EVS32 **Symposium**
Lyon, France, May 19-22, 2019

Automotive batteries in hybrid energy systems

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Executive Summary

The energy transition has created various challenges and new markets in Germany. Due to the increase in fluctuating energy in the German power grid and the decommissioning of conventional power plants, u.a. the stability of the electrical supply network put to the test. In order to be able to continue providing security of supply, various solutions are being developed by the various actors. One approach is to integrate battery storage systems into the electrical utility grid. The battery storage can provide network-related applications and thus serve as a flexibility option. In this work, the technical and economic aspects of a battery storage in a municipal environment are analyzed in more detail. In order to evaluate the economy of the battery storage system, an Excel tool is developed. This tool provides a quick overview of the most important key figures

The total cost of ownership of batteries is calculated from different viewpoints, but mainly from the perspective of the selected small business prosumer. From the supplier cost perspective, all costs of procurement and operation of a Smart Storage System shall be evaluated. Benefits of the Smart Storage increase by means of near “continuous” self-usage of the self-generated energy in conjunction with the supplier net stability on AC side by means of buffering of the energy from electricity cost optimization.

Keywords: Battery Storage System, Renewable Energy, Primary Control Power, Peak Load Capacity, Net present value method, Total Cost of Ownership, Second-life batteries

1 Technical-economic analysis of the integration of a (2nd life-) battery storage into a hybrid municipal energy system

The energy transition has created various challenges and new markets in Germany. Due to the increase in fluctuating energy in the German power grid and the decommissioning of conventional power plants, u.a. the stability of the electrical supply network put to the test. In order to be able to continue providing security of supply, various solutions are being developed by the various actors. One approach is to integrate battery storage systems into the electrical utility grid. The battery storage can provide network-related applications and thus serve as a flexibility option. In this work, the technical and economic aspects of a battery storage in a municipal environment are analyzed in more detail. In order to evaluate the economy of the battery storage system, an Excel tool is developed. This tool provides a quick overview of the most important key figures

1.1 Introduction

Renewable energies have been playing an important role for quite some time, but first the setting of the "20-20-20" targets at the European level in 2009 and the disaster in Fukushima in 2011, which resulted in the withdrawal of nuclear energy, as decided by Federal Governments, has accelerated the further expansion of renewable energies. The "20-20-20" targets, officially "Climate and Energy Pact 2020", focus on reducing greenhouse gas emissions (by 20% compared to 1990 levels), increasing energy efficiency (by

20%) and expanding energy efficiency renewable energy sources (share of 20% of gross final energy consumption in EU should come from renewable sources) by 2020. In addition to the objectives for a sustainable energy supply and the protection of the environment, which are regulated in the Climate and Energy Pact 2020, national standards, among others, also apply (e.g. the Law for the Development of Renewable Energies (EEG)). The EEG envisages 40% to 45% of gross electricity generation in Germany by 2025. This proportion should then be increased to at least 80% by 2050. Gross electricity generation from renewable energies in Germany in 2017 amounted to approximately 217 TWh, which represents a share of renewable energies of approximately 33%.

With the expected rapid take-up of electric vehicles in Europe in the coming 5 to 10 years, the suppliers must reshape its technical strategy and better redistribute the grid load during peak-power consumption periods. Previously, the suppliers achieved this largely through increased generation capacity, improved efficiency; better overall system monitoring, upgraded grid infrastructure, and promoting intelligent appliance remote management. However, ultimately in many situations load distribution / peak shaving in the form of power buffering with battery storage will be required.

As previously stated, the expected rapid take-up of electric vehicles will later provide a considerable source of second-life high-energy lithium-ion batteries. In order to guarantee reliable vehicle performance and to retain customer satisfaction, the majority of OEM's will decommission their electric vehicle batteries, when the battery nameplate capacity (NPC) falls to at least less than 70 %. Consequently, the suppliers propose to offer the vehicle manufactures a form of energy partnership. Whereby, the remaining usable energy capacity (i.e. 70 %) of the decommissioned motive batteries could acquire a new lease of life i.e. "second-life" as stationary peak shaving batteries for selected small business consumers.

