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Capacity Estimation of a Utility-Scale Lithium Ion Battery in an Autarchic Environment by Comparing two Different Battery Models

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***Abstract*— The autarchic communities are an attractive scenario that more and more local actors strive to achieve. In electricity autonomous cases a battery system stands as prerequisite to succeed renewables time shifting due to the intermittent nature of decentralized generation. In the present study the local autarky in the electricity sector is examined for a system composed of a photovoltaic installation, a wind farm, a biogas combined heat power plant and a battery. The selected storage system is a Lithium Ion battery and two different modelling alternatives have been applied. Consequently, the two system versions have been tested for three autonomous case study regions in north, central and south Germany. The system is subsequently operated, and the minimum battery capacity is estimated for each case study based on dynamic simulations. Simulation results indicate that the autarky in the electricity sector can be feasible, but the capacity is underestimated almost up to 30%, if the aging effect of the battery is neglected and the efficiency grade is considered steady. Moreover, outcomes show that the calculated battery capacity is higher for the south city due to the solar power variability as an outcome of the seasonal variation.**

***Keywords*— autarchic community, Lithium ion battery, energy storage, renewables, regional system modelling**

I. INTRODUCTION

Sustainable development is the key force against the climate change and the fossil fuels depletion. To this extent, the autarchic communities are an attractive scenario that more and more local actors, policymakers and stakeholders strive to achieve. Feldheim is already a self-sufficient region in Germany [1] while various other areas plan to be fully independent in the electricity sector in the upcoming years (Wildpoldsried [2], Alheim [3], Wunsiedel [4]). Although it is strongly controversial that the autarky is the future in the climate change it is considered challenging and environmentally positive at the same time to develop a relatively or exclusively local sustainability where no energy sources ought to be imported [5].

To succeed a local autarky several sources of energy have to be adopted to secure the stability of supply. Wind, solar and biomass would be an ideal combination of energy mix, where biomass could be used to cover the base load while wind and solar energy could support the intermediate and peak demand. Given though the intermittent character of wind and solar energy a battery system stands also as prerequisite to succeed renewables time shifting and peak shaving.

In literature there are already various studies and paradigms in the field of autarky. Popp [6] has considered an autarchic constellation, consisting of wind and solar plants, which are supported also from a battery installation. The German Environment Agency had also investigated the techno-ecological feasibility of an isolated solution for a city and a village based on simulations regarding storage capacity [7]. In this study only wind and solar energy have been taken into account while for the battery a lead acid model with a constant efficiency grade is considered. Static and dynamic simulations were carried out in order to define the minimum battery capacity. Faßbender and Waffenschmidt have also investigated an option for an autarkic operation of a communal power grid, by applying renewable energies and a battery [8]. In this case it was analyzed the maximum time span that the community could be self-sufficient in island operation while no long-term solution has been sought.

In addition, various other studies deal with the topic of autarky but not in "island" applications rather on grid-connected topologies with a zero-annual balance. For example, Schmidt in [9] has examined whether and under what conditions a fully renewable electricity supply in Germany is possible while Klaus et al. in [10] performed dynamic simulations of the feed-in of renewable energies and the load for the year 2050 in Germany. In this case pumped storage plants were considered as storage facilities.

It can be thus concluded that the aspect of a completely self-sufficient region, where solar, wind and biomass sources constitute the local energy mix and a biogas storage system as well as a large-scale lithium ion battery support the grid stability and the security of supply, has not yet been technically thoroughly examined in the literature, especially with dynamic simulations, which could reveal potential critical functional aspects of the autarchic system. Furthermore, the added value from a technical point of view of a realistic validated battery model has not yet been assessed and analyzed in such a context in comparison to an ideal voltage source with a constant efficiency. In this frame, the scenario of an energy self-sufficient community is in this study investigated and the technical feasibility of the conceptualized system evaluated. The extracted outputs have been also further compared for three different regions in Germany. The aim is to examine the differentiations that the weather conditions introduce to the on-site energy balance, with the focus on the technical aspect when novel concepts are studied and simplified models are used. A cost analysis is within the scope of this study not included.

