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Markets for Battery Storage

Sub-sector analysis on the market potential for battery storage in Tanzania

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Currency

1 USD	=	TZS 1,903.6 (March 2015)
1 EUR	=	TZS 2,041.5 (March 2015)

Measurement

W	Watt	Wp	Watt peak	Wh	Watt hour
kW	Kilowatt	kWp	Kilowatt peak	kWh	Kilowatt hour
MW	Megawatt	MWp	Megawatt peak	MWh	Megawatt hour
GW	Gigawatt	GWp	Gigawatt peak	GWh	Gigawatt hour

List of Acronyms

AC	Alternating current
AHK	German Chambers of Commerce
BSW Solar	German Solar Association
BVES	German Energy Storage Association
CAES	Compressed air energy storage
CAPEX	Capital expenditures
DC	Direct current
DoD	Depth of discharge
EAPP	East African power pool
EUR	Euro
EWURA	Energy and Water Utilities Regulatory Authority
F	Frequency
GDP	Gross domestic product
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GoT	Government of Tanzania
GTAI	Germany Trade and Invest
Hz	Hertz
IPP	Independent power producer
kW	Kilowatt
LAB	Lead-acid battery
LCOE	Levelized cost of electricity
LIB	Lithium-ion battery
NAS	Sodium sulphur batteries
OPEX	Operational expenditures
P	Power
PDP	Project Development Programme
PV	Photovoltaic
RE	Renewable energy
SAPP	South African power pool
SME	Small and medium enterprise
SoC	State of charge
TANESCO	Tanzania Electric Supply Company
TAREA	Tanzanian Renewable Energy Association

TTB	Tanzania Tourist Board
UPS	Uninterrupted power supply
USAID	United States Agency for International Development
USD	United States Dollar
VRLA	Valve-regulated lead-acid battery
ZECO	Zanzibar Electric Corporation

1. Introduction

1.1 Scope and thematic outline

This report targets to analyse the market potential for battery storage in Tanzania. It is directed to local business people and politicians who are interested in battery storage products and applications offered by German companies. Additionally, German companies can benefit and explore new market opportunities within the power supply sector of Tanzania. Therefore the report is focused on the potential implementation of battery storage systems in off-grid hybrid mini-grids or as back-up supply in regions with weak grid connection. For the latter case a simulation tool has been developed to enable the aforementioned target groups to conduct a swift feasibility study of battery systems for back-up power supply.

The East-African state of Tanzania has approximately 50 million inhabitants and generated a GDP of 85 billion USD in 2014. With only 1,700 USD GDP per capita Tanzania is among the 25 countries with the lowest GDP per capita worldwide. Nevertheless, a constant growth of 7% per annum and stable political conditions draw a promising future for this country. Increasing economic activities lead to a rising demand for electricity. Consequently, grid connected regions will further suffer from power outages due to a lack of power generation capacities. For new electrification projects in remote regions mainly decentralised mini-grids will be installed as they are cost competitive compared to electrification via grid connection.

Currently, for both cases decentralized diesel power generation is the prevailing method of choice to supply the uncovered demand. Diesel generators are almost everywhere available in Tanzania and easy to use. In addition, they are highly flexible in their operation mode which means quick starts as well as fluctuating loads. However, from economic and environmental viewpoints diesel generators bear significant disadvantages. Fuel expenditures can drive diesel power generation costs up to more than 0.50 EUR/kWh in remote regions and for small application ranges due to high diesel fuel and transport costs as well as low efficiencies. Additionally, the combustion of diesel fuel causes harmful emissions that affect the health of the local population. The identification of alternative modes of electricity and back-up power supply is thus crucial for a sustainable growth of the country.

An environmentally friendly and economically viable way to substitute diesel power is the introduction of renewable energies and/or battery storage systems. Due to abundant resource availability, renewable technologies such as solar photovoltaics (PV) are competitive alternatives to diesel plants in Tanzania. Hybrid mini-grids with high renewable energy shares may benefit from battery storage systems as those allow for an optimal use of a fluctuating generation from renewables. In grid-connected areas, batteries may substitute diesel generators and provide back-up power during power outages.

Tanzania bears an attractive and growing potential for battery storage systems in off-grid and grid-connected applications. Within this report, detailed insights into a number of different fields of application in Tanzania as well as an analysis of the battery product portfolio provided by German companies are provided.

1.2 Structure of the report

An overview of energy storage systems is given in section 2.1, followed by a comparison of lead-acid batteries and lithium-ion batteries (section 2.2) and a technical description of battery systems for back-up power supply in section 2.3. Overall, these sections provide basic knowledge of battery storage systems and their technical characteristics. Chapter 3 focuses primarily on German battery companies and their products. This enables Tanzanian suppliers and project developers to identify potential project partners and matching products. In addition, results of an empirical study with German companies are presented, showing challenges and opportunities within the Tanzanian market. These market characteristics are further described in chapter 4 in which the country's economic conditions and information about the electricity sector are outlined, and specific fields of application are examined regarding their attractiveness for off- and on-grid battery storage systems. To assess the economic viability of battery storage systems

as back-up power supply, a simulation tool has been developed which is described in section 5.1 and applied for six case studies in section 5.2. The case studies reveal the economic performance of different battery storage systems under different project conditions. Finally, the report summarizes the main findings and gives recommendations for further project development and research activities in chapter 6.

2. Energy storage technologies

2.1 Overview of energy storage systems

Energy storage systems are technical means to store secondary energy (e.g. electric power). Their purpose is the spatial or temporal decoupling of energy availability and energy demand. Typical fields of application for energy storage systems are mobile devices (e.g. cell phones, laptops), the balance of intermittent power generation (e.g. fluctuating supply from renewable energy sources) and the provision of back-up power supply in case of blackouts or the unavailability of power. Different types of energy storage are chemical energy storage, electric or electromagnetic energy storage, mechanical energy storage, and thermal energy storage (Table 1).

Table 1: Categorization of different types of energy storage

Chemical energy storage	Electric/Electromagnetic energy storage	Mechanical energy storage	Thermal energy storage
Electrochemical storage	Capacitor storage	Compressed air energy storage (CAES)	Latent heat storage
Thermochemical storage	Magnetic storage	Pumped hydro storage	Capacitive heat storage
Fossils fuels and solid biomass	Flywheel storage		

Source: Neupert et al. 2009

Each energy storage type is characterized by specific technical capabilities and constraints. Due to these characteristics each type of energy storage performs optimally in a specific field of application. Figure 1 provides an overview of the typical capacity and temporal storage availability of different energy storage technologies.

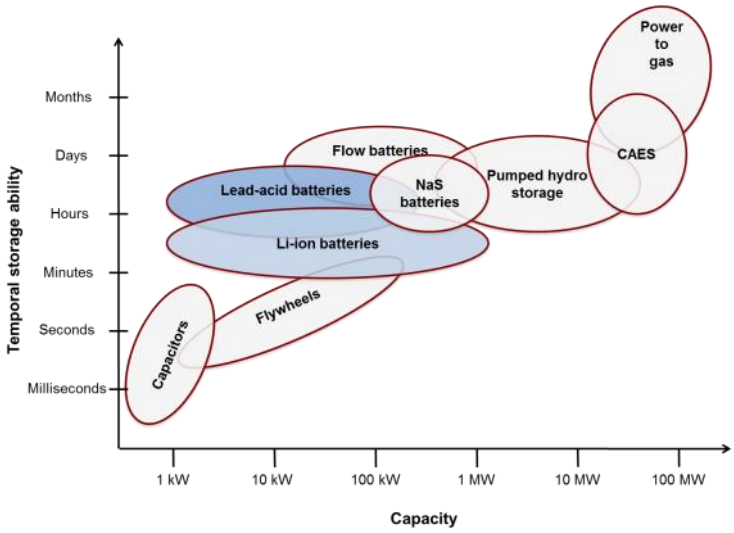

Figure 1: Characteristics of different energy storage technologies

Source: Own illustration adapted from Sterner et al. (2015).

(CAES = Compressed air energy storage; Li-Ion = Lithium-Ion batteries; NaS = Sodium-sulphur battery)

A study of Neupert et al. (2009) considers electrochemical energy storage systems (e.g. batteries/accumulators) as the most suitable technology for the provision of decentralised back-up or off-grid power supply due to their technical maturity, simple operation mode

and relation between storage capacity and power. Another study by Sterner et al. (2015) regards battery storage systems as most technically feasible and economically viable for compensating power outages. Thus, battery storage systems are selected for further analysis in this study.

2.2 Battery storage technologies

Electrochemical storage systems are commonly known as batteries or accumulators. In the following, all kind of electrochemical storage systems are synonymously called batteries. Batteries store energy in form of chemical binding energy through reversible electrochemical processes. Batteries consist of a cathode (positive pole), an anode (negative pole), a separator, deflectors, and an electrolyte solution (see Figure 2).

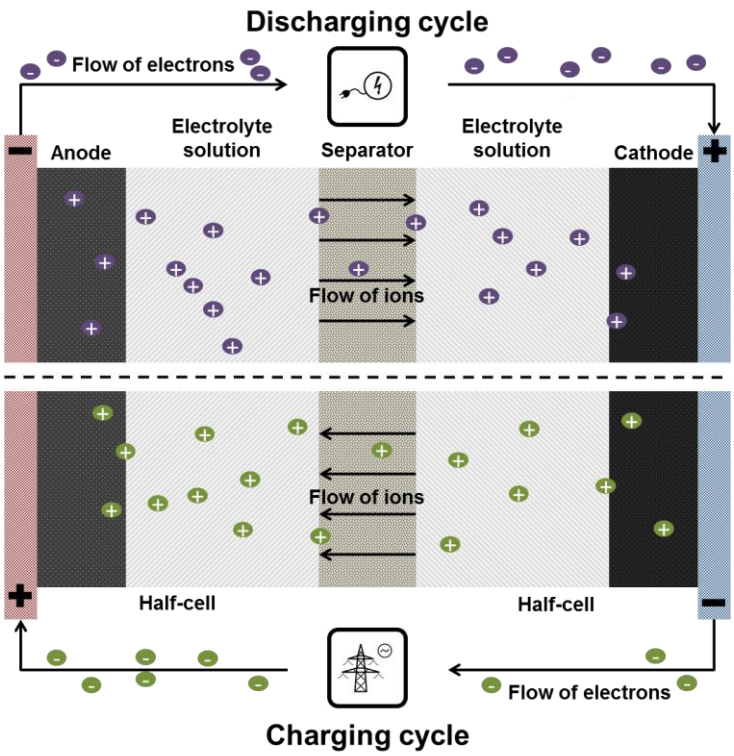

Figure 2: Scheme of a battery cell

Source: Own illustration according to Strauch (2011)

The functional principle of a battery cell is the electric potential difference between the anode and the cathode in two half-cells and the corresponding movement of ions and electrons between both poles. The electrolyte solution facilitates the conductivity of ions whereas the separator only allows ions to migrate between the two half-cells and prevent electrons from doing so. As soon as an external circuit between both half-cells is established the electrons flow to the other half-cell. Through that, the electrochemically stored energy is discharged in form of electric energy. The battery is recharged by reversing the potential of the electrodes through electricity from the grid or another energy source. As a consequence, the flow direction of electrons and ions is reversed and the chemical system in both half-cells is restored. A large number of such cells are combined in batteries to allow for larger capacities.

Figure 1 reveals that lead-acid batteries (LAB) and lithium-ion batteries (LIB) are the most suitable for decentralised applications in the range of 1kW to a few MWs and storage time up to several hours. Such applications are suitable for off-grid energy supply systems as well as grid connected back-up systems or home-storage for PV. For the analysis of potential usage within Tanzania they are selected as the two most promising battery types. Their working principle is similar to the description above but they are employing different materials. The specific characteristics and a comparison of both types are presented in the following sections.

2.2.1 Lead-acid batteries

LABs are the most common rechargeable battery technology in the world. They consist of two lead plates and utilize sulphuric acid as electrolyte solution, all comprised in an acid resistant box. LABs can be considered as the most mature battery technology and are applied for a wide range of applications such as starter batteries in cars, back-up batteries for uninterrupted power supply (UPS) and bulk power storage in combination with solar-home-systems. Closed cycle batteries are called valve-regulated lead-acid batteries (VRLA) and are less maintenance intensive than open cycle LABs which allow certain gases such as hydrogen to diffuse from the battery box.

2.2.2 Lithium-ion batteries

LIBs are a more recent energy storage technology than LABs. A major advantage of LIBs is their high energy density and the resulting low weight and space requirements. Consequently, the evolution of LIBs is strongly linked to the deployment of mobile devices (mobile phones, notebooks). Due to increasing cost reductions LIBs are considered a future key technology for the application in battery-based electric vehicles as well as for stationary applications. LIBs are comprised of a lithium based cathode combined with graphite or oxide as anode, commonly based on manganese or cobalt. The compilation of chemical substances significantly impacts the performance of the battery.

2.2.3 Comparison of lead-acid and lithium-ion batteries

The following Table 2 provides an overview of the different technical characteristics of LABs and LIBs. An explanation of key technical parameters of battery storage systems is provided in Appendix 1 – Battery characteristics.

Table 2: Comparison of technical characteristics of lead-acid and lithium-ion batteries

Technical parameter	Lead-acid batteries (VRLA)	Lithium-ion batteries
Energy density (Wh/kg)	20 – 45	100 – 200
Power density (W/kg)	100 – 200	200 – 4000
Lifetime (years)	3 – 10	10 – 15
Cycles (at 100% DoD)	200 – 470	3000 - 5000
Max. depth of discharge	~ 50%	~ 80%
Self-discharge (at 20°C)	< 5% per month	< 5% per month
Roundtrip efficiency	60 – 85%	90-95%
Capital expenditures$_{2013}$ (EUR/kWh)	250 – 500	800 - 1600

Sources: Data taken from Neupert et al. (2009), Strauch (2011), IRENA (2012), Juelch (2015), Sauer et al. (2013)

LIBs have several key advantages when compared to LABs as described in Table 2: Energy and power densities are significantly higher for LIBs than for LABs. This results in higher energy capacities comprised in smaller battery stacks with less weight for LIBs. Although space and weight are considered less important for stationary applications, they can influence the feasibility of deployment as transportation is easier for LIBs. LABs are more sensitive to deep-cycle discharging which results in aging and thus a loss of capacity. Therefore, it has to be assured that when discharging LABs a specific depth of discharge (DoD) is not violated. As a consequence, LABs need higher nominal capacities in order to allow for the respective energy demands. LIBs are characterized by higher roundtrip efficiencies leading to a higher amount of usable energy. Another important advantage of LIBs is the higher lifetime, both in terms of years and charging cycles which allows for a much longer utilization time. Additionally, the use of LABs implies

environmental concerns as the spillage of lead-acid to water sources endangers human health. Nevertheless the comparative cost advantages of lead-acid batteries have compensated the technological disadvantages so far which is why lead-acid batteries are most widely spread and used for back-up power supply. With future cost reductions of LIBs, this cost competitiveness might be equalized.

Besides LABs and LIBs, several other electrochemical storage concepts are under development with focus on applications for bulk energy storage. Interesting concepts are zinc-air, sodium-ion or aqueous hybrid-ion batteries which are all still in an early development stage and not further considered for this study.

Detailed insights into expected price developments for LIBs and LABs are given in the next subsection.

2.2.4 Future trends for battery storage technologies

Among all types of electrochemical storage technologies LABs have reached the most advanced stage of maturity. It is not expected that further significant advancements in terms of technical performance (e.g. energy density) will be reached within the near future (Kondziella et al. 2013). However, it is projected that investment costs for LABs will be further reduced to a range of 50 - 150 EUR/kWh till 2023 (Sauer et al. 2013). Research for energy storage technologies is currently strongly focused on lithium-based battery technologies. Scientists are pursuing two main goals: Increase the energy density of the batteries (400 Wh/kg by 2017) and reduce manufacturing costs (300 USD/kWh by 2020). Besides the technical improvements a lot of efforts are undertaken to reduce the costs of LIBs by the automotive industry which focuses on lithium-based storage concepts for the development of electric vehicles. The centre for solar energy and hydrogen research (ZSW) compared different cost projections for LIBs (Schott et al. 2010). All surveyed projections assume a quick development with major cost reductions until 2020 and a slightly slower learning curve between 2020 and 2030. Most of the projections predict costs of below 300 $/kWh in 2030.

According to a 2012 study by McKinsey, focusing on automotive applications costs are expected to reach the benchmark of 300 USD/kWh already by 2020 (Hensley et al. 2012). Cost reductions are based on technical advances in cathodes, anodes and electrolytes (40%), manufacturing productivity improvements (40%) and decreasing costs of raw materials (20%). A study by the Rocky Mountains Institute and Homer Energy compared the most recent cost projections from consulting groups and market analysts for lithium-ion battery pack costs (Bronski et al. 2015). The cost expectations for 2020 vary largely between the evaluated reports (see Figure 3).

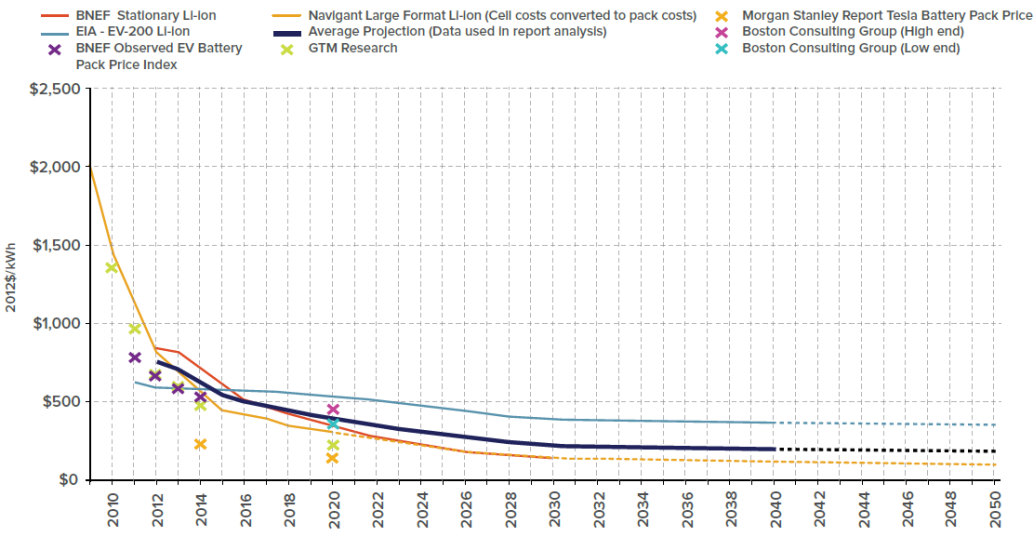

Figure 3: Expectations for cost reductions of lithium-ion battery cells in USD/kWh

Source: Bronski et al. 2015

Most projections expect costs of around 300 USD/kWh by 2020. However, when comparing the presented projections of 2010 to the projections of 2012 and 2015 it becomes evident that target costs are achieved in a shorter time period as initially assumed. This price

decrease is confirmed when taking recent product announcements of Tesla Motors Inc. into account. Tesla is an American company that designs, manufactures, and sells electric cars, electric vehicle powertrain components, and battery products. In April 2015, Tesla presented a lithium-ion battery for residential application at 350 USD/kWh and a utility-scale battery at 250 USD/kWh. Another scientific study shows that in the automotive industry battery costs declined much quicker than projected for the period of 2007-2014, and expects a cost reduction of 6-9% p.a. from 2015 onwards (Nykvist & Nilsson 2015). Cost reductions in automotive lithium-ion batteries are most likely to affect the costs of stationary lithium-ion batteries.

Summarizing the projections and taking into account the recent developments in implementing enormous production capacities it is most likely that the more progressive price reductions will be achieved. Thus, lithium-ion battery packs below 250 USD/kWh could be achieved on a global level for 2020.

2.3 Implementing battery systems for back-up power supply

Battery systems usually consist of the battery itself, bidirectional AC/DC inverters, charge controllers, and battery management systems. For battery systems connected to the main grid or to conventional power generation sources such as diesel generators, these sources determine the frequency and perform grid forming services such as frequency and voltage control, black-start capacity, reactive power control, and provision of short circuit current. The charging or discharging power of the batteries is either controlled by direct communication of an installed energy management system with the charge controller or by implemented P-f controllers (see Figure 4). P-f controllers automatically react to frequency drops, and increase and govern the charge or discharge power of the battery system. If the frequency drops beyond a certain threshold, the discharge power of the battery has to be increased and vice versa (Serban & Marinescu 2014).