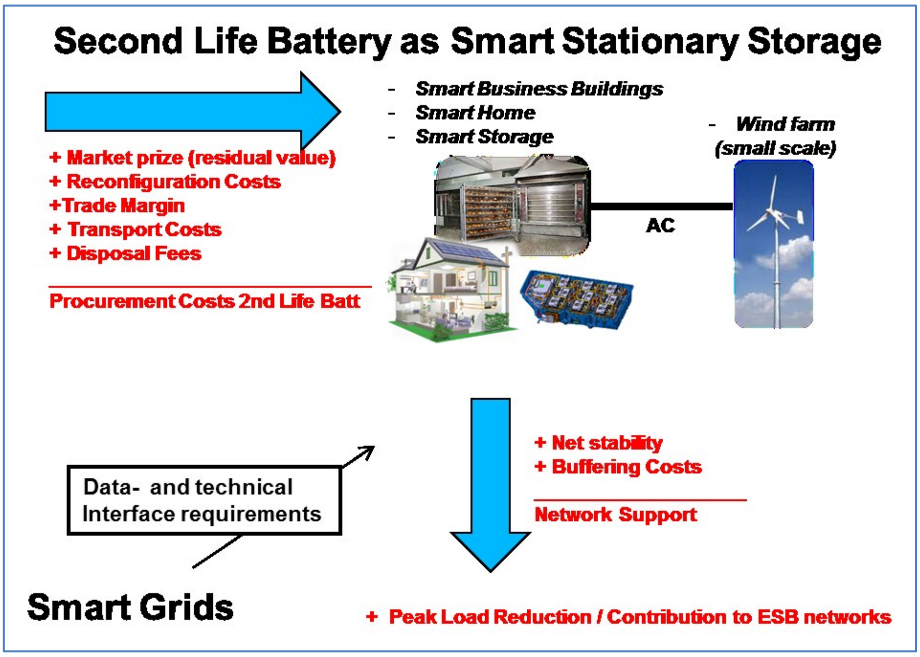


Figure 1: Second Life Battery as Smart Stationary Storage

Ultimately, the total cost of ownership (total cost of ownership) of the lithium-ion motive battery must be distributed across the greatest number of interested parties i.e. OEMs, car owners, and small business consumers. This strategy could assist in reducing and spreading the initial first time purchase cost of the motive lithium-ion battery and the following topics addressed:

- the calculation of the total cost of ownership of the motive battery and facility life cycle
- the development of system wide / grid monitoring and management technology/strategy
- the alignment of the technical requirements of the battery / OEM / supplier / consumer
- the applied integration of a second-life battery within a dynamic power grid environment
- the safe and reliable operation of such a complex facility in the field

2 Goals and structure

The present paper deals with the integration of a communal store into a small commune. This work deals both with the simulation of a stationary battery storage system, which is to be used as a municipal storage for a small community, as well as with the economics of the considered battery storage system. In addition, this work will also highlight the legal and legal design framework for battery storage systems.

The aim of the simulation is to map the energy supply network in the municipality and to carry out a corresponding design of a stationary battery storage system. Furthermore, various applications for a stationary battery storage are considered and investigated.

The findings gained here should then be used for the economic analysis. The economy of communal storage will be considered using the capital value method and a total cost of ownership calculation. For the consideration of the economy a tool will be developed and the economic efficiency of the communal storage will be calculated.

Research questions:

• Which criteria are the decisive parameters in order to be able to consider a storage economically?

• Which legal and legal framework must be observed? How does the storage have to be dimensioned and what conditions does the storage have to fulfill in order to work economically? Can a store operate economically in the sample region?

• How could a business model that focuses on the integration of stationary battery storage within the model area be structured?

Objectives of this paper:

• Working out the key criteria for calculating the economics of a stationary battery storage system

• Development of a tool for evaluating the economy of a stationary battery storage using the NPV method and total cost of ownership method.