The rest of the paper is structured as follows. In Section 2 the model of each component is described and the overall system is also presented. In addition, the chosen case study regions are introduced. The results of the simulation are provided and analyzed in Section 3 and finally in Section 4 conclusions are drawn.

II. METHODOLOGY/ SYSTEM DESCRIPTION

The proposed system is composed from a photovoltaic (PV) installation, a wind farm, a biogas plant accompanied from a Combined Heat and Power (CHP) unit and a battery. Each of these subsystems has been modelled and simulated in a Matlab/Simulink environment, while each component has been validated and verified based on data stemming from real installations and units which belong to the Ostfalia University of Applied Sciences [11].

A graphical illustration of the proposed designed system configuration is depicted in Fig. 1.

The detailed description of each model part is given below.

A. *Solar energy system model*

The main components of the photovoltaic systems are the panels, which are connected in series to achieve the anticipated output voltage, or in parallel to reach the required current level. Panels are formed from one or more modules, and are preassembled, while modules consist of the photovoltaic (PV) cells, which are the semiconductor units that convert the incident irradiance into electricity. Since the produced current is direct, an inverter is in most cases required to convert it in alternating current.

The DC output power P_{DC} of one module is analogous to the radiation that hits the panels and the nominal power of the modules, and is also related to the temperature which is developed on their surface [12,13]. Mathematically it is described from the following equation:

$$P_{DC}=\eta_{ext\ losses}\cdot\left\{P_{peak}\cdot\left(\frac{G_{eff}}{G^*}\right)\cdot\left[1-\beta\left(T_c-T_C^*\right)\right]\right\} \quad (1)$$

where: $\eta_{ext\ losses}$ are losses for modules mismatching, diodes and dirt (%), P_{peak} is the rated power of one module (W), G_{eff} is the effective global radiation (W/m^2), G^* is the radiation in standard conditions (1,000 W/m^2), β is the temperature losses coefficient (°C^{-1}), T_C is the operation cell temperature (°C), T_C^* is the standard operation cell temperature (25 °C).

The operation temperature T_c is calculated as follows [13]:

$$T_c=T_{amb}+\left(NOCT-T_{NOCT,std}\right)\cdot\left(\frac{G_{eff}}{G_{NOCT}}\right) \quad (2)$$

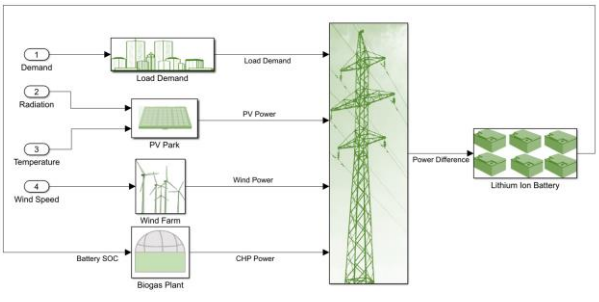

Fig. 1. Graphical illustration of the designed system

where: T_{amb} is the ambient temperature (°C), *NOCT* is the nominal operation cell temperature (°C), $T_{NOCT,std}$ is the ambient temperature at *NOCT* conditions (20°C), G_{NOCT} is the radiation at *NOCT* conditions (800 W/m^2).

So as to calculate the AC output of the plants the inverter was also modeled based on the characteristic curves of manufacturers.

The validation part was conducted with data from the photovoltaic plants which are installed on the roof top of the Faculty of Supply Engineering of the Ostfalia University in Wolfenbüttel and of the on-site weather station [12]. The PV installations are composed of BP 585S modules and are connected to the grid with SMA inverters.

B. *Wind turbine model*

The wind turbine converts the kinetic energy coming from the wind into electrical. The fundamental algebraic equation that describes the relation between wind speed and electrical power extracted [14] is:

$$P_w=\frac{\rho}{2}\ c_p(\lambda)A_R v_w^3 \quad (3)$$

where: P_w is the power generated from the wind turbine (W), ρ is the energy density of the air in atmosphere (kg/m^3), c_p is the power coefficient, λ is the tip speed ratio (s^{-1}), v_w is the wind speed (m/sec), A_R is the swept area (m^2).