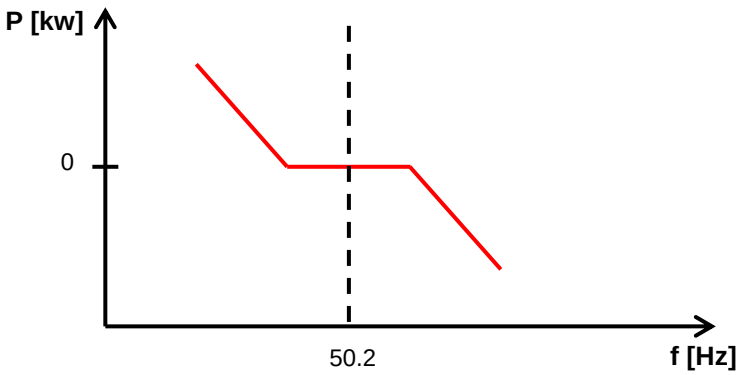

Figure 4: Frequency controlled power regulator

Source: Own illustration

In case of blackouts or non-operating conventional power sources, the battery tales over grid forming services. Many suppliers offer battery systems with this so-called isolated power supply option. The battery system is equipped with sophisticated control algorithms and power electronics to provide the same grid forming services as conventional power sources. It can be applied in off-grid regions or in cases of blackouts within grid-connected systems. For the latter case, UPS and back-up power supply can be distinguished. For UPS, the requirements for response rate, voltage and frequency are much higher than for back-up power supply. UPS provide further services such as voltage and frequency harmonization, and minimized time for switching from grid supply to battery supply in less than 10 milliseconds. To allow such quick responses the following system design can be applied (see Figure 5).

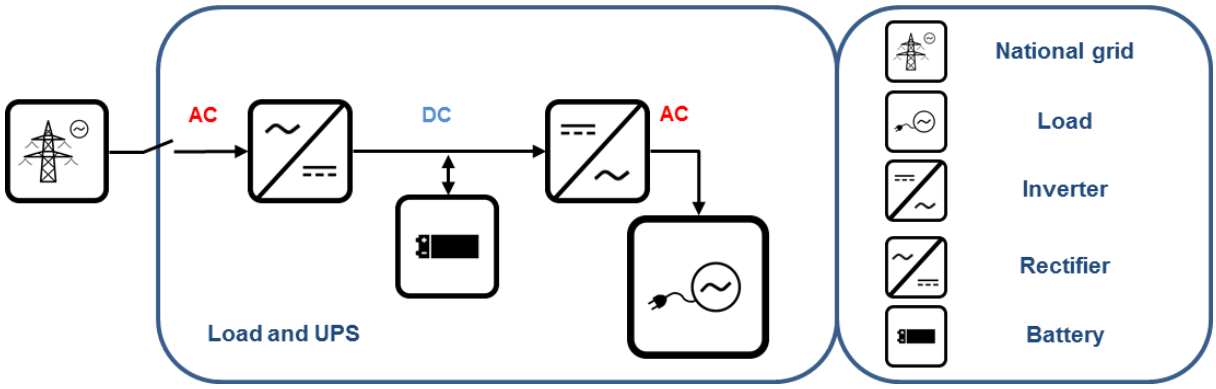

Figure 5: Working principle of uninterrupted power supply

Source: Own illustration

As depicted in Figure 5, electricity from the grid is rectified into direct current to run on the same bus as the battery system, and inverted before transmission to the consumer. This allows the quick change between grid and battery which is defined as UPS and often used for applications in data centres.

For back-up power supply, less strict requirements are set for response time and quality of supply. A short blackout is tolerated for starting diesel generators although time limits may be set (e.g. a maximum of 15 seconds for a hospital). Longer blackout times may pose danger to life and should be avoided. Back-up systems usually consist of one or more diesel powered generators which can be extended or substituted by battery storage systems.

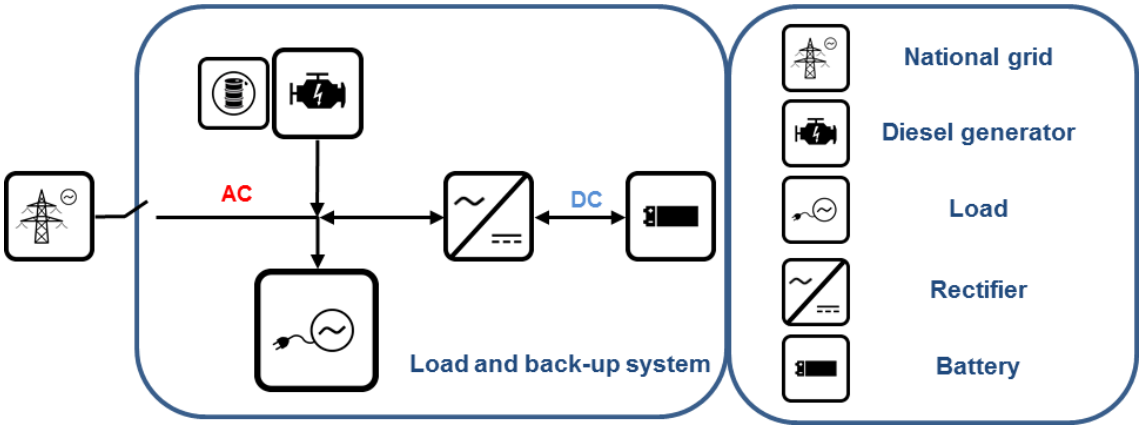

Figure 6: Working principle of back-up power system

Source: Own illustration

Figure 6 reveals the working principle of back-up power systems. In contrast to UPS, grid electricity is directly used by the consumer as AC. In cases of grid failure, back-up systems take over and supply the AC loads. Typical diesel powered off-grid system supported by batteries are dominant where no grid connection exists.

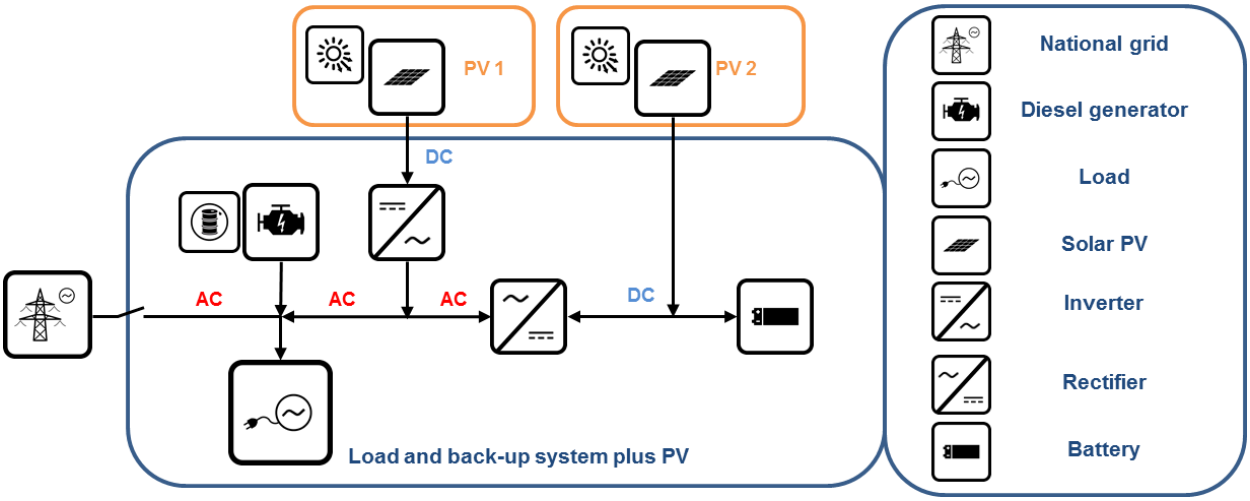

Figure 7: Working principle of back-up power system plus photovoltaics

Source: Own illustration

The inclusion of PV systems into back-up systems is described in Figure 7. Two ways of including a PV system into the consumer grid can be distinguished: it can be connected to the AC bus with its own inverter (see PV1 in Figure 7), but requires grid power to generate AC electricity since the inverter needs a determined frequency. Therefore it is not functional without back-up power. Alternatively, the PV system can be connected via the DC bus of the battery system (see PV2 in Figure 7) if batteries are installed. This allows a direct DC charging of the battery though PV power and reduces the expenditures for inverters.

Figure 7 also describes a hybrid mini-grid for off-grid application. In that case, the battery serves either as simple energy storage unit or as grid forming master unit to control and regulate the entire off-grid system with renewable energies and diesel generators.

3. German battery product portfolio analysis

3.1 Overview of German battery storage industry

The German battery storage industry is diverse and comprised by very different stakeholders and companies: there are companies that provide mature technologies with a longstanding history and high international reputation, but also innovative start-up companies that work on future battery storage technologies for new kinds of application. Germany holds a leading position in the market for battery storage as well as in the field of research and development, and export (GTAI 2014a). The country is renowned for high quality products, product diversity, and a close linkage of industry and research.

Germany has always been a strong research and technology development centre as well as a strong demand market. Initially, battery storage systems were mainly supplied to the automotive industry and to large industrial consumers. Therefore, the German battery storage industry focused on mainly lead-acid based batteries for automotive application and back-up power systems.

However, with the large-scale integration of renewable energies a new important field of application for energy storage technologies evolved. As of today more than 1.4 million renewable energy systems are already installed in Germany summing up to a total installed renewable energy (RE) capacity of 84.9 GW (BMWi 2015). Furthermore, the share of renewable sources in the energy generation mix will continuously increase from currently 30% to 80% by 2050. This will result in a large and rapidly growing demand for energy storage solutions in order to integrate the fluctuating power supply from renewable energies. These developments foster innovation and research in the German battery storage industry. As a consequence of the large-scale implementation of renewable energies the focus of the industry shifted towards LIBs as their characteristics are more suitable for integrating renewable energies. Grid services and primary reserve are typical fields of application for high power on-grid battery systems. In addition, the growing need for increased self-consumption of PV electricity on a household level leads to increased demand for household storage systems which extend the product portfolio of German companies.

Until now, no common certification scheme for battery storage technologies has been developed. A variety of different norms and certificates is applied to ensure operational safety and quality. An excerpt of these rules can be found in Appendix 3 – List of existing standards and certificates for battery systems.

3.2 Battery storage companies and products

A total of approx. 200 companies are associated to the German battery storage industry. Nevertheless, this number cannot be considered as exhaustive due to the fast development in this particular industrial sector. A detailed list is provided in Appendix 2 – List of companies within the German battery sector.

Battery storage companies can be distinguished with the following criteria (GIZ 2013):

- Battery manufacturers
- Battery management and energy management solution providers
- Component suppliers for battery manufacturing and system solution providers
- System solution providers and integrators
- Consultants and project management services
- Research institutions and industry associations
- Insurance, law and financial services
- Utilities

Within the field of battery manufacturers the majority of companies focus on LABs for the automotive sector. This becomes evident when taking the industries' export statistics into account: In 2013, Germany has exported goods categorized as "electric accumulators" with a value of almost 2.3 billion USD. LABs for automotive application contributed to almost 42% of the total sum (UN Comtrade Database 2015). Nevertheless, some of these companies also provide LABs for non-automotive applications. Furthermore, there are a number of specialised companies offering high quality lead-acid based products for stationary batteries.

LIB technologies currently complement the product portfolios of mature German battery manufacturers. Additionally, they are offered by a large number of promising start-up companies. Many of these companies provide containerized solutions which are designed for easy transportation and are capable to withstand harsh weather and climate conditions. When analysing the export statistics for stationary applications the increasing importance of LIBs becomes clear. Although the exports of lead-acid based technologies still comprise the largest share with almost 39%, lithium-ion based batteries already cover a remarkable share of almost 33%. Furthermore, their share of exports increased from 22% to 33% in 2012 (UN Comtrade Database 2015). Nickel-metal-hydride and nickel-cadmium battery products comprise a similar share. The remaining share is composed by supply parts and other technologies (compare Figure 8).

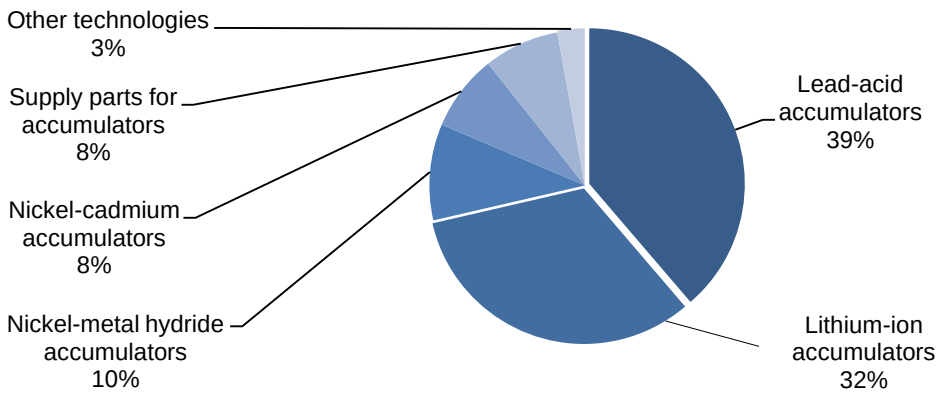

Figure 8: Share of different battery technologies of German electric accumulator exports in 2013[1]

Source: UN Comtrade Database (2015)

Besides manufacturing, several companies focus on the development of energy management systems and software solutions for the operation of hybrid energy systems. Furthermore, some companies are specialised on the optimal interaction of battery storage systems with the electrical grid system.

Other companies concentrate on the supply of materials, components and software solutions to the manufacturing sector of the industry. This sector can be described as fragmented as it is comprised of small and medium enterprises specialised on only a few products, and large companies with a wide product range (GIZ 2013).

Due to the high demand for renewable systems an increasing number of companies offering technical and implementation services for renewable systems have established. Battery storage systems become increasingly important for the self-consumption of renewable energy, hence there are more companies focusing on such battery storage systems.

More than 29 leading industrial and public institutions conduct research in the field of battery storage systems in Germany. Private and industry associated institutions aim on improvements in battery performance, in the battery value chain, and cost reductions. Public institutions are more focused on large-scale energy storage integration into the electrical energy systems. Generally, there is a strong trend towards lithium-ion technology in research.

Two important associations are active and provide support for manufacturers as well as for potential customers: The German Energy Storage Association (BVES) and the German Solar Association (BSW Solar).The main target of BVES is to speed up the

[1] Excluding automotive starter batteries

development of the battery storage market and offer expertise to policy makers and the public. Members of the association include companies from all sectors related to energy storage and add up to 100. Among other political and industry-related activities, BVES started a working group "Export Platform for Energy Storage" in October 2013 with the aim to develop an international network and establish business relationships. Thus, the association can be a valuable mediator for all the stakeholders during this process.

The German Solar Association is comprised of more than 800 members which are part of the solar energy value chain. One of its aims is securing a suitable policy framework for stable growth, and thus on ensuring investment security throughout the solar industry. With great commitment, the BSW works for the improvement of conditions for solar technology deployment worldwide. As solar energy will cover a significant share of global energy consumption in the medium to long-term, global support for the development of new solar markets is a key focus of the international activities of BSW. The association cooperates closely with solar industry associations and other stakeholders worldwide. For example, a partnership with the Tanzanian Renewable Energy Association (TAREA) was established in 2014.

Figure 9 and Table 3 on the following page show major German battery storage companies.

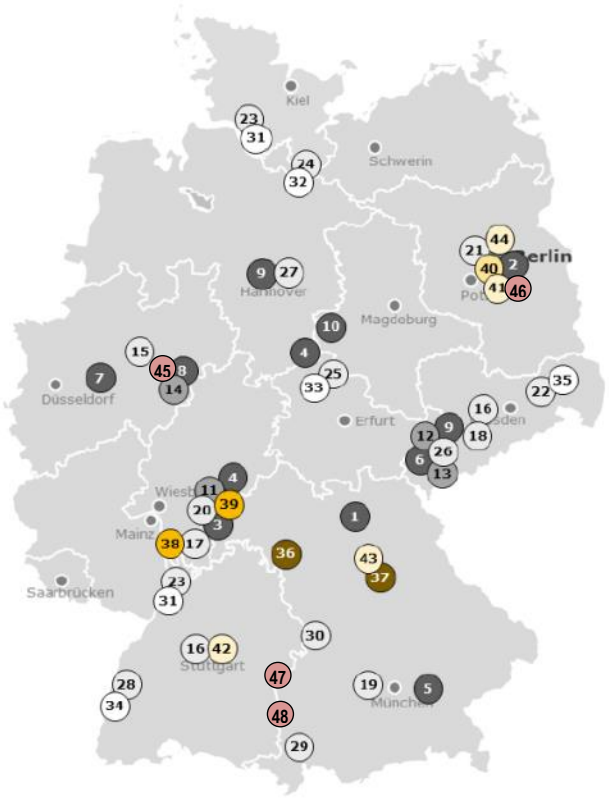

Figure 9: Location of key companies of the German battery storage industry –company details in Table 3

Source: GTAI (2014a)

Table 3: List of important battery storage companies corresponding to Figure 9

Type of battery	No.	Company
Lead-acid	01	Akkumulatorenfabrik Moll GmbH + Co. KG
	02	BAE Batterien GmbH
	03	BMZ Batterien-Montage-Zentrum GmbH
	04	Exide Technologies GmbH
	05	F.X. Mittermaier & Söhne GmbH & Co. KG
	06	GAZ Batterie GmbH
	07	Hawker GmbH
	08	HOPPECKE Batterien GmbH & Co. KG
	09	Johnson Controls Inc. Autobatterie GmbH
	10	Werbat Wernigeröde Batterie GmbH
Nickel-cadmium	11	BMZ Batterien-Montage-Zentrum GmbH
	12	GAZ Batterie GmbH
	13	GAZ Geräte- und Akkumulatorenwerk GmbH
	14	HOPPECKE Batterie Systeme GmbH
Lithium-ion battery production	15	Accusysteme Transwatt GmbH
	16	ads-tec GmbH
	17	AKASOL GmbH
	18	Axxellon GmbH
	19	Be-Power GmbH
	20	BMZ Batterien-Montage-Zentrum GmbH
	21	Dan-Tech Energy GmbH
	22	Deutsche ACCUmotive GmbH & Co. KG
	23	Dispatch Energy Innovations GmbH
	24	ECC Repenning GmbH
	25	GAIA Akkumulatorenwerke GmbH
	26	HOPPECKE Advanced Battery Technology GmbH
	27	Johnson Controls Inc. Autobatterie GmbH
	28	Leclanché SA
	29	Sonnenbatterie GmbH / PROSOL Invest
	30	VARTA Storage GmbH
Lithium-ion cell production	31	Dispatch Energy Innovations GmbH
	32	ECC Repenning GmbH
	33	GAIA Akkumulatorenwerke GmbH
	34	Leclanché SA
	35	Li-Tec Battery GmbH
Redox-flow Batteries	36	GILDEMEISTER energy solutions / a+f GmbH
	37	Vanadis Power GmbH
Others	38	AKASOL GmbH
	39	BMZ Batterien-Montage-Zentrum GmbH
Battery management Systems	40	Dan-Tech Energy GmbH
Storage System Integrator	41	Energiequelle GmbH
	42	Robert Bosch GmbH Bosch Energy Storage Solution LLC
	43	Siemens AG
	44	Younicos AG
Additional system integrators and power electronics	45	AEG Power Solutions GmbH
	46	Qinous GmbH
	47	Solar23 GmbH
	48	Phaesun GmbH

Source: GTAI (2014a)

3.3 Tanzania as a market for German battery companies

The selection of companies for qualitative interviews is based on their product portfolio and experience in East Africa. Only companies using either LABs or LIBs as presented in subsection 2.2 have been chosen for the analysis. Table 4 lists the interviewed battery companies and their respective products and battery types.