3 Installed energy storages and future demand in Germany

An overview of the installed energy storages in Germany is provided by the DOE Global Energy Storage Database. This database is managed by the US Department of Energy (DOE) and lists all energy storages by type, installed power, operational status and location.

Table 1: Installed energy storages in Germany

Type of energy storage	Number of operational energy storages	Installed Power in GW
Pumped Hydro Storage Power Plant	27	6.2
Battery storages	36	0.307
Redox flow batteries	5	0.001
Hydrogen storage	6	0.02
Flywheel	2	0.4
Compressed air storage	1	0.29
Total	**77**	**Approx.. 6.9 GW**

It should be noted all operational domestic battery storage systems in Germany are regarded as one large battery storage system in the DOE Global Energy Storage database. According to the aforementioned database, a total power of approximately 6.9 GW can be provided by the installed and operating energy storages in Germany. The share of battery storage systems accounts for 4.4 % of the installed storage capacity. Most of the battery storage included in the database are large battery storage systems that are not intended for domestic use. The following figure shows the location of most operational large-scale battery storage systems in Germany. The location of the individual battery storage systems also provides an interesting insight in the main economic revenues. Battery storage systems, which are situated near the borders, are mainly used for arbitrage deals. Although most battery storage systems in Germany are used for providing primary control power or are used for research purposes, and are thus located near industrial sites or near research facilities. In total, battery storage systems with a capacity of nearly 250 MW are prequalified for the provision of primary control power.

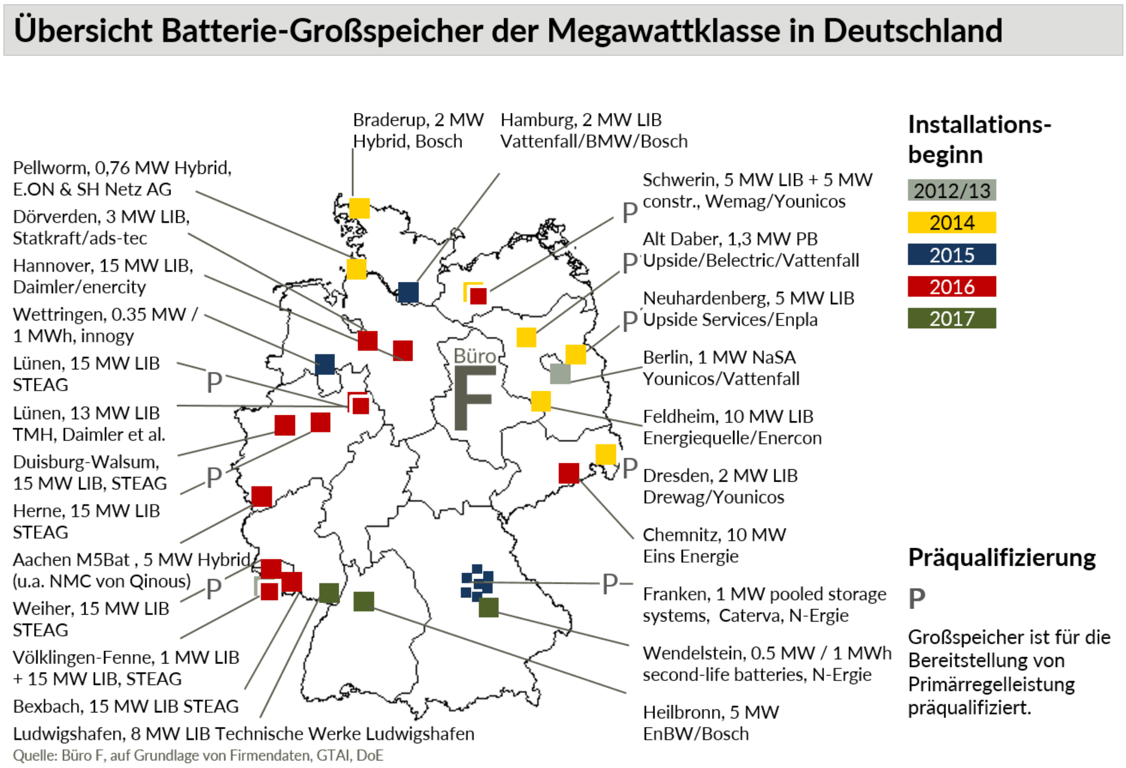


Figure 2: Overview of large-scale battery storage systems in Germany. Source: Büro F