For a wind turbine with a stall regulation, as it is in this case study considered, the power coefficient c_p is estimated from the following equation [14]:

$$c_p(\lambda)=(46.4\ ((\frac{1}{\lambda}-0.01)-2))e^{-16.5\lambda-0.165} \quad (4)$$

The AC power output is then extracted after subtracting the losses of the inverter and the model has been evaluated and validated with data stemming from a wind turbine Micon M700 installed in Osterberg, Germany.

C. *Biogas unit with CHP model*

The production of bioenergy in this model is composed of two steps. In the first step the process of anaerobic digestion is simulated to describe the formation of biogas from substrate. In the second step the conversion of the biogas into electrical energy is performed. In this system the anaerobic digestion is modelled with a simplified Monod equation describing the formation of biogas with first-order kinetics [15]:

$$V(t)=V_{max}\ (\alpha\ k_h\ e^{-k_h\,t}+(1-\alpha)\ k_l\ e^{-k_l\,t}) \quad (5)$$

where: V_{max} is the mass-specific maximum volume of biogas that can be produced from the substrate ($\frac{m^3}{t}$), α is the part of rapidly degradable fraction of the substrate, k_h is the kinetics constant for the biogas formation from the rapidly degradable fraction (d^{-1}), k_l is the kinetics constant for the biogas formation from the slowly degradable fraction (d^{-1}).

Experimental data obtained from biogas kinetic tests, which have been performed at the Laboratory for Bioprocess Engineering of the Faculty of Supply Engineering at the Ostfalia University of Applied Sciences, as well as quasi-continuous biogas tests in laboratory scale (reactor volume: 12 l) were used to validate the model. The conversion of the biogas to electrical energy by a CHP unit is modelled considering the energy content of the gas resulting from the concentration of methane in the produced gas and considering the electrical efficiency of the CHP unit.

D. Lithium-ion battery model

Lithium ion batteries are considered a nascent technology in the field of energy storage and are currently preferred not only for small scale installations but also for utility scale solutions. In the literature several methods exist to model this battery type. In the frame of this study the battery is designed based on the equivalent circuit-based models. Equivalent circuit-based models are an optimal solution for designing real-time electrical models when a quasi-accurate but also not time-consuming solution is sought [16]. Since in this case a systemic analysis over years is pursued, a more complex model would demand high computing time. It was thus decided to apply the R_{int} model. This belongs to the equivalent-circuit model category and is favored since it is composed of fewer components than other similar models and thus demands less computation time per cycle. In particular, the R_{int} model (Fig. 2) uses an ideal voltage source to represent the open circuit voltage and an internal resistance to quantify the systemic losses.

The internal resistance as well as the Open Circuit voltage voltage (U_{OCV}) have been expressed as functions of the State of Charge (SOC) of the battery and their values are based on constant current curves, obtained from charge and discharge tests and measurements on a 48 V/ 135 Ah LiFePO4 battery. The SOC of the battery is consequently expressed as a fraction of the stored energy to the maximum energy capacity of the battery and was in each time step calculated based on the:

$$SOC_t = SOC_o + \frac{1}{C}\int_0^t i dt \qquad (6)$$

where: SOC_t is the State of Charge at time step t, SOC_o is the State of Charge at time step 0, C is the battery capacity (Ah), i is the current that flows in or out of the battery (A).

In addition, the aging effect of the battery has been also integrated in the above designed electrochemical model. Stroe et al. [18] examined experimentally the degradation behavior of a lithium ion battery. According to their study the battery capacity is linearly by 20 % reduced after a period of 10 years [18]. This aging factor is subsequently adopted in the abovementioned R_{int} model and the capacity of the battery is in each simulation step respectively reduced. Apart from the battery itself, losses from the peripheral components, as the inverter is, have also been taken into account. Therefore, the inverter efficiency was also considered in the modelling part and the complete system has been validated based on the measured data extracted from tests performed on the LiFePO4 battery of the CALB USA Inc. manufacturer with cell capacity of 72 Ah and 3.2 V nominal voltage, which exists at the premises of the Laboratory for Electrical Engineering and Renewable Energy Technology of the Ostfalia University of Applied Sciences. Further auxiliary systems were at this point left out of this system analysis.