Table 4: Overview on interviewed battery companies showing products and battery types

Company name (No. in Fig. 9 and Tab. 3)	Products and applications	Battery storage types
ads-tec GmbH (16)	• Small-scale home storage systems (min. 8.3 kWh) • Large containerized solutions (> 100 kWh) for industrial customer and mini-grids • Back-up power supply	Lithium-ion and lead-acid
AEG Power Solutions GmbH (45)	• UPS as core business • Power electronics for battery integration and management and secure operation • Off-grid island solutions	Technology open, can use lithium-ion and lead-acid
BAE Batterien GmbH (02)	• Batteries (25 Ah – 4,940 Ah) only, without inverters • Stationary and mobile applications • Rural electrification	Lead-acid
Hoppecke Batterien GmbH (08)	• Batteries (10 Ah – 3,500 Ah), MWh scale possible • Batteries for UPS and back-up supply • Long track record for off-grid systems (e.g. in combination with sunny island inverters (SMA))	Lead-acid (OPzV) and lithium-ion
Leclanché SA (28)	• Small-scale home storage systems (min. 3.2 kWh) • Large containerized solutions up to 40 feet container (> 4.2 kWh, up to 1 MWh) for industrial customer and mini-grids • Back-up power supply and smoothing of on-grid PV	Lithium-ion
Phaesun GmbH (48)	• Wholesale company for off-grid energy systems • Mainly German storage products	Lead-acid and lithium-ion (small-scale)
Qinous GmbH (46)	• Complete energy storage systems – containerized (min. 30 – 50 kWh) • Back-up energy supply with frequency and voltage regulation • Off-grid and on-grid applications (industrial)	Lithium-ion and aqueous hybrid-ion
Solar 23 GmbH (47)	• Complete energy systems including storage • Appliances (e.g. fridge) can be included in planning • Systems for weak grids or off-grid solutions	Lead-acid and lithium-ion (upon request)
Younicos AG (42)	• Energy storage system solutions (> 500 kWh) • Off-grid and island energy supply • Primary reserve for on-grid	Lithium-ion, sodium sulphur, redox-flow

Sources: Personal interviews with respective companies

3.3.1 Experience in the Tanzanian market

All of the interviewed companies have a general interest in entering the Tanzanian market. Furthermore, most of them are already active in Sub-Saharan Africa. Their different strategies and experiences are presented in the following.

Most of the storage systems in place are connected to hybrid off-grid systems. In these systems diesel mini-grids are combined with renewable energy technologies and battery storage. In the past, they often have been donor-financed, but new business models emerge and new payment structures make them increasingly economically viable. Furthermore, the application in weak grids receives rising attention. Within these areas diesel generators are usually applied as back-up systems which can be substituted by battery storage systems combined with PV. Currently, installed projects are of rather small size with little data available.

While German project developers and system integrators (e.g. juwi, Energiebau, INENSUS) have a long track record of sales in Tanzania, manufacturers do not directly sell in Tanzania, but via international distributors or project developers due to their well-established networks and business connections. The focus has so far been on LABs, the more mature and common technology.

One interviewed project developer focuses mainly on Kenya but has some linkages and small projects in Tanzania. Other technology and full system providers have experiences with off-grid mini-grids in Namibia or Mali. In these regions the first projects started with LABs in off-grid energy supply systems.

Interviewed energy or storage system developers underline their interest in the Tanzanian market, while manufacturers and established storage solution suppliers prefer German project developers or international distributors as customers. Those companies do not directly enter the Tanzanian market, but seek partners to collaborate. Young companies however, prefer to develop energy projects to sell their battery storage systems, even if this is not their core business.

In general, the company survey has revealed that Tanzania is considered an attractive market for battery storage systems. Various ways to access this market are demonstrated in Figure 10.

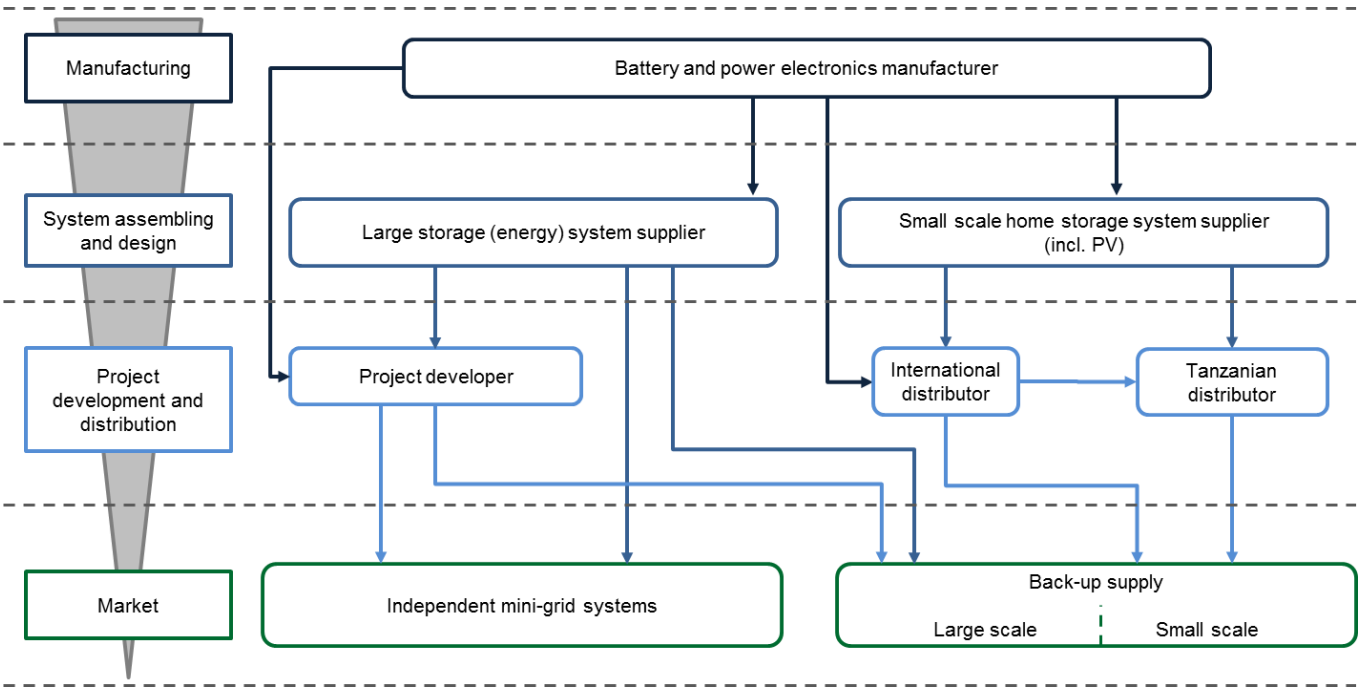

Figure 10: Distribution ways to access the Tanzanian battery market

Source: Own illustration

Figure 10 shows three levels in the value/distribution chain before reaching the end-customer (market). On the first level are manufacturers which would usually not sell directly to Tanzanian end-customers. Their products are used by project developers and combined with other technologies such as inverters according to project needs. Project developers develop either own solutions for mini-grids or large scale back-up supply or use predefined concepts of large storage system suppliers. Alternatively, large or small storage system suppliers buy batteries and integrate them into their storage concepts and solutions. These solutions are either applied in independent off-grid mini-grids or for large scale back-up supply. Small-scale standardized systems are sold to international or Tanzanian distributors which deliver them to the end-customer. The market for solar home systems which can be applied on- and off-grid is not reflected in this analysis.

3.3.2 Challenges and solutions for market entry

As presented, all of the interviewed companies are either already active in the Tanzanian market or are interested in entering the market. The second step of the value chain differentiates between large and small scale battery system providers. Large scale means mainly containerised solutions starting around 100 kWh storage capacities which are individually adapted to the customer needs. Small scale systems are pre-defined solutions which can be directly applied by the customers.

Battery and power electronics manufacturers do not sell directly to the Tanzanian market, therefore they compete more on an international than on a local level. A strong brand image and strong links to project developers and system suppliers are thus crucial. Amongst the challenges for manufacturers are the following:

- Strong international competitors with low cost products
- Distributor or project developer network is necessary
- Local distributors have to know the technology (maintenance failures can lead to product failures and a damaged reputation)

Large scale system suppliers focus primarily on large mini-grids or utility scale projects. They cooperate with German or international battery manufacturers to design their products or projects which are sold directly to the end-customer. They provide turn-key solutions with reduced maintenance effort to satisfy customer needs. The design and optimization of the hybrid energy and storage system increases the upfront costs and efforts for large scale storage projects. Challenges for large storage system suppliers and project developers are the following:

- High consulting and marketing effort to promote projects (individual design of each project)
- Standardization of projects is difficult
- Financing of large scale projects is often not feasible locally
- Pilot projects or proofs of concept are demanded for new technologies

Small scale system suppliers focus primarily on the residential market. They usually rely on intermediate distributors or create local branches to sell their products. Such systems are either offered as turn-key solutions or are assembled by local electricians. Private or commercial customers buy such systems via online stores or at local shops and/or engage local experts to install them. Small-scale home storage suppliers and distributors face the following specific challenges:

- Customers react very price sensitive (preference for low cost instead of high quality)
- Payment structures, upfront payment, difficulty to obtain local loan
- Import taxes on battery products increase price level
- Missing quality standards in Tanzania for small-scale battery products

During a workshop conducted with TAREA and GIZ PDP in November 2014 the following results have been elaborated (GIZ 2015): The most important hurdles to the development of PV-hybrid mini-grids were identified to be insufficient transparency in grid

connection planning, insufficient investment security for mini-grid operators, the complexity of administrative procedures for projects, and the lack of skilled labour. In addition, access to financing is mentioned as challenge, especially due to the small project volume and difficulties to mobilise private investors.

Figure 11 summarizes key challenges and provides potential solutions.

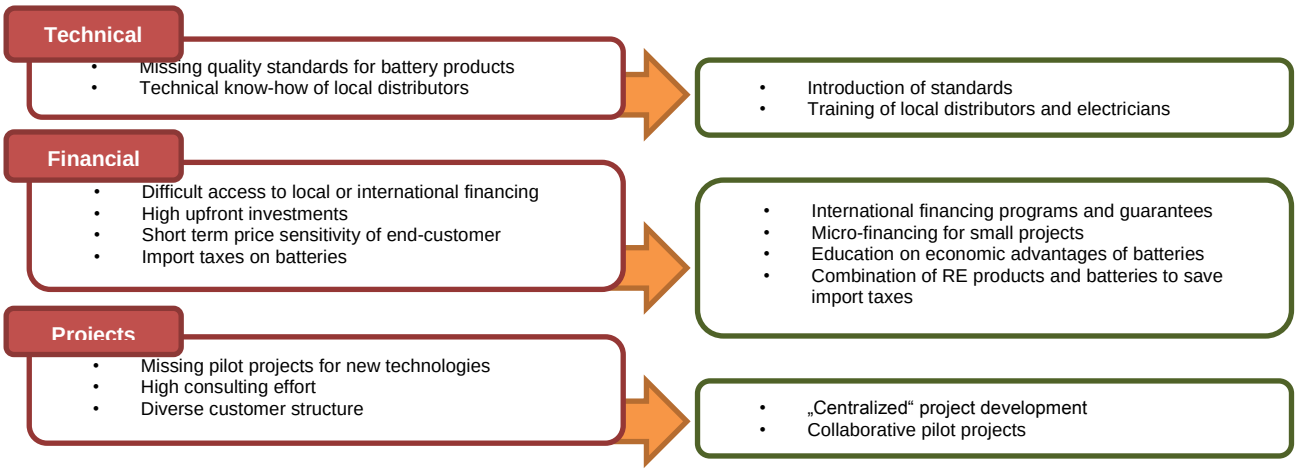

Figure 11: Technical, financial and project based challenges and solutions for introducing battery systems to the Tanzanian market

Source: Own illustration

The introduction of standards for batteries and battery systems would support high-quality products. Education and training ensures better handling and therefore longer lifetime of batteries, but also creates a better understanding of the economics of battery storage.

Financial challenges can be targeted by the provision of cheap loans for project developers or end-customers. Large scale projects require debt financing with low interest rates or secured power purchase agreements. For small-scale projects a micro-financing framework specialised in energy related projects could enable paying high upfront investments with long term saving effects.

To reduce the import tax on batteries it is recommended to import entire systems including renewable technologies and batteries as those are tax-free in Tanzania.

For large scale projects it is suggested to aggregate potential project sides and customers in a “centralised” unit to overcome the high project development and consulting costs for the diverse customer structure. Additionally, collaborative pilot projects should be supported to prove the applicability of new battery technologies in Tanzania.

4. Markets for battery storage in Tanzania

This chapter outlines Tanzania as a country in general and the Tanzanian energy sector in particular. In addition to the sector overview, potential applications for battery products and systems are presented. These are clustered along the different customer groups for both off-grid and back-up power supply.

4.1 Country information Tanzania

Tanzania is located in Eastern Africa. It is bordered by the Indian Ocean to the East and by eight countries to the North, West and South. The country gained independence in 1961 and obtained its final borders by the unification of mainland Tanganiyka and the islands of Zanzibar to the United Republic of Tanzania in 1964. The country has a population of 49.5 million. At the same time it has one of the lowest gross domestic products (GDP) per capita with 1,700 USD worldwide. A share of 28.2% of the population (13 million people) lives below the poverty line. Nevertheless, the economic situation is improving based on a stable GDP growth of 7% p.a. and a shrinking rate of inflation of 6.1% in 2014. Despite of the large share of people living in poverty and concerns about corruption, Tanzania is generally considered as one of the most stable countries in the East African region and remained for the most part in a peaceful situation since its independence.

The Government of Tanzania (GoT) pursues an ambitious target with the "Tanzania Development Vision 2025" formulated in 1999. This vision aims to develop Tanzania to a middle-income country till 2025. The vision is based on the main pillars of a strong and competitive economy, a high quality livelihood, a well-educated and learning society, good governance and peace, stability and unity.

In terms of economic growth the country achieved remarkable progress with an average GDP growth of 7% p.a. over the period of 2004 to 2013 (BoT 2014). The share of the service sector in the GDP is expected to be the largest one in 2014, both the mainland of Tanzania and Zanzibar. For this sector main shares are generated from trade, transport, communication and the service segment (BoT 2014). According to the projections for the GDP, the industrial sector holds a share of 22.1% (15.2% for Zanzibar) and consists of manufacturing, construction and mining. The agricultural sector which is producing crops such as coffee, sisal and tea represents a similar share as the industrial sector with 21.7% (compare Figure 12). Nevertheless, the high importance of the agricultural sector becomes evident when taking into account that still 75% of Tanzania's workforce is employed in this sector.

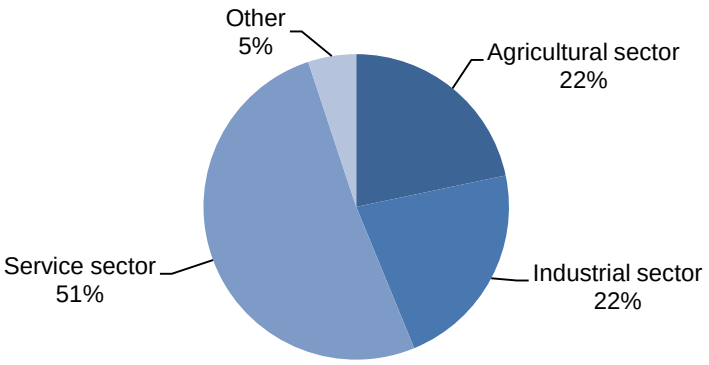

Figure 12: Contribution to GDP per sector for mainland Tanzania

Source: BoT (2014)

The individual sectors are growing with different dynamics. While the service sector and industrial sector have GDP growth rates of 8.7% p.a. and 7.9% p.a. respectively, the agricultural sector grows significantly slower with 5.3% p.a. (BoT 2014). The different sectors contributions to the GDP growth are illustrated in Figure 13. This Figure depicts the differences between the actual portion of

the sector to the GDP and the share of the sector to the growth of GDP. A higher portion in growth than in the actual share indicates a rising importance of the sector in the future.

Tanzania has a negative balance of trade. A large share of imports with 28% is comprised by fossil fuels for power generation (IMF 2014). This contributes to the vulnerability of the Tanzanian electricity supply sector when taking into account the volatility of global fuel prices. Main export goods are gold (34%) and agricultural products (17%) (IMF 2014). As large natural gas reserves have been discovered recently, the focus is now to develop these sources. A decrease in electricity prices is expected if the gas resources are developed in a reasonable timeframe.

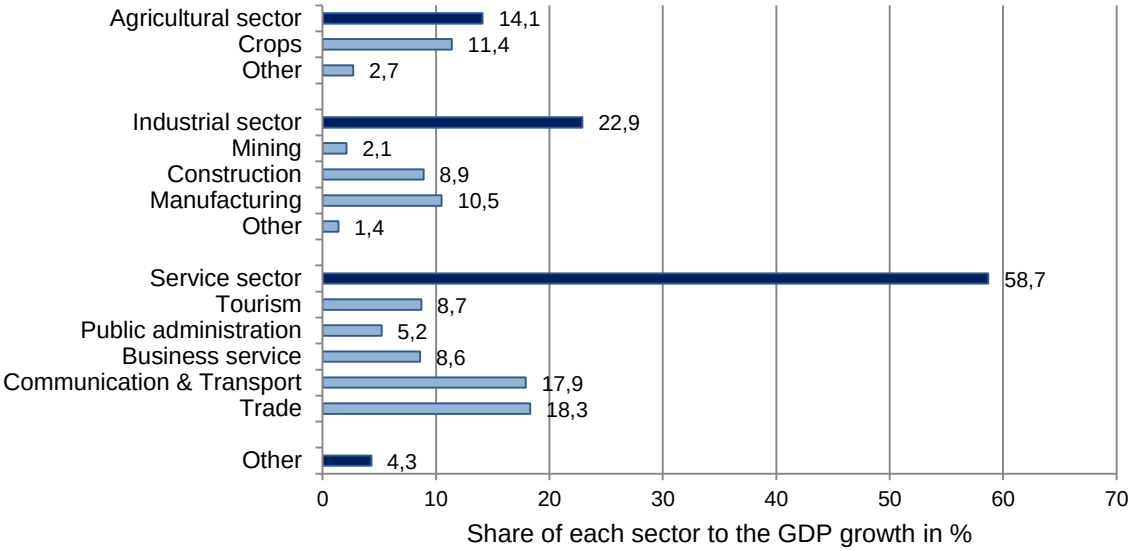

Figure 13: Contribution of each sector and sub-sector to GDP growth (2013-2014)

Source: BoT (2014)

4.2 Electricity sector of Tanzania

4.2.1 Power generation

In general, primary energy supply is still largely based on biomass in Tanzania. This is due to the importance of biomass sources for cooking (e.g. firewood and charcoal) in rural households and the overall low electrification level. This level is between 18% and 12%[2] for the entire country but falls below values of 6% to 2% in rural areas. Detrimental effects of intensive biomass use such as deforestation and erosion are observable in Tanzania. They are about in the same intensity like in other comparable developing countries. The electricity is produced mostly from conventional sources such as gas and oil. Figure 14 depicts the primary energy consumption and the fuel sources for electricity production.

[2] The electrification rate for Tanzania is defined slightly different in each related publication:
18.4 % - Power Supply Master Plan (2013), Ministry of Energy and Minerals.
18 % - National Electrification Prospectus (2014), REA 2014
16.4 % - Tanzania in Figures 2012 (2013), National Bureau of Statistics, Ministry of Finances.

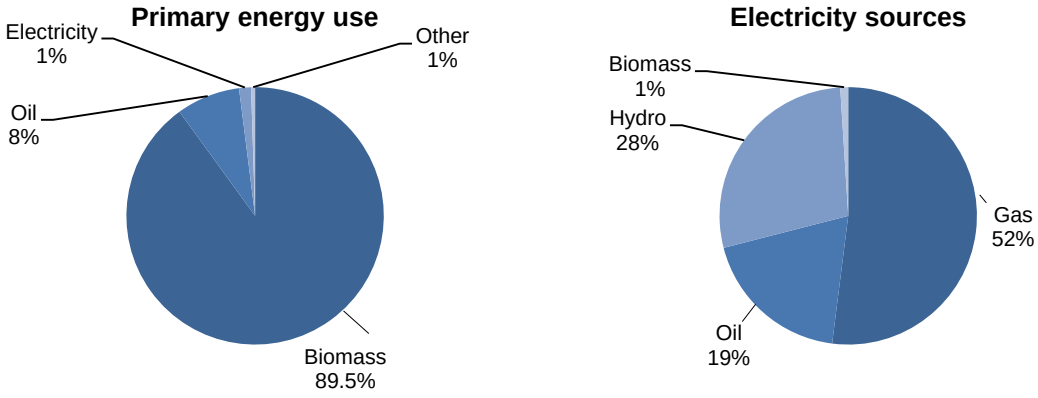

Figure 14: Primary energy use and electricity mix by sources in Tanzania for 2013

Source: AHK (2013)

The electricity sector is dominated by the Tanzania Electric Supply Company (TANESCO). TANESCO is a public company and was the former state monopolist, responsible for power generation, transmission and distribution. Today TANESCO and several independent power producers (IPPs) are contributing to the power generation portfolio. The available power capacity is described inconsistently in different publications. They range from 1,359 MW (MEM 2013a), to 1,491 MW (MEM 2013b) and 1,564 MW (AHK 2013). Nevertheless, all sources provide a similar picture of the share of power generation: fossil fuel 71%, hydropower 28% and other sources with 1% (including biomass and imports). TANESCO operates 62% of the capacity, the IPPs manage 17% and rented power generation facilities contribute 21% (MEM 2013b). The Oil/Diesel based generation of electricity counts 31% of the overall generated electricity with a capacity of 495 MW installed (AHK 2015).