The demand for energy storage in Germany at the present time can be estimated as rather low. Also in the future, especially short-term storage should have a hard time against other flexibility options. The need for battery storage will depend on the individual need of individual persons / companies for individual load shifting or self-consumption optimization, as well as an uninterruptible power supply. In some cases, a battery storage can slow down the network expansion or completely prevent it. Furthermore, the requirement for battery storage devices will mainly depend on the price development with regard to the investment costs.

4 Fields of application and markets for battery storage in Germany

Battery storage systems can be used in many ways and have therefore a relatively large field of application. Battery storages are defined as short-term storage. The typical application areas and marketing possibilities of battery storage systems are briefly listed in the following table.

Application or marketing opportunity	Explanation
Power and electricity trading	arbitrage business by trading electricity at the stock exchange
Provision of control or balancing power	Battery storage can be pre-qualified for the provision of primary control power and participate in the control energy market.
Redispatch	Uptake of excess energy from the overloaded network section and release of energy at the underserved network section by means of a network of virtual battery pools
Provision of reactive power	To compensate for voltage differences caused by an imbalance of active and reactive power. Battery storage and their inverters can be used as a phase shifter and restore balance.
Ensuring the voltage quality	Compensating for voltage fluctuations caused by load fluctuations or other disturbing influences
Black start capability	Provide power to grid-related power plants to restore power in the event of a grid-wide power outage.
Compensation of forecast errors (outside the provision of control power)	Uptake or release of energy from the grid when there are forecast errors in the estimation of the feed-in and feed-out load.
Avoidance or delay of grid expansion	Mains battery driving and home battery storage can be used to avoid or delay grid removal at low voltage levels
Peak shaving	Smoothing of peak loads
Uninterruptible power supply (UPS)	Thanks to the stored energy, battery storage systems can provide short-term power to critical infrastructures such as hospitals or computer centers even during a power outage
Electromobility	Battery storage systems are used in electric vehicles as "energy reservoir". Currently, battery storage in electric vehicles can only be used as consumers. By bi-directional charging (infeed and outfeed of electricity from the vehicle battery), the battery storage in e-vehicles will also serve as a supplier of energy in times of electricity shortage in the grid

There are several ways to group the potential market of battery storage. One way to perform a categorization is based on the consideration of the application of the battery storage system. A classification is made whether the selected application of the battery storage is market-oriented or grid-oriented. In grid-oriented applications of battery storage, the focus is on the grid performance of the battery storage, i.e there are predominantly system services, such as the provision of control power, which increases network quality and security of supply. If the battery storage system is market-oriented, the use of the battery storage unit will focus on economic optimization, and not to network efficiency.

Another possibility is to divide the market for battery storage according to market organization: uniform market, non-uniform market and no market. A unified market is understood to mean a market that, for example, controls supply and demand through its own transaction platform (for example, the standard power market). The market is non-discriminatory and free. A non-unitary market encompasses all services and applications that can be traded bilaterally and priced individually (including, for example, the provision of uninterruptible power supplies). Other uses of a battery storage, such as avoiding or delaying grid expansion is not directly priced and therefore does not constitute a market. The following table groups the previously mentioned use and marketing possibilities of battery storage systems with regard to the market organization and the orientation of the application.

Table 2. Classification of applications for battery storage according to mission orientation and market organization

			Market organisation		
			Uniform market	**Non-uniform market**	**No market**
Orientation of the application	**Market-oriented**		Power and electricity trading	Uninterruptible power supply	Peak shaving
	Grid-oriented	**System-wide grid application**	Provision of control or balancing power	Black start capability Provision of reactive power Redispatch	-
		Local grid application	-	Compensation of forecast errors	Avoidance or delay of grid expansion Ensuring the voltage quality

It should be noted that, due to unbundling requirements, network operators are not allowed to offer any market-oriented applications of their large-scale battery storage system. Private individuals who operate a battery home storage, can only enter the market if they form so-called battery storage swarms. For private individuals, the main application of the battery house memory is self-consumption optimization in combination with a photovoltaic system. Companies and businesses often also use a battery storage to increase their own consumption or to cut peak loads.