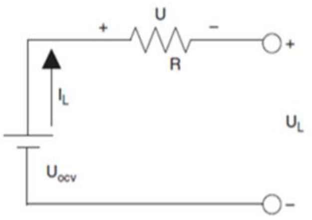

Fig. 2. Circuit structure of R_{int} model [17]

E. Ideal battery model

The ideal battery model is implemented with a constant voltage source and capacity, reduced only by an efficiency grade of 0.9 both for charging and discharging process, while the internal performance is not considered at all.

F. Description of the three cities and their load profiles

The three selected regions have indicatively been chosen as three medium-sized cities which are located in north, central and south Germany with upper target to examine the sizing of the battery system if the renewable energy portfolio is the same for each one. In particular, the north city is Quickborn, the central one is Waltershausen and the south one is Lindau and are shown also in Fig. 3.

For each city the real measured load curves for 2017 have been acquired from the local energy supplier. It should be stressed out that the load demand referred to customers not charged on a capacity basis by means of load profiles (only house load and small commercial customers are integrated) and that they are not standard or forecasted load profiles but real measured values at quarter hour intervals.

Since the annual load demand was not identical for every city and in order to get reliable results by comparing homogenous entities the domestic load curves of the three medium-sized cities have been normalized to the annual demand (1000 MWh/a).

Respectively the renewable facilities which are represented from validated models are respectively sized and scaled up so that the security of supply is always ensured assuming that the electricity production covers exactly the load demand. The energy mix for each city is thus composed of 20 % energy from photovoltaics, 40 % from biogas generation and 40 % from wind energy. This allocation is based on the current share of photovoltaic and wind energy on the renewable energy mix in Germany and the biogas fraction is respectively scaled up so as to reach the complete autarky in the electricity sector [19]. In Table I a synoptic overview of the input data to the model is presented whereas a more detailed description of the holistic system and the control unit is presented in [20].

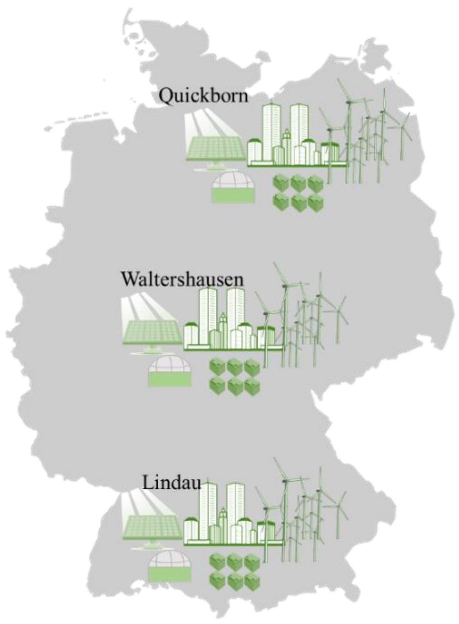

Fig. 3. Map of Germany with the three case study regions (Quickborn (North Germany), Waltershausen (Central City), Lindau (South City))

Similarly, radiation, temperature and wind velocity data for the three different cities have been obtained from the German Meteorological Service (Deutscher Wetterdienst - DWD) and from local on-site weather stations. The data have been used as input vectors for the wind and PV models, so as to calculate at each time step the respective locally produced renewable energy.

Annual simulations for the reference year 2017 have been performed in an island mode operation. The excess of the locally produced energy is stored temporarily in the battery and when the local generation cannot cover the demand the stored amount is retrieved. The simulations have been conducted for each city, with input load and weather data of the respective region.

In addition, the same simulations have been repeated but in this case the battery model has been replaced from an ideal voltage source and the battery characteristics have been completely neglected. Target is to examine the impact of the application of a simplified model on the performance of the system.

