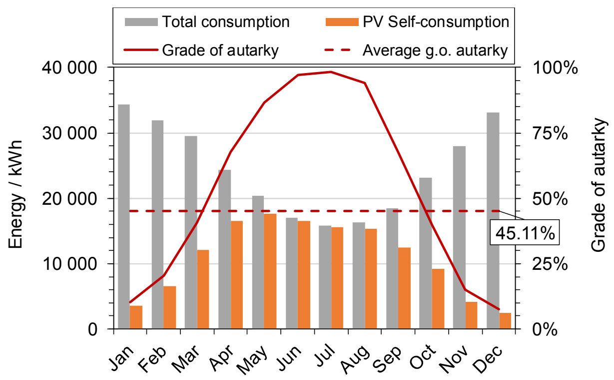

Fig. 11: Grade of autarky and PV self consumption for the assumed case of a common battery.

Alternatively, a smaller common battery storage could be used to achieve the same grade of autarky and PV self-consumption. For the given case a common battery size of only 110 kWh instead of 200 kWh with the same power rating of 50 kW is calculated (not shown as figure). Reducing the battery size in this amount with similar performance gives a significant commercial benefit.

Fig. 12 includes two effects. First, it shows the general benefit of a battery storage on the grade of autarky, which is in effect also at individual storages and has been extensively described in literature. In this particular case, in addition the installed PV power is not sufficient to generate the needed annual energy. Therefore, the grade of autarky cannot exceed 57%, even all PV power is used internally. The use of a mutual storage instead of individual storages is the other effect in Fig. 12. This can be observed in the increase of the grade of autarky from the case of individual storages to a common storage. A more detailed analysis of the effect (not shown) reveals that compensational effects of the residual power profiles (without storage) already increase the grade of autarky. Equal residual power profiles would result in no effect of a mutual storage. It can be stated that mutual battery storages are more beneficial, the more the residual load profiles differ from each other. But to generalize and quantize the results, it would be necessary to introduce a figure of merit describing the difference of the individual residual profiles.

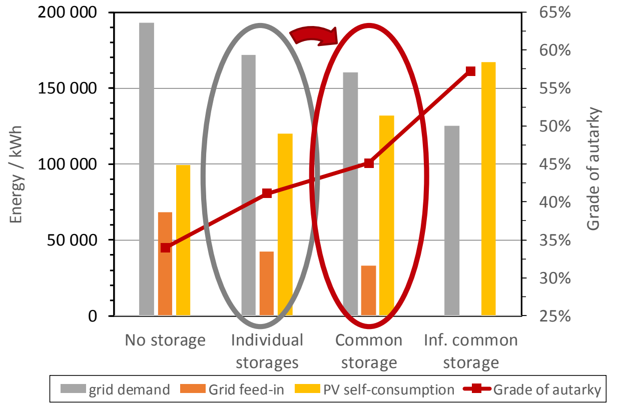

Fig. 12: Comparison of grade of autarky and PV self-consumption for four investigated scenarios.

TABLE II: AUTARKY DATA OF THE EXISTING CASE AND THE COMMON BATTERY STORAGE

	DM	*GA*	*SO*	*Sum*	*Common storage*
Battery load / kWh	18053	1017	11370	30441	34122
Number of cycles	139	102	189	-	171
Grade of autarky	48,9%	24,5%	39,3%	41,1%	45.1%
PV self-consumption				120155	131819
Grid demand / kWh	57064	27488	87510	172062	160399
Grid feed-in / kWh	18728	510	23702	42940	32789

V. CONCLUSIONS

A common battery storage for an area with residential houses is compared to the case of three individual battery storages for the same three buildings with a total capacity of 200 kWh. It is used to improve the self-consumption of the photovoltaic energy generation in the area. It could be shown that the for this particular case the common battery improves the grade of autarky from 41.1% to 45.5% and the PV self-consumption improves by approximately

10%. Alternatively, a battery of only 110 kWh would give similar performance as the three individual batteries with a total capacity of 200 kWh. This correspond to a significant cost reduction for the similar performance.