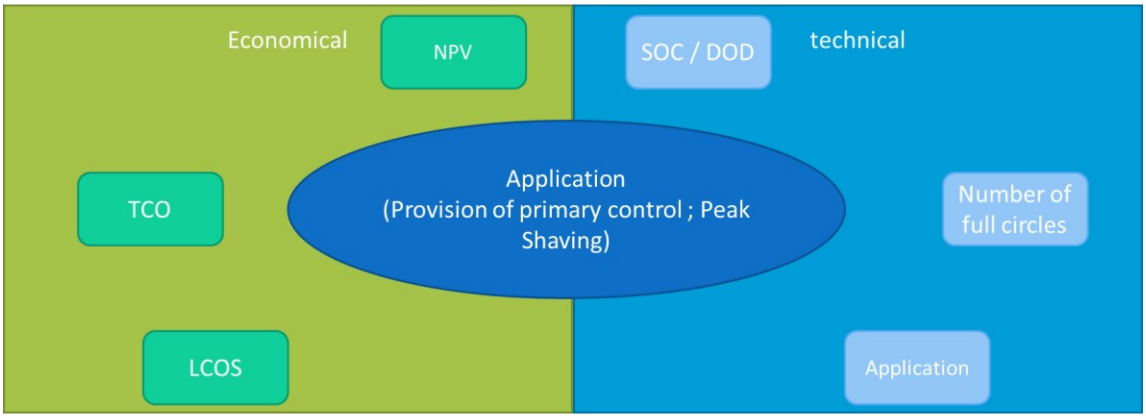
As operator for a large municipal battery storage all operators mentioned in the following table come into question. The business model to be examined in this work is also known as a district model. The large battery storage system is integrated centrally into the local energy grid and used by various producers and consumers for the injection or withdrawal of energy.

Operator	Type of battery storage	Possible applications
Individuals	Household battery storage system	Self-consumption of energy Peak Shaving Forming of a battery swar to provide primary power control
Companies, Commercial institutions	Industrial battery storage system	All market- and grid-oriented applications
Municipality	Industrial battery storage system	All market- and grid-oriented applications
Grid operator	Industrial battery storage system	All grid-oriented applications

5 Method

It should be noted in advance that the economic value of the battery storage is considered from the point of view of the battery operator. In determining the parameters and calculating the cost-effectiveness of the battery storage, the use of a large-scale lithium-ion battery is assumed. This decision is based on the fact that lithium-ion batteries are frequently used for the fields of application to be investigated here, and depicts the state of the art.

The power and energy flows are respectively related to the battery bulk storage, i. A storage of energy is expressed by a positive sign and a withdrawal of energy by a negative sign. The removal or supply of energy and power is presented at 15-minute intervals.The economic section describes the various methods used in this workin order to be able to economically assess the use of a large battery storage in a defined area of application.



In this work, the provision of primary reserve control and peak shaving are examined separately.

The aim of the tools is to give a first overview of the economy of a battery storage in the application-specific case. It is not the goal to present a comprehensive picture of all possible applications of a battery storage in the tools. The tools only look at the "Provision of primary reserve control" and "Peak load shaving" applications. All other uses are not part of these tools and therefore are not included in the economy. The profitability analysis is carried out from the point of view of the large battery storage operator. The economy of the battery storage is determined by the capital value method. The TCO calculation shows the cost of the battery storage over the lifetime of the memory.

The technical calculations, such as the calculation of the state of charge or the number of full cycles of the battery accumulator, are performed from the point of view of the battery accumulator and not from the perspective of the power grid. This means that an uptake of power and energy is described by a positive sign, while the output of energy and power from the large battery storage is expressed by a negative sign.