III. Results

The minimum battery capacity is estimated for each case study based on dynamic simulations as a difference between the minimum and maximum capacity that arises during the annual simulations. In Fig. 3 the SOC course during the year is illustrated. It is obvious for all the cases that till February 2017 when the insolation levels are still low the battery is being almost steadily discharged. Subsequently, the battery is being again charged and then again discharged due to a sudden drop to temperature at the end of April, which led to a rise in load demand and a restricted power generation. In summer months the SOC course has a rising tendency, since the production exceeds the demand followed again from a downward trend at the last quarter of the year. The difference on the start and end value of the SOC is due to the losses which are also integrated in the models but cannot be predefined so as to scale up the facilities respectively.

In the first quarter of 2017 the storage system of the north city undergoes the sharpest drop, probably due to the harder weather conditions in the north part of Germany. However, it is this city that has the higher amount of energy still stored at the end of the year. An explanation to this outcome is that although the share of the renewables is the same in each case study, the north city succeeds a higher power generation after the first half of the year due to the higher wind speed values that are not so strongly seasonally dependent.

The central city shows a moderate SOC course since its location favors an energy mix that is more balanced than the other two case studies. “Dark doldrum” periods affect equally the SOC of the lithium ion battery in every city. Though when only one of the two intermittent power sources’ production is drastically reduced then the second one probably stabilizes the energy deficit for the central city. The biogas production remains constant over the year and hence is not commented on the results.

It is also noticed that the SOC values of the realistic battery model are always lower than those of the ideal battery source. This is an expected output since all the parasitic losses and the aging effect, which deteriorate substantially the battery performance, have been completely neglected by the ideal battery model.

Simulation results indicate also that the autarky in the electricity sector can be feasible, but the capacity is underestimated up to 30 %, as indicated in Table II, if the aging effect of the battery is neglected and the efficiency grade is considered steady. The importance of the use of a realistic model is thus more than evident if reliable conclusions must be drawn. Nevertheless, the battery capacity value remains high in every case, indicating the current unfavorable character of a self-sufficient solution, when the power production is exactly the same as the demand. In cases that the renewable energy production considerably exceeds the load demand then the storage system could be respectively significantly reduced and could be a feasible and plausible option. In addition, seasonality urges high values of battery capacity (great amounts of energy must be stored during summer to be available again in winter). To this extent the cycle estimation is considered not applicable as a metric, since the battery does not perform periodically full cycles.

TABLE I. PARAMETERS OVERVIEW IN SIMULINK MODEL

	Variable Name	***Standard Value***	***Description***
RES Share in Energy Mix	PartPV	0.2	Share of the renewables in the energy mix to cover the local electricity demand. The facilities are respectively scaled up and normalized by dividing the resulting power of each with the annual load demand.
	PartW	0.4	
	PartBG	0.4	
Battery	BattStart	0.9	Initial Value of State of Charge
	η_{Char} resp. $\eta_{Dischar}$	0.9 & 0.9	Constant efficiency grade of the Lithium ion ideal battery model by charging and discharging process
Biogas	$\eta_{CHP,el}$	0.4	Electrical efficiency grade of the CHP
	$H_{I,\ CH4}$	9.968 kWh/m³	Calorific Value of methane
	$m_{Substrate}$	3,434 t_{FM}/a	Mass of substrate for the biogas production
	V_{max}	224 m^3/t_{FM}	Mass-specific maximum volume of biogas that can be produced from the substrate
	α	0.7091	Part of rapidly degradable fraction of the substrate
	k_h.& k_l	0.3586 d^{-1} & 0.0615 d^{-1}	Kinetics constant for the biogas formation from the rapidly resp- slowly degradable fraction
	φ_{CH4}	0.52	Methane content in the produced biogas (V_{CH4}/V_{Biogas})
PV Plant	P_peak	85 W	Rated power of one PV module
	NOCT	47 °C	Nominal Operation Cell Temperature
	β	0.005/°C	Temperature losses coefficient
	$\eta_{ext\ losses}$	9 %	Losses for modules mismatching, diodes and dirt
Wind Turbine	Vcut-in	3.6 m/sec	Cut-in wind speed
	Vcut-off	25 m/sec	Cut-off wind speed
	Vnom	14 m/sec	Nominal wind speed
	R	14.8 m	Rotor blade radius
	Pnom	250 kW	Rate generator power
	n_{wind}	0.82	Inverter Efficiency of the wind turbine
	h	36 m	Hub Height