For the archipelago of Zanzibar (consisting of the islands of Unguja and Pemba) the Zanzibar Electric Corporation (ZECO) is the responsible utility. ZECO is solely importing electricity from TANESCO by underwater cables to Unguja and Pemba. The supply from the mainland is insufficient and long lasting power outages were experienced in recent years. Therefore, it is planned to reinforce the connections to the mainland and develop own power generation sources on the island.

In order to meet the growing demand and compensate ageing infrastructure and high losses within the TANESCO transmission grid, it is planned to significantly increase the centralised power generation capacity in short-term (2013 – 2017) and mid-long term expansion plans. Under the short-term expansion plan it is targeted to realise at least an additional 2,784 MW by 2017 (MEM 2013b). The generation technology focused on in this expansion is mainly based on gas. However, a capacity of 200 MW for wind power and 60 MW for solar PV are planned. Within the mid- and long term expansion plan additional capacity of more than 6,000 MW shall be realised mainly based on large hydropower and coal power plants (AHK 2013).

Additionally, at least 82 MW of generation capacity are planned to be installed in isolated grid systems (MEM 2013a). Most of these systems are located in the not yet connected regions of Kigoma, Rukwa, Lindi, Mtwara and Ruvuma and are supplied by diesel generators (53 MW) and gas power plants (29 MW) (TANESCO 2015).

Furthermore, there are a huge variety of small independent diesel generators installed and operated. These generators serve either remote off-grid consumers or provide back-up electricity for grid-connected customers in times of blackouts. Data coverage for these small diesel generators is insufficient but it can be assumed that there is a considerable number installed in Tanzania similar to other sub-Saharan countries (Mini-Grid 2015). This would represent an attractive business case for implementing renewable energies and battery storage systems. This attractiveness is very sensitive to diesel fuel costs which are varying throughout the country (see Figure 15

Figure 15).

The Energy and Water Utilities Regulatory Authority (EWURA) is providing cap prices based on historic price trends for petroleum products such as gasoline, diesel and kerosene on a monthly basis for all regions and districts of the country. The regional diesel fuel cap prices for February 2015 show that on average diesel fuel costs around 0.89 EUR/l. What is also visible in Figure 15 is the impact of transportation costs on final fuel prices. The prices are increasing from the easy accessible coast towards the western borders of the country. The final diesel price is therefore significantly higher than the original cap price set by authorities. The price gain is up 77% to 1.6 EUR/l. (EWURA 2015).

However, these prices only reflect the costs in the provincial capitals. If diesel fuel has to be transported further to more remote regions, additional costs have to be included. These costs are displayed in the right image of Figure 15. The final regional diesel prices were calculated based on the work of Szabo et al. (2011). This approach takes into account the travel time, the characteristics of the terrain (topography) as well as the expenditures for fuel and transportation necessary to deliver the fuel to a final destination.

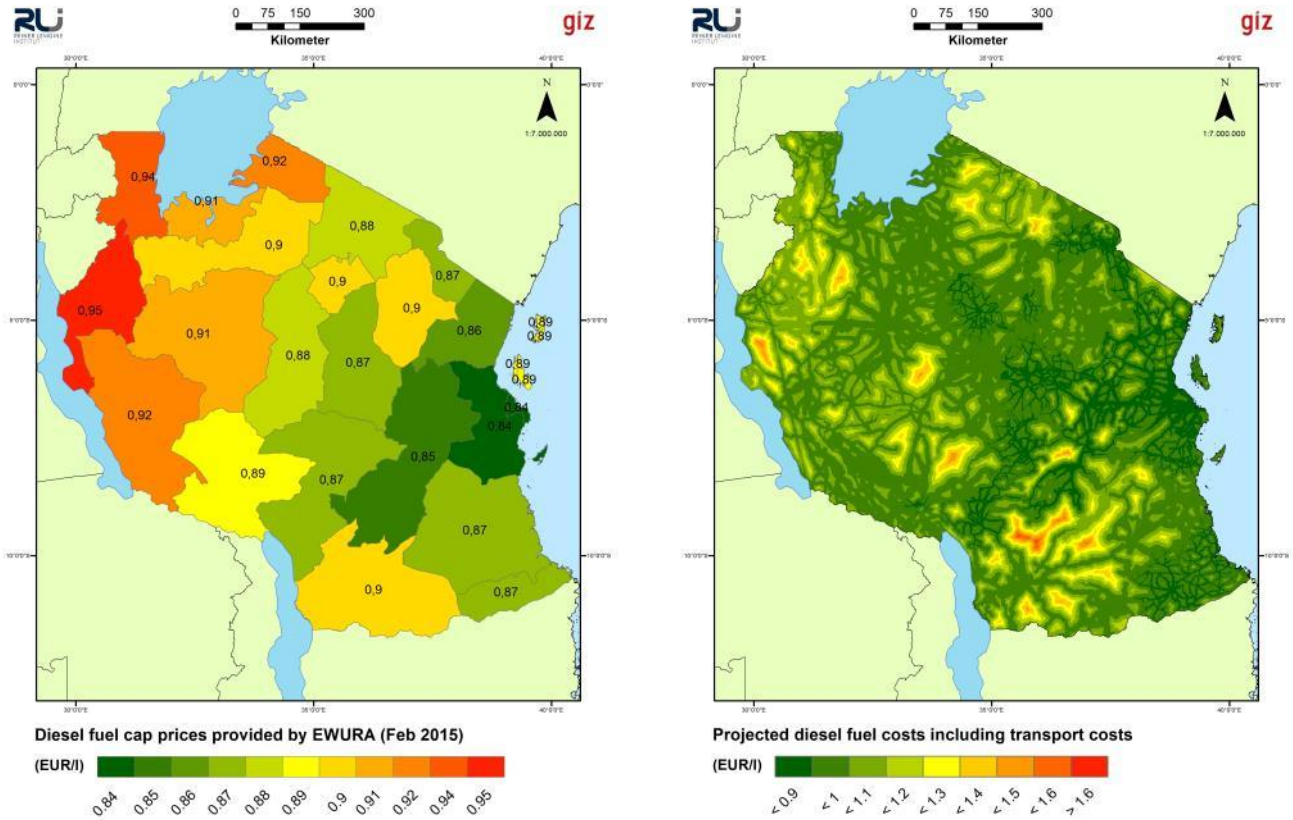

Figure 15: Regional diesel cap prices (left side) compared to projected diesel fuel costs including transportation costs (right side)

Source: Own illustration according to EWURA (2015) and Szabo et al. (2011)

4.2.2 Transmission system

The Tanzanian electricity transmission network mainly covers the northern, north-eastern, eastern and central parts of the country (see Figure 16). Transmission lines are operated at 220 kV, 132 kV and 66 kV over more than 4,600 km. Submarine cable connections to the islands of Unguja (132 kV) and Pemba (33 kV) are in place. Further the network is comprised by almost 19,000 km of 33 kV and 11 kV cables. Finally, the distribution grids operate usually at 400 V or 240 V and cover a distance of more than 26,000 km (MEM 2013a). Furthermore, several isolated grids are in place in towns and regions without access to the central grid system.

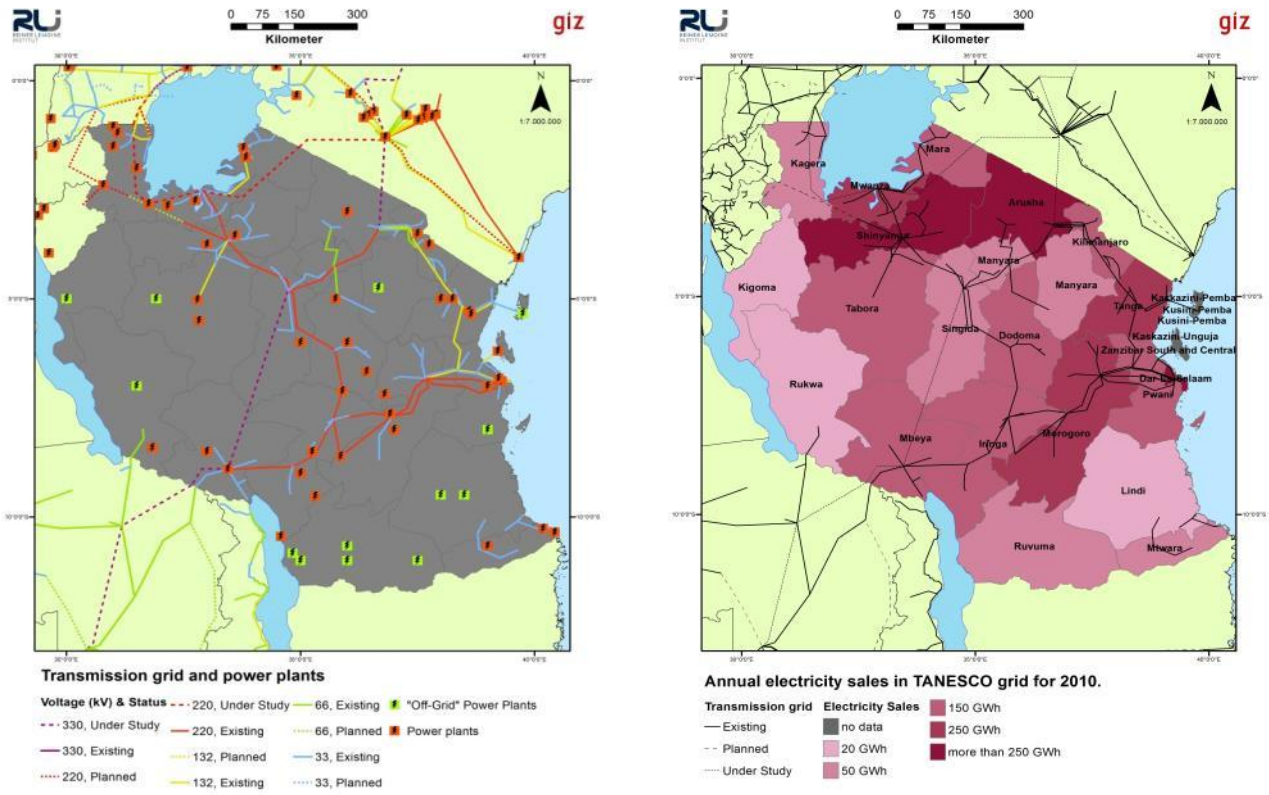

Figure 16: Transmission grid of Tanzania and main power stations (left side) and electricity sales (right side)

Source: Own illustration according to AfDB (2012) and MEM (2013)

The electricity system is facing very high energy losses both in the transmission and in the distribution network. According to an assessment conducted in 2010 the overall losses added up to 25%. They comprised of 5.3% losses in the transmission grid and 19.7% losses in the distribution grid (AHK 2013a). As a consequence several grid reinforcement projects are commissioned with the objective to reduce the transmission losses to a level of 15.5% in a first step (MEM 2013a).

The Tanzanian transmission network is already connected to the Zambian power system through 66 kV and 33 kV lines. The regional grid system of Kagera region is connected to the Ugandan grid via 132 kV transmission lines. Tanzania is an importer of electricity from Uganda and Zambia. In order to ensure the security of supply further connection projects to all neighbouring countries are planned. Tanzania holds a unique and important role in the further development of the African power systems as it will provide the linkage between the East African Power Pool (EAPP) to the South African Power Pool (SAPP). So far the connection projects are most advanced for the initial linkage to Kenya, and new connections to Uganda and Zambia. These linkages are expected to be finalized within the year 2015. Until 2021 the further linkages to Rwanda, Burundi, Malawi and Mozambique are expected to be realized (MEM 2013a).

4.2.3 Energy demand and tariffs

For 2015 a peak demand of 2,073 MW and a consumption of electricity of 8,873 GWh are expected (MEM 2013a). IN 2011, the Ministry for Energy and Mines assessed the Tanzanian power system and identified a huge gap between supply and demand. At this time the supply system was restricted to a peak demand of 832 MW. At the same time the theoretical (unrestricted) peak demand was expected to be at 1,054 MW (MEM 2013a). Although additional generation capacity has been installed, the gap has not been closed.

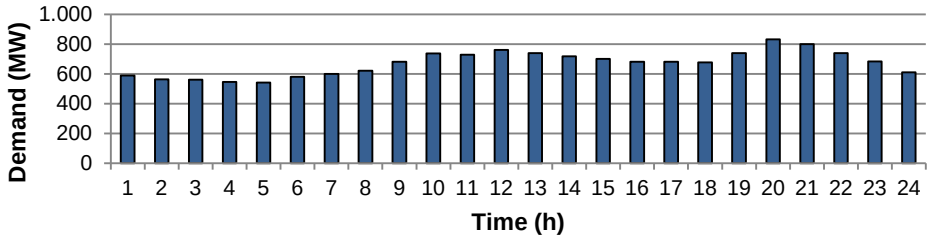

Figure 17: Average load profile TANESCO grid for an exemplary day in 2010

Source: Own illustration according to TANESCO (2015)

In Figure 17 an average load profile for the TANESCO grid system is presented (TANESCO 2015). The average daily load pattern is comprised by a small midday and a larger evening peak. Only Sundays differ from that scheme and are characterized by morning and evening peaks and a lower overall load compared to weekdays (MEM 203a). The load curve is not affected by seasonality. Nevertheless, the daily load pattern in isolated grids may differ from the presented scheme due to less industrial consumers.

According to the power master plan published by the Ministry of Energy and Minerals (MEM) the energy demand is expected to rise significantly in the next years. This is triggered by high growth rates, new large consumers (mining and industrial sector), and improvements in rural electrification (MEM 2013a). The electricity demand will grow by 11.9% p.a. according to conservative expectations. Load shedding affects around 100 GWh p.a. in Tanzania. A regional distribution of the electricity supplied by TANESCO is illustrated in Figure 16 (right side). The respective tariffs to the centralised electricity sales are presented in Table 5.

Table 5: Tariff system of Tanzania

Customer category	Description	Component	Unit	Approved Tariff 2015
D 1	Low usage tariff for domestic customers who, on average, consume less than 75 kWh per month.	Service charge	TZS/month	not applied
		Energy charge (0 – 75 kWh)	TZS/kWh	100 (0.05 EUR)
		Above 75 kWh	TZS/kWh	350 (0.17 EUR)
T 1	General usage tariff for customers including residential, small commercial and light industrial use, public lighting, and billboards.	Service charge	TZS/month	5,520 (2.76 EUR)
		Energy charge	TZS/kWh	306 (0.15 EUR)
		Maximum demand charge	TZS/kVA/month	not applied
T 2	Industrial consumers with monthly consumption greater than 7,500 kWh and demand less than 500 kVA.	Service charge	TZS/month	14,233 (7.11 EUR)
		Energy charge	TZS/kWh	205 (0.1 EUR)
		Maximum demand charge	TZS/kVA/month	15,004 (7.5 EUR)
T 3 – MV	Applicable to customers connected at medium voltage.	Service charge	TZS/month	16,769 (8.39 EUR)
		Energy charge	TZS/kWh	163 (0.08 EUR)
		Maximum demand charge	TZS/kVA/month	13,200 (6.6 EUR)
T 3 - HV	Applicable to customers connected at high voltage.	Service charge	TZS/month	not applied
		Energy charge	TZS/kWh	159 (0.8 EUR)
		Maximum demand charge	TZS/kVA/month	16,550 (8.28 EUR)

Source: TANESCO (2015)

4.2.4 Power outages

The Tanzanian electricity supply system struggles under frequent power outages. These power outages are partly due to overload of the system and partly due to planned load shedding of TANESCO. Especially, during the dry season the occurrence of power outages increases by reason of reduced power generation by the large hydropower plants. Tanzania faced a period of severe power outages in 2006 which forced the country to install cost-intensive power rental services. The power supply to Zanzibar broke down for one month in 2008 and for further three months during 2009 - 2010 (Ilskog 2011).

However, no official statistics on power outages, brownouts and load shedding are available. The frequency and duration of blackouts has to be derived from conducted surveys and other secondary sources. In 2013 enterprise surveys have been conducted in Tanzania as a part of a global study commissioned by the World Bank. In total 813 enterprises of different sectors and five different regions of Tanzania (Dar-es-Salaam, Arusha, Mwanza, Mbeya, and Zanzibar) were surveyed. These questioned companies faced on average 8.9 power outages per month, with average outage durations of 5.1 hours (World Bank 2013). Nevertheless the structure of power outages differs strongly within the geographic regions and sectors (compare Figure 18). A coffee farm surveyed in early 2015 suffered from regular blackouts which sum up to an entire work day per week (AHK 2015). Another survey revealed that grid-connected telecommunications stations are facing power outages of six hours per day on average (GSMA 2012).

A survey among 30 hotels and resorts on Zanzibar islands explored that the tourism sector experiences on average 18.5 power outages per month with an average duration of 117 minutes (Mathematica 2011). The regularly occurring power outages impede the fast economic development in Tanzania due to production losses and communication break downs. Thus, many grid-connected consumers own and operate back-up diesel generators to compensate the power outages. Instead of using expensive and polluting diesel power, batteries could also serve as back-up supply as described in section 2.3.

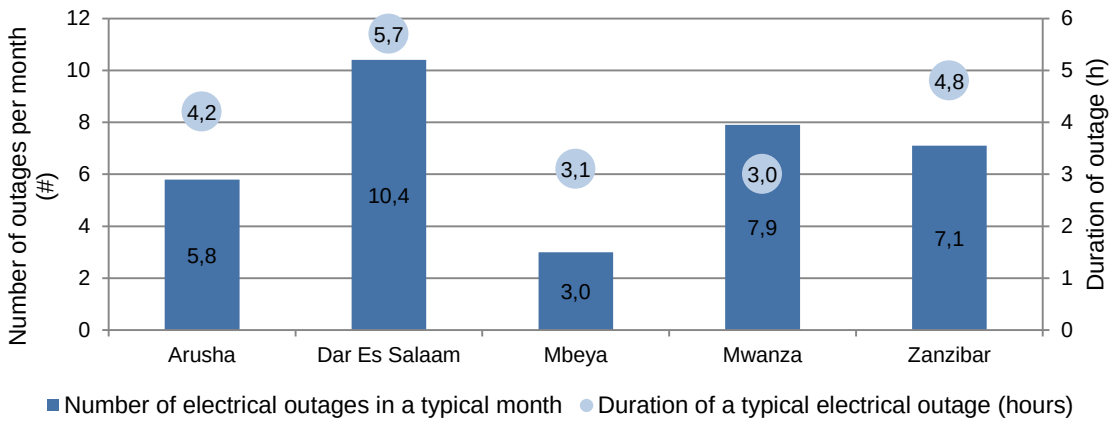

Figure 18: Power outages per region in Tanzania

Source: World Bank (2013)

4.3 Fields of application for batteries in Tanzania

After the presentation of the current situation of the Tanzanian electricity sector, typical fields of application for battery systems in Tanzania are elaborated in the following section. Such systems can be applied as back-up power supply for grid connected customers with or without renewable energy capacities. Another option is to use batteries within hybrid mini-grids for off-grid energy supply. These possibilities and estimations for the related market size are given for the following five fields of application: Households and villages, commercial sector, tourism, telecommunication, health care and administrative buildings.