All calculations are performed at 15-minute intervals.

6 Total cost of ownership of 2nd Source Automotive Traction Batteries

A number of potential candidates (small business consumers) for a pilot project that would test interactions between energy generation, storage, and sink technologies in the field have been identified. Furthermore, the selected small business consumer will act as a benchmark application in the examination of the total cost of ownership for the utilization of decommissioned (70 % NPC) motive second-life batteries for stationary peak shaving applications. Such a project would enable the supplier to better specify the mechanical, electrical, functional second-life battery requirements and accurately cost their end of life cost. This would ultimately make E-mobility accessible to all social strata.

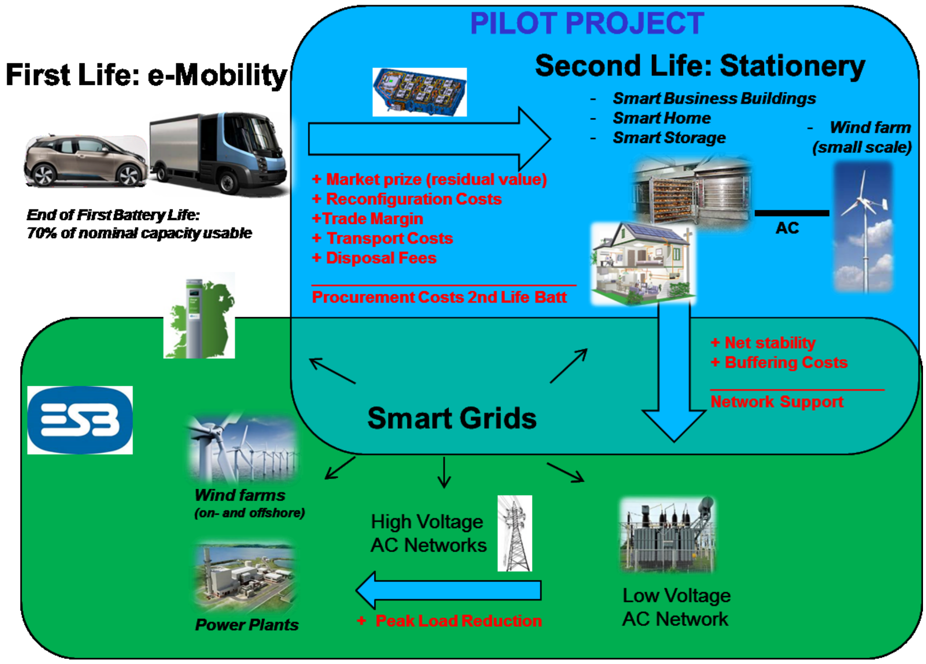


Figure 3:Life cycle ofa mobile battery storage system

Historically, a supplier has two types of energy consumer: (1) domestic and (2) industrial consumer with each having their own individual energy profiles. However, the supplier has identified a third energy producer / consumer (prosumer) that is neither a high energy industrial (> 50 kW) consumer or a moderate to low energy domestic consumer (< 10 kW). This “prosumer” not only consumes energy but also feeds self-generated energy into the grid by means of solar, wave, or wind. This so-called “prosumer” is often a commercial small business consumer (10 – 50 kW).

The domestic consumer has a relatively regular and predictable peak usage pattern. Equally, the high-energy industrial consumer predictable; largely manage their energy needs self-sufficiently by means of on-site high voltage sub-station facilities. The commercial small business consumer is often the most unpredictable asymmetric power producer / consumer. The commercial small business power consumption is often too low to benefit from the “flat-rate” for energy of the industrial consumer. This means they often pay the full rate energy rate.

The small business consumer is punished for their unpredictable production / consumption behavior. Increasingly, the small business prosumer and the domestic consumer will merge (10 – 20 kW) due to their increasing usage of electric vehicles and other high-energy devices. Therefore, action is required now develop technologies and strategies to cope with this asymmetric energy behavior.