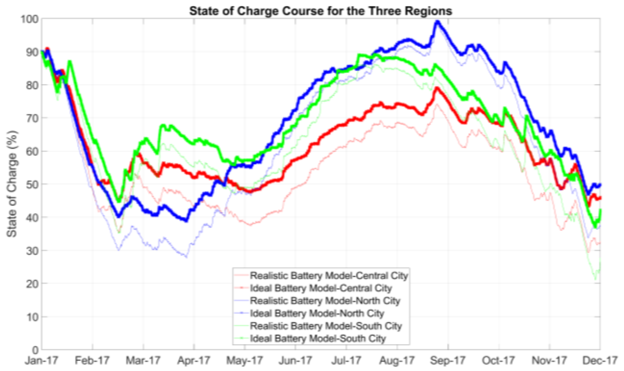

Fig. 4. State of Charge course after annual simulation with real load and weather data for the three case study regions

TABLE II. CALCULATED BATTERY CAPACITY

Total Battery Capacity	*Ideal Battery Model*	*Realistic Battery Model*	*Percentage Error (%)*
North City	129.9 MWh	158.6 MWh	22.1 %
Central City	115 MWh	149.7 MWh	30.2 %
South City	126.5 MWh	165 MWh	30.4 %

Moreover, if we concentrate on the absolute values when considering the overall system with the ideal voltage source as the storage facility, the minimum battery capacity is needed for the central city while the south city needs a 10 % larger battery and the north 13 % greater than the central region. When the realistic model is used for estimating the minimal battery capacity then again the central city demands a lower battery capacity while in this case the south city demands a 10% higher battery capacity and the north city almost the same as the central city. The switch of the higher capacity demand between north and south city if the ideal battery model is replaced from a realistic one, is due to the fact that the efficiency of the realistic and validated battery model varies depending on the current SOC.

The next research step to be addressed is to consider different concepts which would contribute to the decrease of the storage demand. Further research should include an economical evaluation (cost analysis) of such concepts and an examination of the seasonal storage capacity variation.

IV. CONCLUSIONS

In the current study a holistic system composed of renewable energy sources and a storage system, which is in this case a lithium ion battery, is evaluated in an island operation for three case study regions. In addition, the added value of the use of a realistic battery model instead of an ideal one is demonstrated. Annual dynamic simulations have been also performed and the minimum battery capacity is estimated for each case study. The results show that the application of validated models which capture the non-ideal performance of a lithium ion battery is considered as essential if realistic solutions are desired, since the capacity may be up to 30% underestimated. Furthermore, it is identified from the outcomes that the calculated battery capacity is higher for the south city due to the solar power variability as an outcome of the seasonal variation.