4.3.1 Households and villages

The residential sector bears a limited market potential for battery storage technologies. Generally, only a small portion of high income households would be financially capable for investing in battery storage technologies. Furthermore, the average daily electricity consumption is very low although high income households almost reach the level of average European households. Figure 19 highlights the daily electricity consumption for low, medium and high income households in three different regions of Tanzania (REA 2014). For the residential sector battery technologies can be applied both in on-grid and off-grid surroundings. In the case of households connected to the grid, batteries serve as back-up supply and in case of off-grid locations, batteries are implemented in combination with a renewable power generation system as explained in section 2.3. As previously mentioned the market potential in the residential sector is assumed to be limited although some households may value energy security despite the high investments necessary. The main competitors of batteries in the residential sector are diesel generators providing back-up supply. Therefore a market potential is likely to be found in regions with high diesel costs (compare Figure 15) and significant electricity sales (compare Figure 16 on the right).

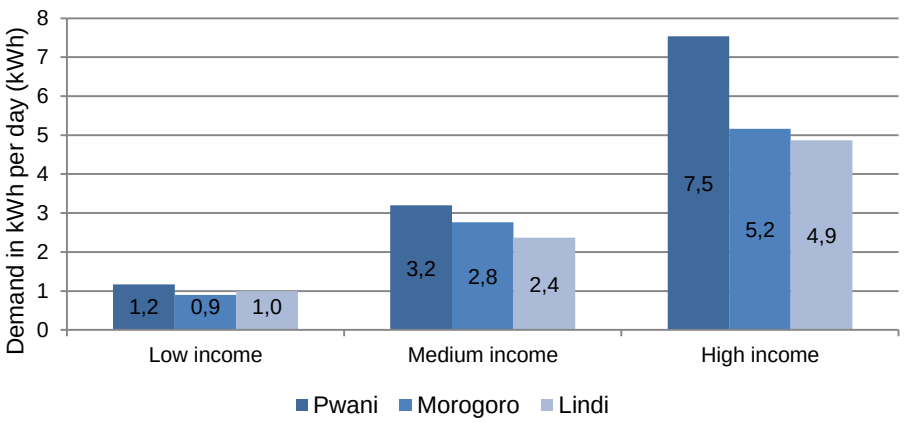

Figure 19: Electricity consumption per day for low, medium and high income households in different regions of Tanzania

Source: National electrification prospectus (REA 2014)

A potential market segment for battery storage technologies will evolve with the ongoing electrification of villages in rural Tanzania. In the year 2014 on average 18% of households had access to electricity with 45% in urban areas and 6% in rural areas of Tanzania (REA 2014). The low electrification rate is considered as one of the main barriers for economic development and increasing the access to electricity is one major objective of the GoT. Access to electricity shall be realized in steps of 30% by 2016, 50% by 2020 and 75% by 2035 (REA 2014). A strategy achieving these goals has been developed by the National Electrification Prospectus commissioned by the Rural Energy Agency (REA).

Proposed activities to increase access to electricity are densification of connections in urban areas, extension of the transmission grid to rural areas and off-grid electrification in remote areas. Off-grid electrification realised with renewable based off-grid systems implies a large market potential for battery storage technologies. Batteries are inevitable for storing intermittent renewable energy and shifting generated solar power from the day to the main hours of consumption during the evening. Both LABs and LIBs can play a significant role here although currently LABs are predominantly deployed. The main factors determining the attractiveness for battery storage technologies are the remoteness and the diesel fuel prices. In a study from 2013 focusing on nine selected diesel-fuelled off-grid locations in Tanzania it has been shown that hybridization with PV and LABs is cost-effective at battery capital expenditures (CAPEX) of 475 EUR/kWh (under PV CAPEX of 2,000 EUR/kW and fuel costs ranging between 1.3 and 1.4 EUR/l) (Bertheau et al. 2014). CAPEX for batteries and PV already fell below the mentioned thresholds and diesel fuel costs are in the mentioned range in some areas of the country (compare Figure 15).

Within the National Electrification Prospectus activities recommended for increasing the access to electricity are the densification of grid connection in urban areas or grid extension to rural areas. Generally, grid connection is considered to be more cost-effective compared to off-grid solutions for locations within a distance of 10 km to medium voltage lines, a population larger than 500 and a not too scattered settlement structure (REA 2014). Nevertheless, these assumptions have to be evaluated and even under these assumptions grid connection is realized for only roughly 5,500 settlements by 2022 leaving more than 6,000 settlements for off-grid electrification (REA 2014). Even though villages are planned to be connected to the grid in 2022 a supply by a PV-battery system could be realized in the meantime. Figure 20 provides an overview about the electrification status in the country. On the left image electrified and non-electrified villages are depicted and on the right image the planned date for a connection to the grid is outlined.

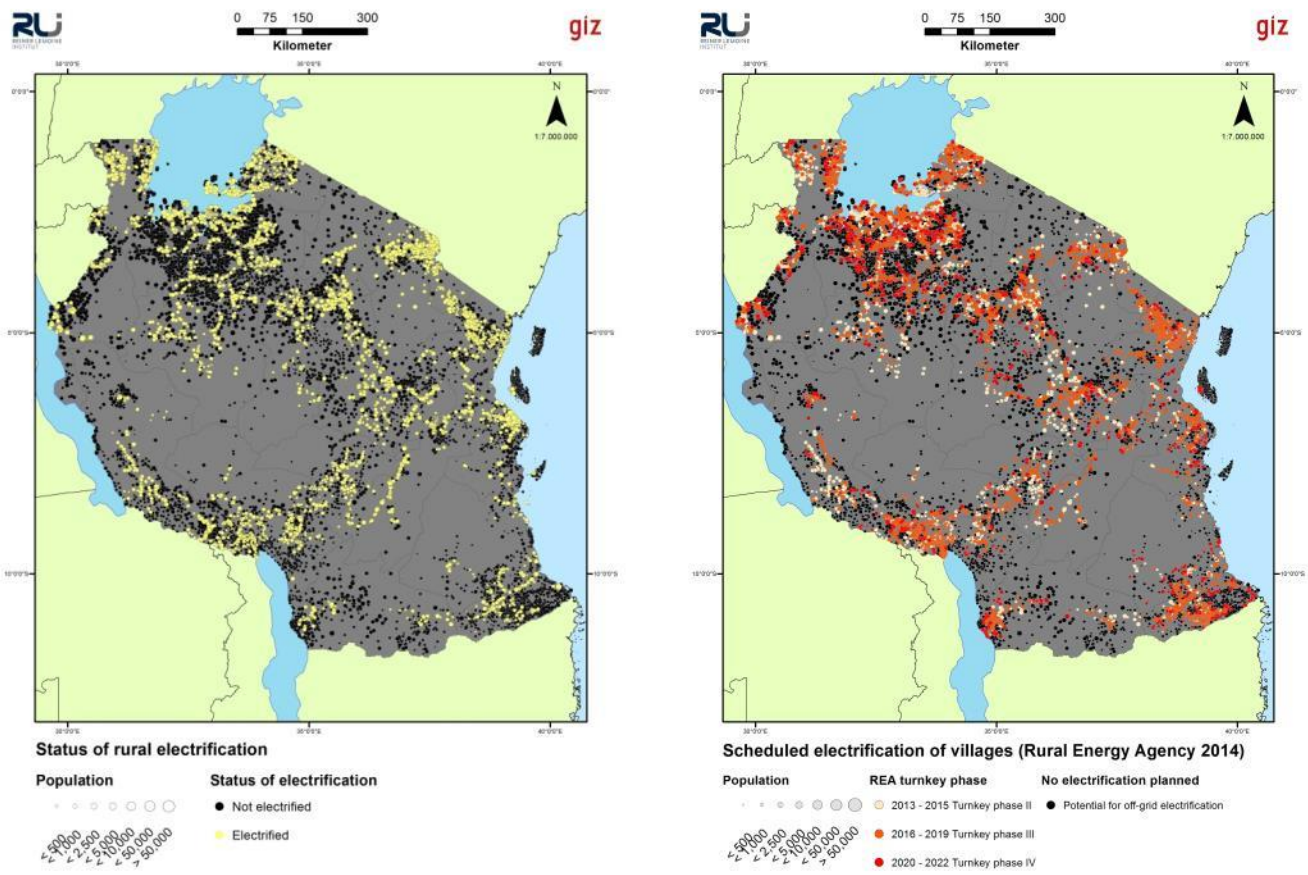

Figure 20: Status of rural electrification (left side) and scheduled link to transmission system for villages of Tanzania (right side)

Source: Own illustration according to National electrification prospectus (REA 2014)

To conclude, the grid connected residential sector is not expected to develop a significant demand for battery systems within a short period due to the low income and low electricity consumption of average Tanzanian households. Rural electrification bears a large potential for storage technologies as batteries are necessary for continuous electric power supply and the optimized exploitation of renewable energies. The market potential depends upon how quickly the intended electrification processes are realized and which technologies are going to be applied.

4.3.2 Commercial sector

The definition of the commercial sector in this work refers to the agricultural, industrial, manufacturing and service sector. The contribution to the GDP and main products are described in section 4.1.

The market potential for battery systems in the commercial sector is high due to the enormous demand for back-up power supply systems. This is further highlighted when taking into account an enterprise survey conducted by the World Bank. Among the ten biggest obstacles for doing business in Tanzania, the top three are access to finance (37.9%), reliability of electricity supply (24.9%) and tax rates (8.3%) (World Bank 2013). When taking the size of the surveyed enterprises into consideration the situation becomes even more critical (compare

Figure 21). Large companies with more than 100 employees consider the supply with electricity as the by far (45.4%) largest obstacle for doing business followed by medium sized enterprises which consider unreliable electricity supply (24%) almost as severe for their business as the lack of financing instruments (25.1%) (World Bank 2013). The companies lose on average 15.5% of annual sales because of power outages. As an adaptation strategy a high percentage (54.3%) of companies operates diesel generators for back-up power supply. These generators contribute 26.1% to the companies power supply. These facts highlight the demand for battery storage systems but as well the high maturity of diesel generators which are the key competitor for battery storage systems in Tanzania.

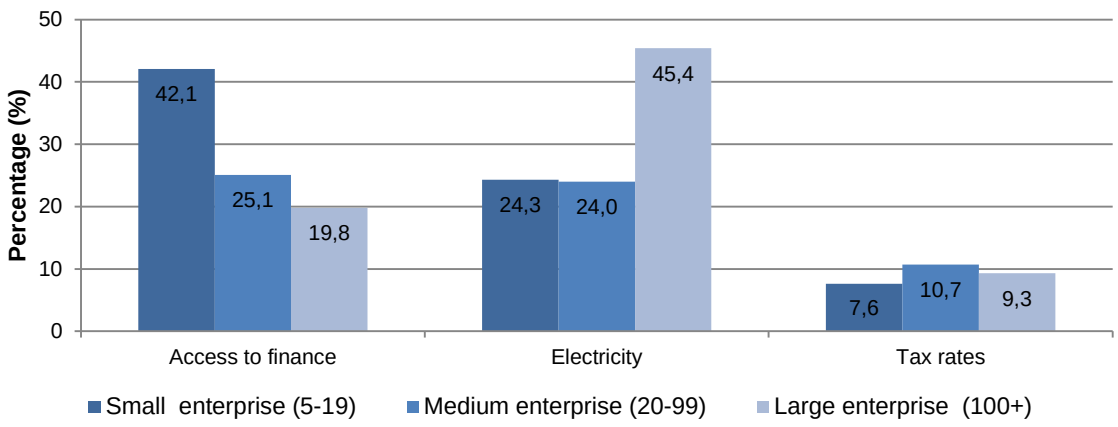

Figure 21: Three biggest obstacles for doing business in Tanzania for enterprises[3]

Source: World Bank (2013)

The statistics stated above underline the necessity of back-up power supply for the commercial sector. Potential markets are evolving both in the on-grid and off-grid contexts. Within the grid-connected areas the demand for back-up systems rises mainly from the service sector (computers, phones, office devices, air condition) and small industries (machines, tools). Batteries are especially of

[3] Number of employees in brackets

interest for customers suffering from frequent but short power outages or frequency instability. Both battery technologies LIB and LAB can be applied here, although LIBs fit better due to the technical abilities to quickly charge and discharge. Already a large number of diesel generators is operated by companies with connection to the grid in case of blackouts. The economic attractiveness of battery systems compared to diesel generators strongly depends on the necessary capital expenditures and operational expenditures (OPEX) but as well on the typical scheme of blackouts. In the case of short and frequent outages the efficiency and life span of diesel generators are quickly reduced due to frequent starts of the engine (Huyskens & Blechinger 2014). Battery systems are more capable of compensating short and frequent outages as shown in section 2.3.

Customers connected at the end of electric power grids face a different situation. The grid is often overloaded and performs weak with long lasting power outages. Commercial customers in such framework conditions are mostly agricultural processing companies. The main agricultural products processed are sisal, coffee, tea, vegetables and flowers. Electricity is mainly consumed for water pumping and irrigation systems, processing machines, workshops and offices. Most commonly the water pumping devices are consuming the largest share of electricity (up to 85%) for agricultural customers. Typical electrical consumption for this type of customers is in a range of 1,200 kWh to 3,000 kWh per day (AHK 2015). However, some larger processing companies consume significantly higher amounts of electricity and the electric consumption depends on the season in the agricultural sector. Agricultural customers have a demand for back-up power supply which is already realised by diesel back-up generators. To substitute these generators by battery systems only could bear a market potential for battery systems, but it is most likely that this will happen in combination with the implementation of renewable energy capacities. This would enable a higher utilization of the generated solar power depending on the time of consumption. The agricultural sector bears an interesting market potential mainly in combination with solar PV. However, farms can take advantage from crop residues and implement biogas or combustion plants.

The demand from the commercial sector originates both, from customers located apart from the grid and within the grid. Especially for customers with grid connection batteries are a promising solution for substituting diesel generators as the companies are already spending a significant share of their income for diesel fuel. Grid-connected customers are mainly small industrial companies located in the vicinity of urban areas or agricultural processing companies on the far end of the grid system with weak supply.

Apart from the grid-connected areas a demand exists mainly from industries located in remote locations such as mining companies. With the increasing installation of solar PV power plants, the market potential for batteries is further increasing. Most influencing are the local specific diesel costs

4.3.3 Tourism sector

While taking the wider effects of the tourism industry (e.g. investments and supply chain) into consideration, the total contribution of Travel & Tourism to the Tanzanian GDP was 14.0% in 2014, and is expected to rise 6.6% every year by its own value until 2025 (WTTC 2015). It primarily reflects the economic activity generated by industries such as hotels, travel agents, airlines and other passenger transportation services, but also includes, for example, the activities of the restaurant and leisure industries directly used by tourists. Tourism directly generated 402,500 jobs in 2013 (3.8% of total employment) and indirectly 1,196,000 jobs in the same year. In terms of capital investments the tourism sector accounts for more than 800 million EUR in 2013 and is expected to rise to 9.6% of all investments to Tanzania in 2024 (WTTC 2014). Tanzania attracted almost 800,000 international visitors in 2011 (UNWTO 2011) which increased to over one million tourist arrivals in 2013 (WTTC 2014). According to the database of the Tanzania Tourist Board (TTB) there are 110 licensed accommodation facilities. These are comprised by hotels (52), lodges (30) and tented camps (28) (TTB 2015). Accommodation facilities hold a total capacity of 65,000 rooms (AHK 2015). Nevertheless, it is expected that the capacities of the tourism sector are significantly larger than depicted by these numbers as many accommodation facilities are not licensed by the TTB. Most of the hotels and lodges are located in urban areas and have grid connections.

The touristic centres of mainland Tanzania are Arusha and Dar-es-Salaam (TTB 2015). Table 18 (in Annex 4) provides an overview about the quantity of licensed tourism facilities in mainland Tanzania. Average hotels consume between 500 and 1,500 kWh per day. However the consumption strongly depends upon the accommodation capacity. Major power consumers within touristic facilities are commonly laundry and kitchen. Further demand origins from air conditioning, fans and lighting in the guest rooms. For a detailed listing of all the tourist facilities in the different regions please refer to Annex 4.

The Zanzibar archipelago is the most important tourism destination of Tanzania. More than 237 hotels and accommodation facilities are located on both islands (ZCT 2015). Furthermore almost all hotels have back-up power generation facilities in place which is highlighted in a survey among hotels on Zanzibar island which found out that without any exception each hotel had a diesel back-up generator (Mathematica 2011). This makes the tourism sector a very interesting market field for batteries. For grid-connected hotels batteries can significantly reduce the expenditures for diesel fuel and therefore allow a saving of expenditures. The most interesting regions are Arusha, Dar-es-Salaam and the Zanzibar Archipelago as the most hotels are located in these regions.

Another market area is found for hotels and lodges which are located apart from the grid. Generally, the electricity there is generated by diesel generators. The market potential for solar PV systems in this field of application is estimated to be in a size of 2 MWp (AHK 2015) of which a significant battery storage potential can be derived.

Tourism facilities are expected to be a strong market field for battery technologies as they highly value energy security for their customers and have an additional interest in utilizing a high share of renewable energies as a further added value in the eco-tourism sector.

4.3.4 Telecommunication sector

Similar to other Sub-Saharan countries the growth rate of mobile phone users increased remarkably in recent years and is totally unbundled from access to electricity supply in Tanzania. The mobile connection rate reached 32.3 million people in 2014 which results in market penetration rate of 62.4% (GSMA 2015a). The mobile network 2G covers 41% of the total area and approximately 76% of populated areas. Nevertheless the coverage of the 3G network which enables access to the internet is much lower with 27.6% (GSMA 2015b).

Figure 22 provides an overview about the mobile network 2G coverage for the example of the Vodacom mobile network.

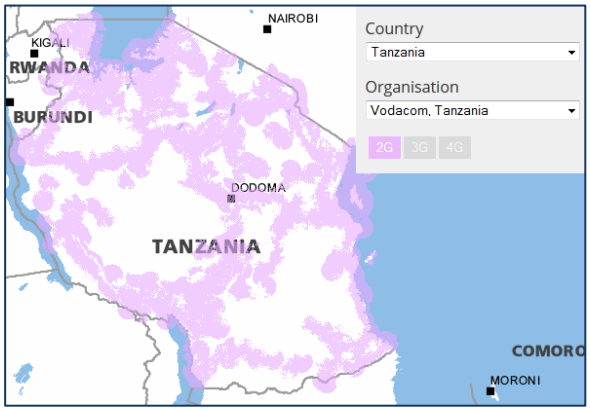

Figure 22: Mobile network coverage of 2G network for the example of Vodacom

Source: GSMA (2012)

Vodacom and Airtel have around 10 million customers each and the smaller company Tigo has around 7 million customers. According to the AHK (2015) report each of them operate around 2000 telecommunications towers (AHK 2015). Other sources from 2012 cite at least 4,600 telecom towers in operation in Tanzania (GSMA 2012). An annual growth rate of 19% p.a. is expected which results in an approximate additional of 1,000 towers each year (GSMA 2012). Out of the existing telecom towers two-third are connected to the grid contrasted by the remaining one-third of telecom towers operating off-grid. Nevertheless, almost all telecom towers have a diesel based or hybrid back-up power supply system installed due to frequent power outages. From all grid-connected telecom towers in Tanzania in 2012 (3,151), 18.5% faced power outages longer than 12 hours per day, 33.3% were affected by

blackouts between 6 – 12 hours per day and 48.1% faced power outages below 6 hours per day (GSMA 2012). The energy costs for both, telecom towers operating on the grid and off the grid are comprised by high costs for purchasing diesel itself and diesel transportation costs (compare Figure 23). To conclude telecom power bears a high market potential when it is realized to compete with diesel generators.

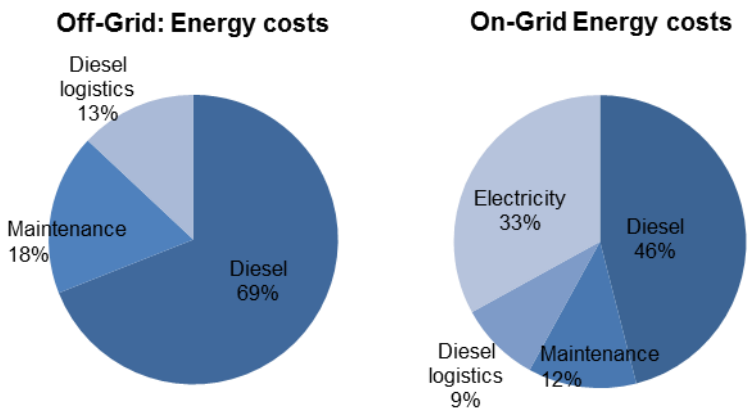

Figure 23: Electricity supply costs for off-grid and on-grid operating telecom towers

Source: GSMA (2015c)

4.3.5 Health care and administrative buildings

This section highlights the potential for back-up power supply for health care facilities and public infrastructure. Although this work focuses on health care facilities with regard to their essential demand for electricity in order to provide sufficient services, it shall be pointed out that further administrative buildings and customers (e.g. administrative buildings of national parks, remote police and governmental stations) are an interesting market segment for battery storage systems as well.