Already, a number of mid-level power consumers with a small electric vehicle fleet are in daily operation. However, the power requirements are currently not large enough to justify an industrial power supply (sub-station). Therefore, the supplier wishes to achieve three key goals in the proposed project:

1) Evaluate the total cost of ownership of second-life lithium-ion battery.

2) Offer an attractive integrated energy management concept to “prosumer” small business clients.

3) Redistribute and improve grid stability by of shifting the peak customer power consumption off grid and onto alternative energy storage devices.

7 Conclusion and forecast

The following conclusions can be derived from the analysis:

7.1 Municipal storages

• Large storage can provide primary control reserve

• Primary control charges depending on the grid frequency

  o This can lead to the capacity limits of the memory being reached

  o In order to remain operational, network behavior of the memory may then occur (store energy when high consumption)

• increase in capacity -> increase in investment costs

• Revenues remain the same, but profitability drops (because the extra capacity only serves to stay in operating mode)

• Alternative

  o Pool with other primary control reserveprovisioning facilities

  o Combining the memory with a flexible consumer (power-to-heat)

  o Combined operation of storage and industrial plant

• Does it make sense to install a battery storage to provide primary control reservein communities?

  o Operator: Municipality

   Rather no, the municipality would have to found a society for it. Only meaningful if flexible consumers or producers are already in municipal hands (such as: CHP or P2H)

  o Operator: industry / trade

   Rather, yes, but primary control reserve delivery no longer brings revenue like in the past

• Peak Shaving:

• Battery storage suitable for peak loads

• Does it make sense to run a battery storage for peak load in municipalities?

  o Operator: Municipality

Rather less, if only to cut peaks at their own farms (however, which municipalities have this problem by approaching machines?) Relief of the ONT? Avoidance of replacement RONT or network expansion

It only really pays off if flexible consumers and producers are present in the network

o Operator: industry / trade

Useful when energy spikes occur by starting up machines, etc. or other energy-intensive applications; Reduces the performance price

• Battery storage is suitable for running these applications

• Battery storage cost drivers are:

o investment costs

o electricity costs, if the electricity is not obtained from own generation facilities (where, is the proof)

• Economy is given / not given

Outlook:

o Economy should increase if a "multiple use" of the memory is allowed -> horizontal stacking of applications

o Further price decline for lithium batteries expected -> lowers the investment costs

o Depending on the political will and the regional NIMBY movement, as already mentioned in the paper, no major needs for battery large storage are to be expected. They are only used there singularly to relieve the power supply network at the specific point of view.

7.2 Second-life of automotive traction batteries

- Small Business Customer Evaluation and Requirements Phase
  a) Total cost of ownership calculation
  b) Analysis of second-life decommissioned motive batteries i.e. old vs. new battery
  c) Specification requirements and system architecture of a selected case study
     i.e. simulation model, software, hardware, communication, operational and monitoring requirements.
  d) Analysis of second-life battery recommissioning process.
  e) Specification of design and safety protocols for second-life batteries with reference to the OEM manufacturers.
  f) Final selection of case study application
- Ramp- up Phase
  a) Costing, assembly, and integration of specified components for pilot project facility.
  b) Starting of data collection and profile analysis.

- Monitoring and evaluation of test system data on- and offline.

Authors

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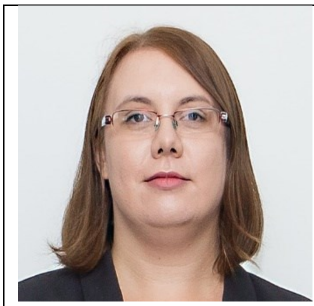	<u>Professional Background:</u> 2018 -now ACTARON, Project manager storage systems and innovative energy technologies 2013-2013 ENNI Energie & Umwelt Niederrhein GmbH Corporate Communications, Internship <u>Education:</u> 2015-2018 Hochschule Ruhr-West Bottrop M.Sc. Industrial Engineering Energy Systems 2011-2015 Hochschule Rhein-Waal, Kamp-Lintfort B.Sc. Environment and Energy

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	robotics