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REFERENCES

[1] W. Frohwitter, Ein Gemeinschaftsprojekt der Energiequelle GmbH, der Stadt Treuenbrietzen und den Feldheimer Bürgerinnen und Bürger, Energiequelle GmbH
[2] A. Zengerle, M. Lucke, A. Armstorfer, A. Hammer, and A. Amthor, Inselnetzversuch Wildpoldsried, 30.08.2017, IREN2.
[3] Universität Kassel, „Energieautarke Siedlung: Alheim auf dem Weg zu einer höheren Selbstversorgung - Projekt Energieautarke Siedlung“, Alheim.
[4] M. Heinrichs, Siemens liefert Batteriespeicher an Stadtwerke Wunsiedel, EW Magazin für die Energiewirtschaft, 2016.
[5] S. Hartard, “Peace and Security by Resources Self-Subsistence Strategies”, in: Competition and Conflicts on Resource Use. Natural Resource Management and Policy, vol 46, S. Hartard and W. Liebert, Eds. Cham: Springer, 2015
[6] M. Popp,Speicherbedarf bei einer Stromversorgung mit erneuerbaren Energien. Berlin, Heidelberg: Springer-Verlag Berlin Heidelberg, 2010.
[7] S. Peter, Modellierung einer vollständig auf erneuerbaren Energien basierenden Stromerzeugung im Jahr 2050 in autarken, dezentralen Strukturen, Umweltbundesamt, Dessau-Roßlau, 2013.
[8] S. Silvan Faßbender, and E. Waffenschmidt, “Options for an autarkic operation of a communal power grid using a battery and renewable energies”, [12th International Renewable Energy Storage Conference (IRES 2018), Düsseldorf, 2018].
[9] SRU, Sachverständigenrat für Umweltfragen: 100% erneuerbare Stromversorgung bis 2050: klimaverträglich, sicher, bezahlbar, Berlin: Erich Schmidt Verlag GmbH & Co. KG, 2010.
[10] T. Klaus, C, Vollmer, K. Werner, H. Lehmann, and K. Müschen, Energieziel 2050: 100% Strom aus erneuerbaren Quellen, Umweltbundesamt, Dessau-Roßlau, 2010.
[11] E. Boggasch, M. Heiser, and R.D. Patzelt, Busgestütztes Energiemanagement eines Verbundes regenerativer Energieanlagen am Institut für Verbrennungstechnik und Prozessautomation an der Fachhochschule Braunschweig/Wolfenbüttel, AGIP-Forschungsvorhaben F.A.-Nr. 2003.525 Report, Wolfenbüttel, Germany, 2006.
[12] S. Dimopoulou, E. Boggasch, and A. Rausch, “A comparative study of diffuse irradiance models on inclined surfaces for Wolfenbuettel”, November 2014 [4th Solar Integration Workshop, Berlin, Germany, November 2014].
[13] O. Perpiñan, E. Lorenzo, and M. A. Castro, “On the calculation of energy produced by a PV grid-connected system”, Prog Photovoltaics: Research and Applications, vol. 15, pp. 265–274, May 2007.
[14] J.G. Slootweg, H. Polinder, and W.L. Kling, “Initialization of Wind Turbine Models in Power System Dynamics Simulations”, 2001 IEEE Porto Power Tech Proceedings (Cat. No.01EX502), Porto, Portugal, vol. 4, 2001 [2001 IEEE Porto Power Tech Conference, Porto, Portugal, 2001].
[15] A. Converti, A. Del Borghi, M. Zilli, S Arni,. And M. Del Borghi, “Anaerobic digestion of the vegetable fraction of municipal refuses: mesophilic versus thermophilic conditions”, Bioprocess Eng, vol. 21, pp. 371 – 376, 1999.
[16] M. R. Jongerden, and B. R. H. M. Haverkort, „Battery Modeling. (CTIT Technical Report Series; No. TR-CTIT-08-01)”, Enschede: Design and Analysis of Communication Systems (DACS), 2008.
[17] J. Jiang, and C. Zhang, Fundamentals and applications of lithium-ion batteries in electric drive vehicles, Singapore: John Wiley & Sons Singapore Pte. Ltd., 2015.

[18] D. I. Stroe, M. J. Swierczynski, A-I. Stroe, R. Teodorescu, R. Lærke, and P. C. Kjær, Degradation Behaviour of Lithium-Ion Batteries based on Field Measured Frequency Regulation Mission Profile, Proceedings of the 2015 IEEE Energy Conversion Congress and Exposition (ECCE), pp. 14 -21, 2015 [2015 IEEE Energy Conversion Congress and Exposition (ECCE) Montreal, QC, pp. 14 -21, 2015].

[19] Umweltbundesamt, "Strommix in Deutschland - Nettostromerzeugung in Deutschland 2016 nach Primärenergieträgern", Umweltbundesamt 2017.

[20] J.Kohl, F. Bozankaya, S. Drescher-Hartung, T. Ahrens, and C. Klapproth, "Sustainable management of energy supply including the use of waste-based biogas processes", in: Detritus, Multidisciplinary Journal for Waste Resources and Residues, vol. 02 – 2018, R. Cossu, Eds. Padova: Cisa Publisher, 2018, pp. 142-149.