A reliable electricity supply is essential for health infrastructure. If, for example, the cold chain is interrupted vaccines, blood, and other medicines are wasted. Furthermore, having an appropriate illumination is prerequisite for proper medical treatment and several medical appliances rely on electricity supply. Thus, the application of battery systems providing back-up power for health stations is not only an economic issue but also crucial to sustain vital services. In Tanzania the health system is largely underdeveloped and not satisfactory. Although 7% of GDP are spent for the health sector there is only one physician available for every 125,000 inhabitants and one nurse for every 5,000 inhabitants (World Bank 2015). Health care is mainly provisioned by governmental owned facilities comprised of dispensaries, health centres, clinics and hospitals. Figure 24 provides an overview about the spatial location of these facilities.

As mentioned before the health infrastructure in Tanzania can be distinguished in dispensaries, health center, clinics and hospitals. Dispensaries serve a population of 6,000 to 10,000 people. They are the smallest and most basic health facilities. These locations typically have no permanent doctor or nurse on staff. Dispensaries serve minor illnesses and minor injuries. In dispensaries only limited medical equipment is used and there is not necessarily a refrigerator in place. The overall energy demand of a dispensary is low with approx. 5 - 10 kWh/day. Health centres provide services for a population up to 50,000 people. These centres are generally larger than dispensaries and health care is provided by nurses and as well by part-time physicians, depending on the size and location of the facility. A health centre offers a wider array of services than a dispensary and possesses equipment allowing for more sophisticated procedures. The low energy requirements of 10 – 20 kWh per day result from the consumption for lighting, maintaining the cold chain and utilizing basic lab and surgery equipment.

Clinics are health facilities covering areas with up to 250,000 people. Educated medical staff is employed. Furthermore, clinics may accommodate more sophisticated diagnostic medical equipment and perform more complex surgical procedures. The energy demand

differs largely depending on the size of a clinic from 20 – 50 kWh/day. Hospitals serve as referral stations for clinics. Here a large number of medical staff is employed. Energy demand is comprised by medical devices, air- conditioning, office activities, cleaning and laundry services. The daily energy demand can increase up to 800 kWh. Table 19 provides an overview about the number of health facilities per region. For a detailed listing of all the medical facilities within the regions please refer to Annex 5.

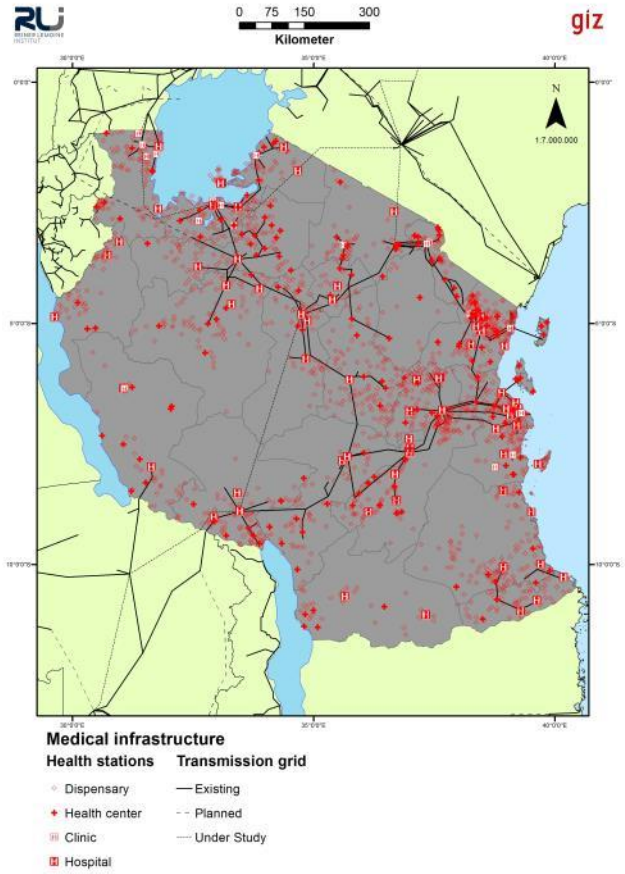

Figure 24: Health care infrastructure in Tanzania

Source: National electrification prospectus (REA 2014)

At a hospital located in Southern Tanzania with no connection to the grid a daily consumption of 160 kWh was recorded (IEA-PVPS 2014). The hospital has a capacity of 157 beds and serves a population of approx. 160,000. The main electricity was consumed by lighting (39%), office appliances (26%), medicinal equipment (11%) and water pumps (10%). The quality of supply is a decisive factor for the health facilities as medical equipment needs to be available at any time (IEA-PVPS 2014).

A study estimated that approx. 50% of all health facilities are provided with access to electricity and 30% with access to reliable electricity supply (no power outages longer than 2 hours) (Practical Action 2013). This once again highlights the demand for battery systems in health facilities with connection to the grid and off-grid. In both situations batteries enable the energy security in case of no supply by renewables or power outages. The improvement of health facilities has attracted donor organizations like USAID which have already supplied a larger number of health facilities in recent years. The demand is expected to grow and donor funded projects supplying hospitals with renewable energy and battery systems might further arise.

5. Economic feasibility study

To assess the economic viability of batteries for back-up energy supply a user-friendly Microsoft Excel based simulation tool has been developed which is presented in the first part of this chapter. In the second part this tool is applied for certain case studies to understand potential business opportunities.

5.1 Battery systems dimensioning tool

The simulation tool for back-up power supply systems allows the comparison of battery storage systems with other back-up power technologies such as diesel generators. For wider distribution the simulation tool is provided in Microsoft Excel (available at www.giz.de/projektentwicklungsprogramm).

The tool assesses the capability of LIBs or LABs to compensate power outages and compares them to diesel generators and potential losses in production. Based on the technical and economic characteristics of each technology, its cost effectiveness is analysed. In addition, the interactions of battery storage systems with installed PV plants are outlined. The demand patterns of the end-user comprise the daily electricity demand (kWh), daily load profile (temporal distribution of electricity demand), and frequency and duration of power outages.

The daily electricity demand, differentiated for weekdays and weekend, needs to be provided. Default values for a number of customer groups are given. The individual load profile of the user is depicted by the hourly demand for one reference day on a percentage basis. Typical load profiles are provided as default values showing either evening peaks or midday peaks. Furthermore, the user describes the typical duration of power outages for each hour of the day in steps of 15 minutes, and determines their frequency (daily, every other day, once a week and once a month).

The data is extrapolated to an entire project year to study the requirements which have to be fulfilled by a back-up power system in order to supply electricity in unserved time periods. The described approach is illustrated in Figure 25.

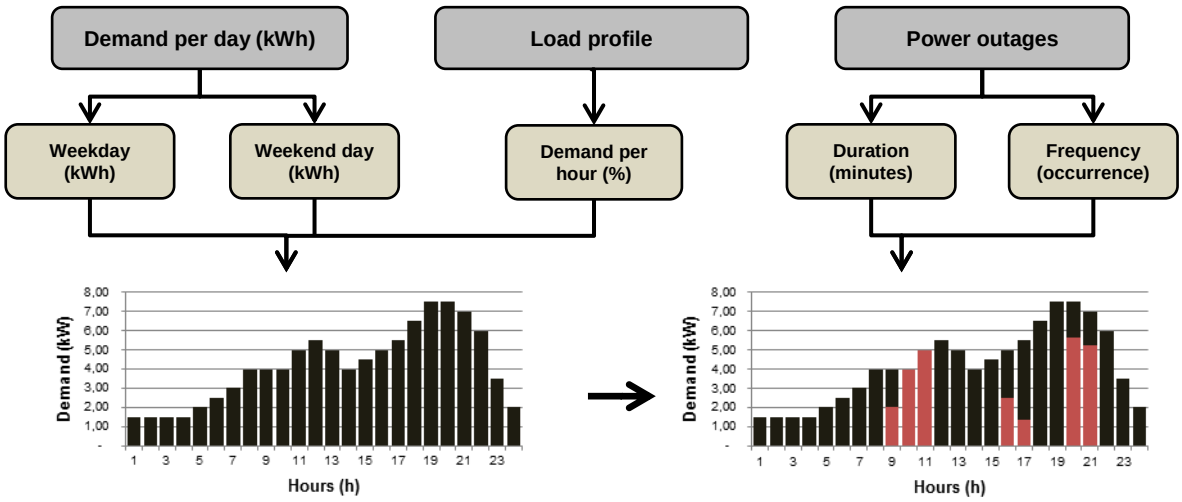

Figure 25: Information necessary to quantify the demand for back-up power supply

Source: Own illustration

After the demand for back-up power supply has been assessed, the technical and economic parameters of the technologies that are being compared are to be revised, and project-specific data entered.

The efficiency of batteries depends on the installed capacity, C-rate, depth of discharge, and respective state of charge (SoC) at the time of a power outage. The charging and discharging efficiencies describe the losses of grid-generated electricity during charging and discharging cycles. Economic parameters that determine the efficiency of battery systems are their CAPEX per capacity (kWh) including inverters, charge controllers, installation costs and other initial costs. In addition, the operating expenditures per installed capacity per year (kWh) and per provided energy unit (kWh) are taken into account (see Table 6). The tool provides typical economic and technical values for both, LABs and LIBs. Alternatively, individual parameters to define battery systems may be inserted. That allows for any battery technology to be technically studied through the tool.

Table 6: Economic and technical parameters for battery systems considered in the battery systems dimensioning tool

Economic input parameters	Description	Technical input parameters	Description
Battery capacity CAPEX (EUR/KWh)	Capital expenditures afforded per each kWh installed (EUR/kWh)	C-rate (kW/kWh)	Ratio of power to the total storage capacity. The C-rate is commonly provided in power per capacity
Battery OPEX var. (EUR/kWh)	Operational expenditures per kWh stored	Max. depth of discharge (%)	Battery capacity that can maximally be discharged related to the total capacity.
Battery OPEX fix. (EUR/kWh)	Operational expenditures per kWh capacity installed	Charging efficiency and discharging efficiency (%)	The amount of energy which a battery can deliver in relation to the energy injected during charging and discharging.
		Life span (years)	Technical lifetime of battery

The capability of a diesel generator to compensate power outages is defined by the installed power capacity (kW). It is assumed that the diesel generator may provide the demand, given continuous fuel supply. The efficiency rate (%) defines the energy conversion rate from diesel fuel (kWh_{th}) into electricity (kWh_{el}). If operated under full load, diesel generators can achieve high efficiencies of 35% to 45%. However, in most cases efficiencies move in the range of 20% to 30% due to partial load operation, small sizes and insufficient maintenance. From an economic perspective, diesel generators are characterized by CAPEX per kW and OPEX per kWh generated. Compared to battery systems, OPEX for diesel generators are usually higher – mainly because of fuel expenditures, but also due to the rotating parts of the engine and the need for supplies such as lubricant oils. Fuel expenditures are determined by the conversion efficiency and the fuel prices. Characteristics of diesel generators are presented in Table 7.

Table 7: Economic and technical parameters for diesel generators considered in the battery systems dimensioning tool

Economic input parameters	Description	Technical input parameters	Description
Diesel CAPEX (EUR/kW)	Capital expenditures afforded per each kW installed	Efficiency (%)	Efficiency factor for converting diesel fuel into electrical energy
Diesel OPEX var. (EUR/kWh)	Operational expenditures afforded per each kWh generated.	Oversizing (times x)	Multiplier defining the size of the diesel generator in relation to the peak load
Diesel OPX fix. (EUR/kW)	Operational expenditures afforded per each kW installed.	Life span (years)	Technical lifetime of diesel generator

As for project-specific parameters, the interest rate defines the economic attractiveness of a loan and the annual capital expenditures for an investment over the project lifetime. The capital recovery factor (annuity factor) is calculated by taking into account the lifespan of a technology and the interest rate (see Equation 1).

$$Capital\ recovery\ facor\ (CRF) = (Interest\ rate * (1 + Interest\ rate)\hat{}Lifetime)/((1 + Interest\ rate)\hat{}Lifetime - 1)$$

Equation 1: Capital recovery factor. The CRF is set according to interest rate and lifetime of technology

The costs for diesel fuel are the main driver for diesel generator expenditures. A litre of diesel usually contains a heat value of 10.8 kWh_{th}. To calculate the power output per litre of diesel fuel the efficiency rate is applied.

For the batteries, it is assumed that electricity is provided from the grid in times of stable grid supply. The charging and discharging efficiencies of the respective battery type determine the amount of electricity needed to compensate outages. Charging costs depend on the customer tariff. The latest electricity tariffs for the TANESCO grid are listed in Table 5.

Annual losses in sales are also considered through taking into account annual earnings and the loss rate. Furthermore, the tool provides a sensitivity analysis to changing input parameters. All described additional economic input parameters are presented in Table 8.

Table 8: Economic parameters considered in battery systems dimensioning tool

Economic input parameters	Description	Technical input parameters	Description
Interest rate (%)	Interest rate of loan provided for investment in back-up storage systems	Annual sales (EUR or TZS)	Annual sales of company
Diesel fuel costs (EUR/litre)	Cost per litre of diesel fuel	Losses due to electrical outages (% of annual sales)	Annual losses due to power outages in percent of annual sales
Electricity tariff (EUR/kWh)	Costs per kWh electricity provided	Sensitivity range (%)	Sensitivity range for varying input parameters

For the dimensioning of back-up supply systems, different approaches are used for diesel generators and battery storage systems. The decisive dimensioning factor for a diesel generator is the largest power demand that occurs during blackouts in one year multiplied by the oversizing factor. For batteries two different scenarios are designed: a 100 percent secure back-up power and a standard security. In the first case, the battery storage system is sized accordingly to the worst-case power outage according to the input parameters, meaning that all power outages occur on the same day. In the latter case, the battery storage system is sized accordingly to the statistical power outages, which means that the frequency of each power outage is taken into account. The distinction is necessary as both systems may vary largely in terms of their economic attractiveness.

Battery 100% secure supply

This system is designed according to the “worst case”. It assumed that all power outages inserted by the user occur at the same day independently from the provided frequency of outages. For the dimensioning of the battery system the largest capacity necessary for compensating a power outage is the decisive factor. This battery system is capable of facing all power outages described by the user during one day. However, it is probably oversized as the probability for the worst case to happen is low.

Battery standard secure supply

This system is designed according to the “realistic case” or “statistical case”. The necessary back-up capacity is calculated according to the provided duration and frequency of power outages. The decisive value is the capacity necessary to compensate the largest power outage over several hours. This system provides sufficient back-up supply for the largest part of cases.

As described above, the dimensioning of the two distinct battery systems is based on the worst-case blackout and the largest blackout. The same methodology to calculate the system size is applied for both battery systems. The minimum power capacity for the battery

is determined based on the maximum power demand (*Blackout_power_max*) during outages. The maximum power demand is divided by the discharge efficiency and leads to the minimum power capacity of the required battery (*Battery_power_min*) (see Equation 2).

$$Battery\_power\_min = ((Blackout\_power\_max)/Efficiency\_discharge)$$

Equation 2: Calculation of battery power capacity

The storage capacity of the battery is calculated according to the largest occurring blackout over time (*Blackout_max*). The battery capacity is also influenced by the maximum depth of discharge (*DoD_max*) and the discharge efficiency (see Equation 3).

$$Battery\_capacity\_min = ((Blackout\_max)/DoD\_max)/(Efficiency\_discharge\ )$$

Equation 3: Calculation of battery storage capacity

Consequently, the ability of the battery system to provide the amount of electricity needed is tested for each hour of the year, taking into account the respective state of charge. If the battery is charged below the maximum depth of discharge at any time the battery capacity is automatically increased. In a final step battery power and capacity are adjusted to meet the fixed C-rate which is previously defined. To this end, either the power capacity or storage capacity are increased until the required ratio of power and capacity (C-rate) is reached and therefore the final battery configuration is determined.

It is also possible to include PV plants in the simulation tool. The solar PV capacity does not influence the dimension of the battery though as it is not able to provide a 100 percent security at any given time. A solar PV system influences the result in two ways: the demand for back-up energy decreases, and surplus energy may be stored in the battery.

The economic viability of each solution is defined through capital expenditures (*CAPEX*), operational expenditures ($OPEX_{fix}$ and $OPEX_{var}$) expenditures for fuel ($Costs_{diesel}$) or electricity charging ($Costs_{el}$). The capital investment is annualized taking into account the CRF. Equation 4 shows the calculation of the final cost per back-up kWh power by batteries or diesel generators.

$$LCOE\_backup = (CAPEX * CRF + OPEX\_fix + OPEX\_var * Energy\_backup + Costs\_diesel + Costs\_el)/Energy\_backup$$

Equation 4: Calculation of levelized costs of back-up energy ($LCOE_{backup}$)

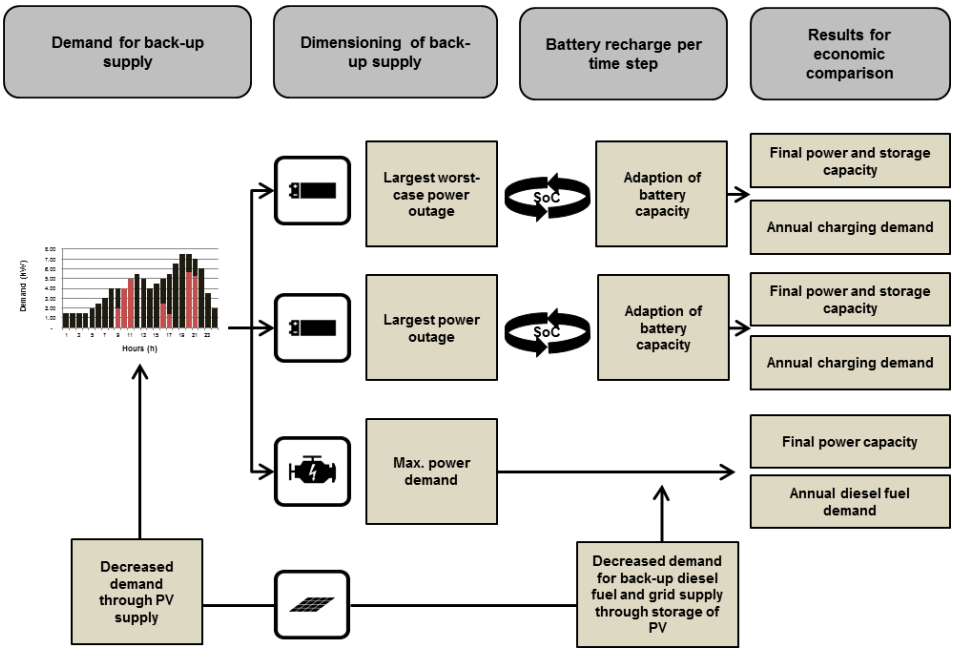

Figure 26: Work flow of battery systems dimensioning tool

Source: Own illustration

Figure 26 summarizes the entire workflow. Key parameters and charts provided in the tool are listed in in Table 9.

Table 9: Key output parameters of battery systems dimensioning tool

Battery (100% and standard secure supply)	Diesel generator	Economic results
Required installed capacity	Required installed capacity	Energy demand
Required installed power	Total Investment	Energy supplied
Total Investment	Annual CAPEX	Blackout
Annual CAPEX	Annual OPEX fix	PV energy supplied
Annual OPEX fix	Annual OPEX var.	PV supplied while blackout
Annual OPEX var	Annual fuel costs	Blackout minus PV supplied
Annual charging costs	Annual fuel consumed	Losses due to electrical outages per year
Total annual costs	Total annual costs	
Annuity factor	Annuity factor	
LCOE battery back-up energy	LCOE diesel back-up energy	Losses per kWh blackout

5.2 Case studies

In the following section the developed dimensioning tool for grid-connected battery backup systems described in section 5.1 is applied. Case studies for the residential, commercial, tourism, telecommunication and public sector are calculated. These case studies are related to the market segments identified and described in section 4.3. If available, real load data and power outage data is applied. For each case study the same technical and financial parameters are applied. Further economic parameters (diesel costs, electricity costs, interest rate) are adapted to the respective case study.