VI. REFERENCES

[1] „Gemeinsame Auslegungsgrundsätze der Regulierungsbehörden des Bundes und der Länder zu den Entflechtungsbestimmungen in §§ 6-10 EnWG“, Version vom 01.03.2006, p.8., online available (checked on 30.9.2019): https://www.regulierungskammer-bayern.de/fileadmin/user_upload/landesregulierungsbehoerde/dokumente/Auslegungsgrundsaetze.pdf

[2] „IREN2 Konsortium – Für das Stromnetz der Zukunft“, project website, online available (checked on 30.9.2019): http://www.iren2.de/de/

[3] Maria Vasconcelos, Nicolas Thie, Reinhold Bertram, „IREN2 Zukunftsfähige Netze für die Integration Regenerativer Energiesysteme – Teilvorhaben RWTH, Nachhaltige Netzintegration Erneuerbarer Energiesysteme“, Abschlussbericht zum Verbundvorhaben, Förderkennzeichen 0325685D, RWTH Aachen, IFHT, 26.9.2018, online available (checked on 30.9.2019): https://www.tib.eu/de/suchen/download/?tx_tibsearch_search%5Bdocid%5D=TIBKAT%3A1663844836&cHash=f8af1875ec20f9e70f9f35900c536360#download-mark

[4] Silvan Rummeny, Eberhard Waffenschmidt, "Autarkiebetrieb eines kommunalen Stromnetzes mit Batterie und Erneuerbaren Energien", Zukünftige Stromnetze, Berlin, 30.-31.Jan.2019.

[5] R. Thomann, Y. Lachmann, O. Prahl, et al., „Strombank: Innovatives Betreibermodell für Quartierspeicher“, Forschungsbericht BWPLUS, Förderkennzeichen: BWE 13017 – 13020, Mannheim, Oct. 2019, online available (checked on 30.9.2019): http://fachdokumente.lubw.baden-wuerttemberg.de/servlet/is/120150/bwe13017_13020.pdf?command=downloadContent&filename=bwe13017_13020.pdf&FIS=203

[6] M. Verbücheln, M. Reinhardt, T. Preuß, P. A. Bunzel, „Erneuerbare Energien und Energieeffizienz in der kommunalen Planungspraxis“, Materialsammlung zur Fortbildung im Rahmen des EU-Projektes SPECIAL, difu – Deutsches Institut für Urbanistik, 2016, pp. 55-57, online available (checked on 30.9.2019): https://difu.de/sites/difu.de/files/archiv/projekte/2016_special_trainingsmaterialien.pdf

[7] “Solar and Storage Trial at Alkimos Beach Residential Development”, Australian Renewable Energy Agency, 8.Sept. 2019, online available (checked on 30.9.2019): https://arena.gov.au/projects/solar-and-storage-trial-at-alkimos-beach-residential-development/.

[8] C. Langolf und D. Strauß, „Quartiersspeicher – das Zukunftsmodell für Stadtwerke“, Projektarbeit FNK 11, SWK Stadtwerke Kaiserslautern Versorgungs-AG, Kaiserslautern, 20.Apr.2018, online available (checked on 30.9.2019): https://www.swk-kl.de/fileadmin/data/downloads/pdfs/Flyer/SWK-Stadtwerke-Kaiserslautern-Quartierspeicher-Projektarbeit-FNK11.pdf

[9] E. Gaudchau, „Quartierspeicher – Definition, rechtlicher Rahmen und Perspektiven,“ ÖkologischesWirtschaften 2.2016 (31), pp. 26-27.

[10] Till Paulzen, "Auswirkungen eines elektrischen Arealnetzes auf den Autarkiegrad einer Siedlung mit Mehrfamilienmietshäusern", Bachelor Thesis, TH-Köln, performed externally, 9. Nov. 2018

[11] Jürgen Deutschle, Wolfgang Hauser, Marco Sonnberger, Jan Tomaschek, Lukasz Brodecki, Ulrich Fahl, "Energie-Autarkie und Energie-Autonomie in Theorie und Praxis", Zeitschrift für Energiewirtschaft , 39, 2015, Nr. 3, pp. 151-162