5.2.1 Input parameters

For the case studies the LIB and LAB cost parameters and technical parameters are set within a range of the values found during literature review and interviews with battery manufacturers and battery experts for this study (compare Table 2). The applied values are listed in Table 10.

Table 10: Values applied for lithium-ion batteries and lead-acid batteries within the case studies

Input parameter	Description	Lithium-ion battery	Lead-acid battery
Battery capacity CAPEX (EUR/kWh)	Capital expenditures afforded per each kWh installed	1,000	350
Battery OPEX var. (EUR/kWh)	Operational expenditures per kWh stored	/	/
Battery OPEX fix. (EUR/kWh)	Operational expenditures per kWh capacity installed	10	7
C-rate (kW/kWh)	Ratio of power to the total storage capacity. The C-rate is commonly provided in power per capacity	1/1	1/3

Max. depth of discharge (%)	Battery capacity that can be, maximally discharged related to the total capacity	80	50
Charging efficiency and discharging efficiency (%)	Amount of energy which a battery can deliver in relation to the energy injected during charging and discharging	95	90
Life span (years)	Technical lifetime of battery	12	8

Values for the diesel generator are selected based on literature values, manufacturer information and experience from field work. The input parameters applied for the diesel generator are listed in Table 11.

Table 11: Values applied for diesel generator within the case studies

Input parameter	Description	Diesel generator
Diesel CAPEX (EUR/kW)	Capital expenditures afforded per each kW installed	300
Diesel OPEX var. (EUR/kWh)	Operational expenditures afforded per each kWh generated	1
Diesel OPX fix. (EUR/kW)	Operational expenditures afforded per each kW installed	0.05
Efficiency (%)	Efficiency factor for converting diesel fuel into electrical energy (kWh_{th} to kWh_{el})	25
Oversizing (times x)	Multiplier defining the size of the diesel generator in relation to the peak load	1.5
Life span (years)	Technical lifetime of diesel generator	15

5.2.2 Households

Background information, load and power outages

The first case study refers to the residential sector described in subsection 4.3.1. Within the residential sector only a small share of high income households may be willing to buy batteries as back-up power systems. This is due to their higher electricity demand, capability of spending the required upfront investment and greater interest in energy security when compared to other income classes.

The presented case study shall reflect a high income household in the state of Arusha. Currently, this state is affected by regular long-lasting power outages. The assessed household has an assumed average daily demand of 6 kWh which corresponds to the average demand stated for high income households of Tanzania (REA 2015). The load profile applied is typical for residential consumers (see Figure 27) with slowly increasing demand over the day peaking during noon with 0.33 kW and during evening with 0.45 kW. Blackouts are occurring on a daily basis from 11:30 AM to 6:30 PM which is reflecting the recent experiences collected during a field trip in March 2015[4].

[4] Personal communication Catherina Cader 16th of April 2015

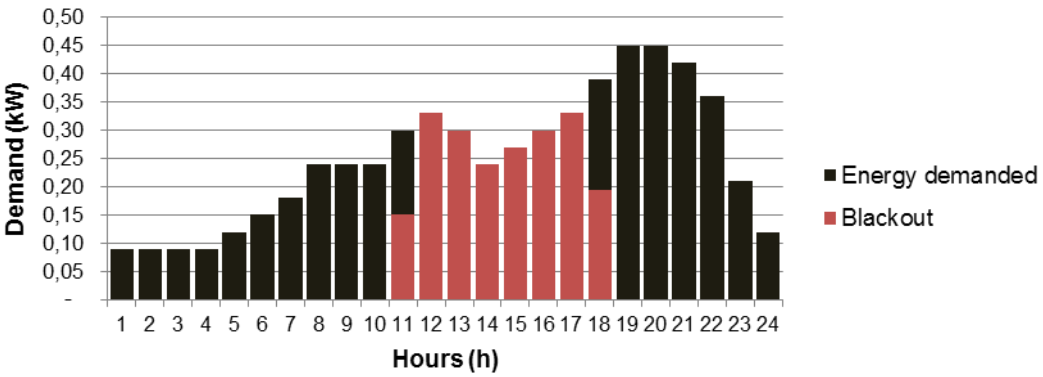

Figure 27: Assumed load profile and power outages for household case study

Source: Own illustration

Specific input parameters

It is assumed that the investment costs for the back-up system are covered by equity only, therefore financing costs are avoided. Diesel fuel costs are set at 1.00 EUR/l which is slightly higher than the cap prices of 0.87 EUR/l for Arusha (Figure 15). Additional costs per litre of diesel reflect expenditures for transport, storage and services. For residential customers with high and medium income electricity tariff group T1 is applied with 0.15 EUR/kWh (see Table 5). Furthermore, it is assumed that a solar PV system with a capacity of 1 kWp is already installed by the customer allowing self-consumption and feeding excess energy to the batteries.

Results

Up to 35% of the demanded electricity is not sufficiently supplied by the grid due to blackouts. A small diesel/gasoline generator with a peak capacity of 600 W would be able to compensate these outages under the precondition of continuous fuel supply. This solution would be the most cost-effective with LCOE of 0.30 EUR/kWh. The attractiveness of the diesel generator is especially comprised by the low initial investment of 176 EUR, however annual fuel costs exceed the initial investment with 180 EUR and with the additional costs for maintenance the operational costs are rising quickly over the lifetime.

In contrast to that, battery back-up systems are characterized by high investment costs and low operational costs. A LAB with a storage capacity of 3.9 kWh is capable of providing the back-up power required unexceptionally and is almost as competitive as diesel generators under the given assumption in terms of LCOE with 0.305 EUR/kWh. Even though the initial investment for the LAB are 8 fold higher than for the diesel generator the annual costs are only 4 EUR higher. LIBs would require a smaller storage capacity of 2.3 kWh but are the most expensive back-up solution with 0.32 EUR/kWh. Finally this case study shows that battery back-up systems can reach costs close to that of diesel generators even for application in the residential sector. Battery storage systems can become more cost-effective than diesel generators if fuel costs increase or battery CAPEX decrease slightly.

Table 12: Results of battery systems dimensioning tool for household case study

Lead-acid battery			**Diesel generator**		
Parameter	*Value*	*Unit*	*Parameter*	*Value*	*Unit*
Installed capacity	3.9	kWh	Installed capacity	0.6	kW
Installed power	1.3	kW			
Total Investment	1,376.6	EUR	Total Investment	175.5	EUR
Annual CAPEX	172.1	EUR	Annual CAPEX	11.7	EUR
Annual OPEX fix	27.5	EUR	Annual OPEX fix	0.6	EUR
Annual OPEX var.	0.0	EUR	Annual OPEX var.	38.6	EUR
Annual charging costs	35.7	EUR	Annual fuel costs	180.4	EUR
			Annual fuel consumed	180.4	litre/a
Total annual costs	235.3	EUR	Total annual costs	231.2	EUR
Annuity factor	0.13		Annuity factor	0.07	
LCOE battery back-up energy	**0.305**	EUR/kWh	LCOE diesel back-up energy	**0.300**	EUR/kWh

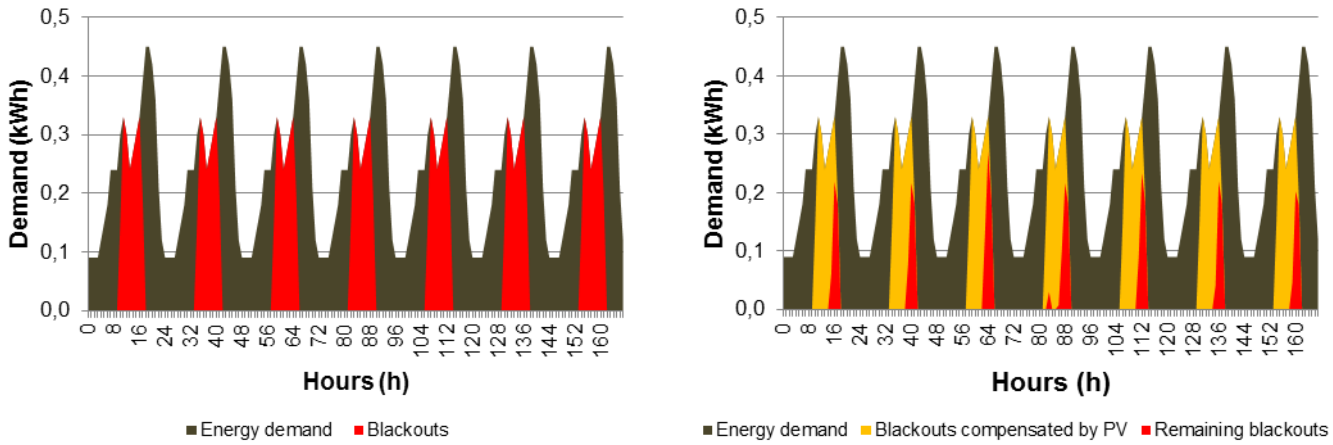

Figure 28: Blackouts (left side) and blackouts reduced by solar PV (right side)

Source: Own illustration

The installed solar PV system is significantly decreasing the demand for electricity during power outages (Figure 28). This is possible because in this particular case study power outages occur during highest power generation from the solar PV system. On an annual

basis the PV system compensates almost 75% of power outages. This has a large influence on the economics of the back-up systems. Without a solar PV system the LCOE for all back-up systems are increasing due to the larger amount of electricity that needs to be provided by the back-up system directly. LABs reach LCOE of 0.44 EUR/kWh and diesel generators result in 0.46 EUR/kWh with the same installed capacities. The implementation of a solar PV system is favoring the cost-effectiveness of the diesel generator in this case because the OPEX for back-up systems (fuel and electricity purchase) are reduced which have a far larger impact on the overall diesel generator costs. Furthermore the battery back-up systems are dimensioned with regard to power outages and are not optimized to another power generation source such as solar PV due to energy security reasons.

To conclude this case study shows that battery storage systems are very close to outcompeting diesel generators for back-up power supply systems in the residential sector. A sophisticated battery management system would even allow a better use of solar energy reducing the overall costs further.

5.2.3 Agricultural companies

Background information, load and power outages

This case study highlights the potential for battery storage systems in the agricultural sector which is part of the commercial sector presented in subsection 4.3.2. A coffee farm is selected as an exemplary agricultural consumer. The load profile was made available by OneShore Energy GmbH[5] and data has been collected in January 2015. Due to the use of energy intensive machinery such as water pumping machines the power demand is almost constant with an average demand of 135 kW per hour. Nearly every day blackouts are occurring between 5:00 and 7:00 PM (Figure 29)[6]. These blackouts result in losses of sales.

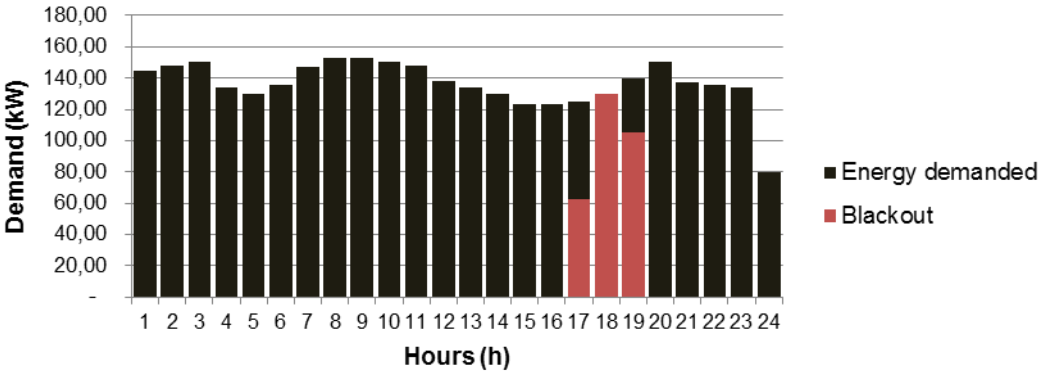

Figure 29: Load profile and power outages for agricultural company case study

Source: Own illustration

Specific input parameters

For the comparison of the different back-up power systems, the following assumptions are chosen. A capital interest rate of 15%, this value reflects the common costs for capital on the Tanzanian finance market[7]. The diesel fuel costs are assumed to be 1.00 EUR/l. The fuel costs are set slightly higher than the average costs due to the remoteness of agricultural customers and the need for

[5] http://www.oneshore.com/

[6] GIZ-PDP Project Factsheet: Load measurement and solar PV system design at a coffee farm in northern Tanzania

[7] Source: World Bank 2010 - 2014 Lending interest rate (%) for Tanzania http://data.worldbank.org/indicator/FR.INR.LEND/countries

transporting and storing fuel in large amounts. The electricity from the grid costs 0.10 EUR/kWh which refers to TANESCO tariff T2 applicable for larger customers. There is no solar PV system in place.

Results

The coffee farm loses almost 9% of the required electricity due to blackouts, a total amount of 102,400 kWh per year. To overcome these power outages large back-up systems have to be implemented. Necessary storage capacities are 456 kWh for LABs and 238 kWh for LIBs. A diesel generator with a capacity of 210 kW would be needed. The most economic back-up power solution is a LAB. The LAB solution results in final costs for back-up power of 0.50 EUR/kWh, while LIBs as well as the diesel generator are more expensive with 0.56 EUR/kWh. This is due to higher CAPEX for LIBs and very high annual fuel costs in the case of the diesel generator (Table 13).

Table 13: Results of battery systems dimensioning tool for agricultural company case study

Battery back-up systems	**Lead-acid battery**	**Lithium-ion battery**		**Diesel generator**		
Parameter	*Value*	*Value*	*Unit*	*Parameter*	*Value*	*Unit*
Installed capacity	455.9	238.4	kWh	Installed capacity	210.0	kW
Installed power	152.0	238.4	kW			
Total Investment	159,581.0	238,427.4	EUR	Total Investment	63,000.0	EUR
Annual CAPEX	35,562.6	43,985.3	EUR	Annual CAPEX	10,774.1	EUR
Annual OPEX fix	3,191.6	2,384.3	EUR	Annual OPEX fix	210.0	EUR
Annual OPEX var.	0.0	0.0	EUR	Annual OPEX var.	5,120.0	EUR
Annual charging costs	12,641.9	11,346.2	EUR	Annual fuel costs	40,959.8	EUR
				Annual fuel consumed	40,959.8	litre/a
Total annual costs	51,396.2	57,715.7	EUR	Total annual costs	57,063.8	EUR
Annuity factor	0.22	0.18		Annuity factor	0.17	
LCOE battery back-up energy	**0.50**	**0.56**	EUR/kWh	LCOE diesel back-up energy	**0.56**	EUR/kWh

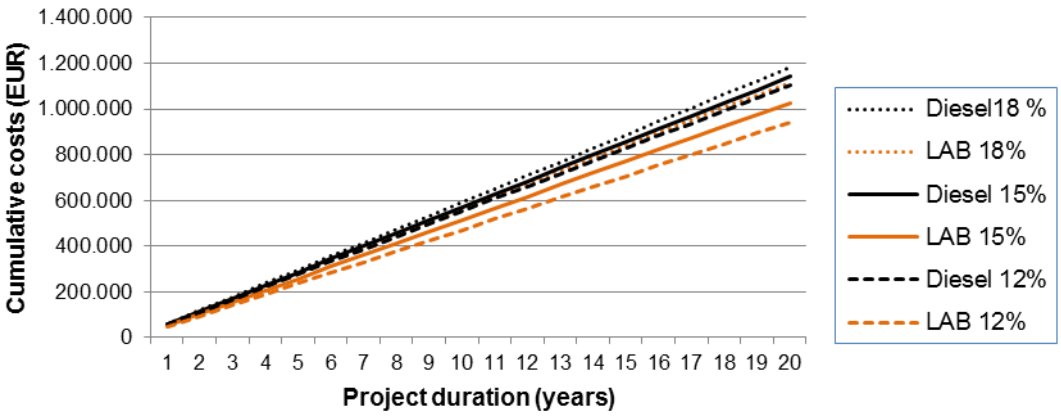

Figure 30: Sensitivity of interest rates on total back-up system costs

Source: Own illustration

The case study reveals the attractiveness of LAB for the specified case with the current unfavorable loan interest rates. A conservative assumption has been chosen with a 15% interest rate. With lower rates the LAB solutions is becoming even more attractive. When changing the interest rate to 18% or respectively 12% it becomes obvious that LAB is cost effective compared to diesel generators even under more conservative conditions (Figure 30).

Conclusion

Finally, it can be stated that under the presented load profile and power outages battery systems provide a competitive solution for back-up power. LABs outperform LIBs due to lower initial costs. In addition, the profile of the power outages is supportive for the technical characteristics of LAB as it has no quick charging / discharging changes within the times of blackouts.

5.2.4 Small and medium-sized enterprises

Background, load and power outages

In this section the service and small industrial sector is studied. As a case study reflecting the commercial/small industrial sector a printing company located in Northern Tanzania has been selected. Electricity consumption only occurs during regular office hours from 9 am to 6 pm and reflects a typical load profile for the service sector. The company consumes more than 125 kWh per day with a peak load of 13.8 kW. Real load data is provided by OneShore Energy GmbH[4] and data has been collected in November 2014 (see Figure 31). Outside the office hours only small base load demand occurs as well as on weekends when electricity is only necessary for standby functions. The printing company is located in an urban area of Northern Tanzania with regular grid supply. Power outages occur but they appear less frequently than compared to the aforementioned case studies. During office hours power outages are usually not lasting for a period longer than 45 minutes. Power outages usually occur one to three times a week. They are therefore hard to predetermine.

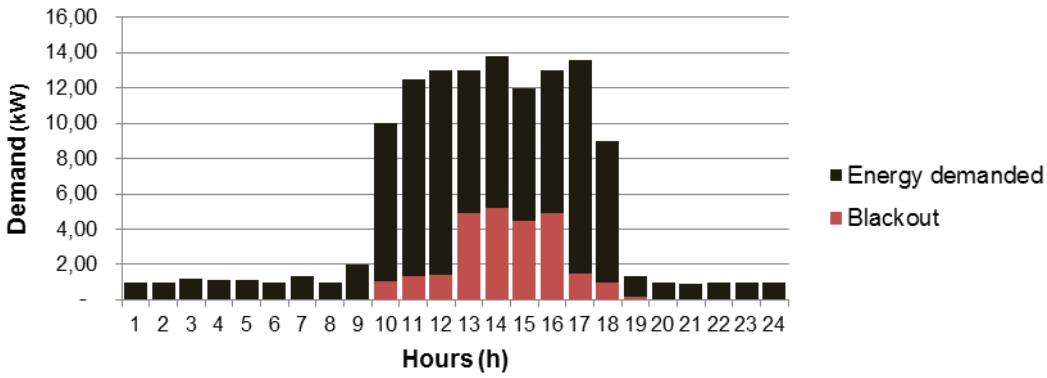

Figure 31: Load profile and power outages for office case study

Source: Own illustration

Specific input parameters

As a small and medium customer with a monthly demand lower than 7,500 kWh the company is consuming electricity at the T1 tariff of 0.15 EUR/kWh. As the company is located in an urban area the diesel costs are relatively low at 0.90 EUR/l. The interest rate for such a company is 15%.

Results

The economic analysis conducted, reveals different opportunities for providing back-up power supply. Due to the unpredictable and short-lasting power outages LIBs are advantageous as they are capable of quick charging and discharging. In the given results in Table 14 a LIB system with a power / storage capacity of 13.8 kW / kWh is the most cost-effective battery solution with annual back-up electricity costs of 0.54 EUR/kWh. This is possible because the LIB is able to quickly recharge as soon as electricity returns from the grid and the capacity can therefore be optimized. This solution is providing a high security. Nevertheless, in the unlikely event that all blackouts happen at same time the proposed LIB would not be able to supply the required electricity. For providing a 100% secure energy supply with battery back-up systems the capacity has to be optimized with regard to the storage capacity rather than the power capacity. Therefore the LIB need to be sized to 29.6 kWh of storage capacity which results in extra high costs of 0.96 EUR/kWh on an annual basis. The competing solution of the diesel generator would require a capacity of 20.7 kW and provide back-up electricity at annual costs of 0.56 EUR/kWh. Under the assumption of continuous fuel supply the diesel generator is able to provide 100% energy security. LABs are not competitive to LIB in this particular case and result in higher energy costs both for the 100% secure supply and high secure supply.

Table 14: Results of battery systems dimensioning tool for office case study

Lithium-ion battery	**100% secure supply**	**High secure supply**	
Parameter	Value	Value	*Unit*
Installed capacity	29.6	13.8	kWh
Installed power	29.6	13.8	kW
Total Investment	29,587.5	13,800.0	EUR
Annual CAPEX	5,458.3	2,545.8	EUR
Annual OPEX fix	295.9	138.0	EUR
Annual OPEX var.	0.0	0.0	EUR
Annual charging costs	1,203.1	1,203.1	EUR
Total annual costs	6,957.3	3,886.9	EUR
Annuity factor	0.18	0.18	
LCOE battery back-up energy	**0.96**	**0.54**	EUR/kWh

Diesel generator		
Parameter	Value	*Unit*
Installed capacity	20.7	kW
Total Investment	6,210.0	EUR
Annual CAPEX	1,062.0	EUR
Annual OPEX fix	20.7	EUR
Annual OPEX var.	361.9	EUR
Annual fuel costs	2,605.9	EUR
Annual fuel consumed	2,895.5	litre/a
Total annual costs	4,050.6	EUR
Annuity factor	0.17	
LCOE diesel back-up energy	**0.56**	EUR/kWh

Conclusion

In this case study LIBs exhibit an interesting business case as they provide the most cost-effective solution. In addition, it can be assumed that some economic factors change in a favorable way (e.g. diesel price of 0.90 EUR/l likely to increase, high interest rate of 15% likely to decrease and LIB CAPEX expected to decrease). This would increase the economic attractiveness of LIBs. However, when an uninterrupted power supply is intended a further back-up system e.g. diesel generator need to be combined with the proposed LIB for ensuring the supply. A 100% secure LIB supply system is far away from competitiveness with higher costs of 0.40 EUR/kWh compared to diesel generators. Anyhow, for this commercial application it should be sufficient to install battery capacities providing the statistical determined high secure supply of back-up energy.

5.2.5 Resorts

Background information, load and power outages

This case study is especially interesting as the tourism sector is generally considered as a market with large potential for storage systems. Uninterrupted energy supply is important and a service expected by many guests. Furthermore, a sustainable energy supply with renewable energies in combination with battery systems is advantageous in attracting further tourists within the eco-tourism sector. The load data of such a resort has been provided by OneShore Energy GmbH[8]. The resort is solely supplied with diesel generators, but for this case study it is assumed that the lodge is grid-connected, as the tool is designed for on-grid back-up supply systems. The energy consumption is characterized by two peaks one in the morning and one in the early evening. The daily demand is roughly 1 MWh. A large amount of energy is consumed by the laundry which reflects the morning peak. The second peak is caused by air conditioning devices in guest rooms. Power outages occur in the evening hours every other day (Figure 32).

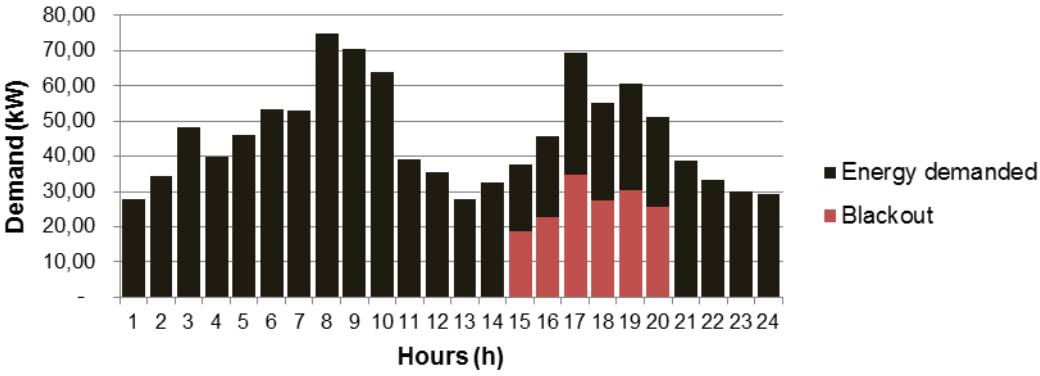

Figure 32: Load profile and power outages for resort case study

Source: Own illustration

Specific input parameters

The tourism facility purchases diesel at very high costs of 1.20 EUR/l due to its remoteness. Capital is said to be available for 8%. Electricity is consumed for 0.10 EUR/kWh as the resort is a T2 consumer. A solar PV power system with a peak capacity of 35 kWp is installed.

Results

Both battery technologies achieve lower back-up LCOE than the diesel generator. LIBs are more cost effective as the storage power is more decisive in this case than the storage capacity. Due to the higher C-rate LIBs can provide more cost competitive storage power. The diesel based back-up supply reaches costs higher than 0.57 EUR/kWh based on the high local diesel costs for the remote lodge. Nevertheless, if a 100% secure energy supply is required, it is suggested to have additional diesel generators as back-up. In the assumed case of statistically distributed power outages no diesel capacities have to be used as the batteries suffice. In the 100%, batteries only scenario high costs of 1.54 EUR/kWh for LIBs and 1.17 EUR/kWh for LABs would occur. Nevertheless, in such remote regions where the lodge is located, continuous fuel supply cannot always be guaranteed. This underlines the attractiveness of combining batteries and diesel capacities for back-up power.

[8] http://www.oneshore.com/

Table 15: Results of battery systems dimensioning tool for resort case study

Battery storage systems	**Lead-acid battery**	**Lithium-ion battery**	
Parameter	*Value*	*Value*	*Unit*
Installed capacity	208.5	69.5	kWh
Installed power	69.5	69.5	kW
Total Investment	72,991.7	69,515.9	EUR
Annual CAPEX	16,266.2	12,824.3	EUR
Annual OPEX fix	1,459.8	695.2	EUR
Annual OPEX var.	0.0	0.0	EUR
Annual charging costs	5,950.4	5,340.5	EUR
Total annual costs	23,676.5	18,860.0	EUR
Annuity factor	0.22	0.18	
LCOE battery back-up energy	**0.42**	**0.33**	EUR/kWh

Diesel generator		
Parameter	*Value*	*Unit*
Installed capacity	104.3	kW
Total Investment	31,282.1	EUR
Annual CAPEX	5,349.8	EUR
Annual OPEX fix	104.3	EUR
Annual OPEX var.	2,833.4	EUR
Annual fuel costs	23,761.5	EUR
Annual fuel consumed	19,801.3	litre/a
Total annual costs	32,049.0	EUR
Annuity factor	0.17	
LCOE diesel back-up energy	**0.57**	EUR/kWh

Conclusion

Due to very high fuel costs the diesel based back-up energy is relatively expensive for this remote lodge. To save fuel and operational expenditures it is recommended to install LIBs for high energy security. If the owner of the lodge intends to avoid any potential power outage over the year, the battery capacities should be combined with diesel generators as additional back-up.

5.2.6 Telecommunication towers

Background information, load and demand

This case study analyses the applicability of battery back-up systems for telecom towers. Telecom towers are an interesting market section as 50% of all grid-connected telecom towers are experiencing power outages of more than 6 hours on a daily basis (compare subsection 4.3.4). A real load profile for a telecom station located in Eastern Africa has been provided by Heliocentris[9]. Telecom towers have a quite stable consumption mainly for powering transmission devices and cooling purposes. The overall daily energy demand is around 45 kWh and increases towards the hours with highest temperatures due to the necessary cooling. Frequent power outages take place for 7 hours every day (see Figure 33).

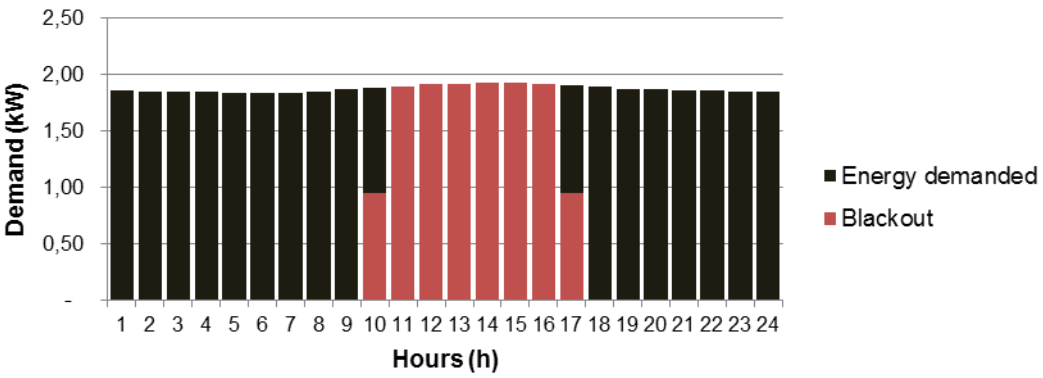

Figure 33: Load profile and power outages for telecom tower case study

Source: Own illustration

Specific input parameters

Grid-connected telecom towers are purchasing electricity from the grid under the T1 tariff for 0.15 EUR/kWh. An interest rate of 10% for financing is applied. The diesel fuel costs are 1.25 EUR/l reflecting costs for transport, storage and frequent fuel theft taking place at remote towers.

Results

The calculation showcases once again that battery back-up systems can be competitive to diesel generators on a per energy unit costs basis. For the given example the LAB is the most cost-effective back-up solution with LCOE for back-up energy of 0.56 EUR/kWh. This is directly followed by the diesel generator with 0.57 EUR/kWh LCOE. The assumed power outage scheme largely influences the cost-effectiveness of the battery systems as the storage capacities have to be quite large due to the long-lasting power outages. Especially for remote telecom towers which are usually facing power outages during the daytime, the implementation of a solar PV power system is recommended. For the given example the installation of a 2 kWp solar PV system would reduce the LCOE of a LAB by 0.09 EUR/kWh and of a LIB by 0.08 EUR/kWh.

[9] http://www.heliocentris.com/

Table 16: Results of battery systems dimensioning tool for telecom tower case study

Battery back-up systems	**Lead-acid battery**	**Lithium-ion battery**	
Parameter	*Value*	*Value*	*Unit*
Installed capacity	25.5	15.1	kWh
Installed power	8.5	15.1	kW
Total Investment	8,941.6	15,128.4	EUR
Annual CAPEX	1,676.0	2,220.3	EUR
Annual OPEX fix	178.8	151.3	EUR
Annual OPEX var.	0.0	0.0	EUR
Annual charging costs	905.3	812.5	EUR
Total annual costs	2,760.2	3,184.1	EUR
Annuity factor	0.19	0.15	
LCOE battery back-up energy	**0.56**	**0.65**	EUR/kWh

Diesel generator		
Parameter	*Value*	*Unit*
Installed capacity	2.9	kW
Total Investment	866.3	EUR
Annual CAPEX	113.9	EUR
Annual OPEX fix	2.9	EUR
Annual OPEX var.	244.4	EUR
Annual fuel costs	2,444.3	EUR
Annual fuel consumed	1,955.5	litre/a
Total annual costs	2,805.5	EUR
Annuity factor	0.13	
LCOE diesel back-up energy	**0.57**	EUR/kWh

Conclusion

Remote telecommunication towers face very high fuel costs for diesel generators which makes LABs the most attractive solutions for providing back-up power supply. If fuel thefts occur regularly, the energy security cannot be guaranteed by diesel generators anymore. Therefore it is recommended to install LABs as back-up solution. Nevertheless for the case that maintenance of LABs is not sufficiently feasible it might be advantageous to use low-maintenance LIBs.

5.2.7 Small hospitals

As the final case study the energy supply of a hospital is assessed. Reliable back-up power supply is essential for the provision of health care. A real load profile of a hospital has been provided by OneShore Energy GmbH[10]. The energy consumption is scaled to 160 kWh per day which reflects the energy consumption of a medium-sized hospital in Tanzania studied in another case study (IEA-PVPS 2014). Most of the electricity demand is used for lighting, medical devices and air conditioning. The hospital is grid-connected. In order to study the costs for reliable supply it is assumed that power outages may occur in any hour of the day for a maximum duration of 30 minutes. These outages have an average frequency of once per week (see Figure 34).

Specific input parameters

The hospital purchases electricity for 0.15 EUR/kWh. Diesel fuel costs are 0.90 EUR/l as the hospital is assumed to be located in an urban area. The interest rate is assumed with 0% as the hospital receives interest-free loan from a development organisation such as USAid.

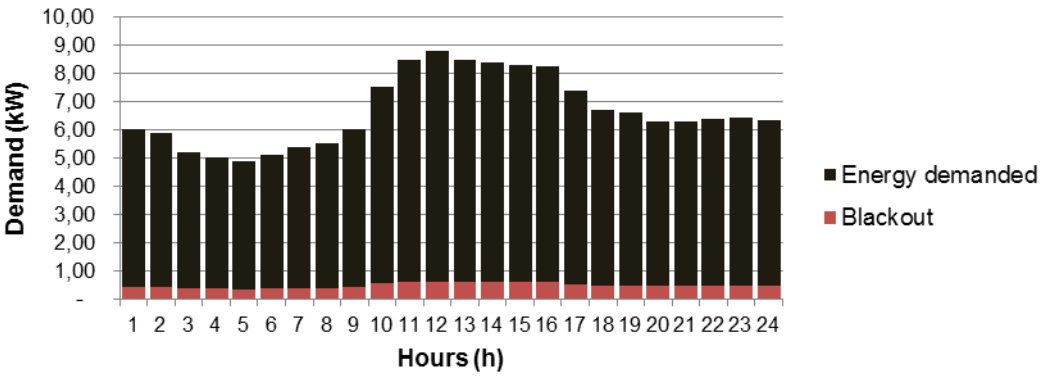

Figure 34: Load profile and power outages for small hospital case study

Source: Own illustration

Results

The analysis reveals that LIBs provide the most cost-efficient back-up supply with costs of 0.37 EUR/kWh. Diesel generators are 0.11 EUR/kWh more expansive than LIBs. LABs are not interesting for this case study as the battery has to be largely oversized in order to supply the required power storage. The power outage scheme with short outages is favouring LIBs as they are able to react very quickly on load changes and power outages. Another advantage of a battery system would be the provision of UPS to ensure a constant power supply for sensitive technical appliances in the hospital. Thus, the diesel based back-up supply is not only more expensive compared to LIBs, it also bears the danger that the reaction time of the back-up power system is to slow for the requirements within the hospital.

[10] http://www.oneshore.com/

Table 17: Results of battery systems dimensioning tool for small hospital case study

Battery back-up systems	**Lead-acid battery**	**Lithium-ion battery**		**Diesel generator**		
Parameter	*Value*	*Value*	*Unit*	*Parameter*	*Value*	*Unit*
Installed capacity	28.5	8.8	kWh	Installed capacity	13.2	kW
Installed power	9.5	8.8	kW			
Total Investment	9,973.1	8,799.3	EUR	Total Investment	3,959.7	EUR
Annual CAPEX	1,246.6	733.3	EUR	Annual CAPEX	263.9	EUR
Annual OPEX fix	199.5	88.0	EUR	Annual OPEX fix	13.2	EUR
Annual OPEX var.	0.0	0.0	EUR	Annual OPEX var.	202.6	EUR
Annual charging costs	750.5	673.6	EUR	Annual fuel costs	1,458.9	EUR
				Annual fuel consumed	1,621.0	litre/a
Total annual costs	2,196.6	1,494.8	EUR	Total annual costs	1,938.7	EUR
Annuity factor	0.13	0.08		Annuity factor	0.07	
LCOE battery back-up energy	**0.54**	**0.37**	EUR/kWh	LCOE diesel back-up energy	**0.48**	EUR/kWh

Conclusion

Special characteristics of health care facilities show that besides cost-effective back-up power supply also quick reaction times are important. For both requirements the LIB outperforms diesel generators and even an UPS could be installed as described in section 2.3. Thus, for the hospital it is recommended to install a LIB based back-up power system.

6. Conclusion

Battery systems have proven to be an economically feasible alternative to the use of diesel generators for many cases in Tanzania. The country can be considered an interesting market for battery storage products: low quality supply and frequent power outages of approximately 45 hours per month on average increase the demand for a reliable back-up power supply. The poor coverage of the national grid in combination with the ongoing electrification of villages in rural Tanzania and the abundancy of renewable resources increases the attractiveness of decentralised renewable-based energy systems which can be combined with batteries. The predominant alternative, diesel fuels, poses a number of challenges. Fuels need to be imported as no domestic oil sources exist. The costs for transportation are increased through large distances and are found to amount to up to 1.6 EUR/l in some areas. Oil/Diesel still account for 31 percent of generated electricity with a capacity of 495 MW installed.

Lead-acid batteries and lithium-ion batteries have been identified to be the most mature, applicable and cost-competitive storage solutions. A battery back-up system can provide different levels of energy security depending on the architecture of the system. The technical characteristics of both technologies have been outlined: Lithium-ion batteries have a higher energy and power density, are less sensible to deep cycle discharging, lose less energy while charging and discharging, and have a longer nominal lifetime. Nevertheless, the cost advantage of lead-acid batteries has compensated their technical disadvantages so far. Lithium-ion batteries are advantageous when highly fluctuating power outages which require quick charging and discharging reactions occur. Lead-acid batteries are attractive for longer steady back-up power supply as their cost per kWh is less. A combination with PVs further reduces back-up power costs.

The unstable supply in grid-connected has a big impact on the profitability of businesses. The commercial sector and the tourism sector are identified to be the most promising fields of application for battery products. Uninterrupted energy supply is a vital service for the growing Tanzanian tourism industry. Not only hotels, but also agricultural and small industrial companies commonly have back-up diesel facilities in place which might be profitably replaced by battery systems. On-Grid telecommunication towers that spend on average 42 percent of their energy costs on diesel, as well as health care stations for which an uninterrupted power supply is crucial, have furthermore been identified as promising market segments.

Case studies in this report reveal the economic viability of battery solutions as a substitute of diesel generators. A major challenge to the wider distribution of the technology is the high cost of capital and the difficult access to project financing which lead to long payback periods. The economic viability of each project hence depends largely on individual project conditions. To the end of taking into account individual project parameters, a simulation tool has been developed. The tool allows for the economic comparison of different battery storage systems and diesel generators based on individual input data in order to assess the individual business case of the user. The real case of a tourism lodge, for example, was used to showcase the potential for savings: battery back-up energy amounts to a LCOE of 0.33 EUR/kWh while the cost for a diesel back-up lies at 0.57 EUR/kWh. The applied interest rate, the local diesel price, and the occurrence of power outages impact the economic viability of battery systems for on-grid applications most strongly.

Obviously, the dynamics and future price developments of battery products will play a crucial role for their wider use, especially in developing markets. In this report, costs for lead-acid systems are set to 350 €/kWh and for lithium-ion systems to 1,000 €/kWh. These cost structures may change rapidly when taking into account future cost projections. For 2020, costs for lithium-ion batteries are forecasted to decrease to a range of 200-350 USD/kWh, and costs for lead-acid batteries to a range of 50-150 €/kWh. The future development of costs might be a game changer for battery storage products and further increase the attractiveness of lithium-ion batteries over lead-acid batteries.

In parallel to a growing economy, the Tanzanian electricity demand will continue to increase. The before mentioned challenges of an unstable national grid and poor grid coverage will be important hurdles to be overcome in order to further evolve economic activities.

Strong personal networks, as well as an investment in local capacity building activities with the objective to strengthen the skills of the local workforce, are key success factors for foreign companies seeking to enter the Tanzanian market.

References

- AHK 2013 – [Außenhandelskammer Deutschland] (2013): Target Market Study Tanzania. Solar PV & Wind Power. German Energy Desk 2013. Retrieved the 13th March, 2015 from http://www.africansolardesigns.com/resources_32_493092621.pdf
- AHK 2015 – [Außenhandelskammer Deutschland] (2015): Factsheet „PV-Hybridsysteme in Tansania". German Energy Desk. Autorin Dr. Georgia Badelt.
- AHK 2015 – [Außenhandelskammer Deutschland] (2015): Zielmarktanalyse Tansania Solar PV. German Energy Desk. Autorin Dr. Georgia Badelt.
- Bertheau et al. 2014: Paul Bertheau, Catherina Cader, Henriette Müller, Philipp Blechinger, Robert Seguin, Christian Breyer, Energy Storage Potential for Solar Based Hybridization of Off-grid Diesel Power Plants in Tanzania, Energy Procedia, Volume 46, 2014, Pages 287-293, ISSN 1876-6102, http://dx.doi.org/10.1016/j.egypro.2014.01.184. (http://www.sciencedirect.com/science/article/pii/S1876610214002008)
- BoT 2014 – [Bank of Tanzania 2014] (2014): Financial Stability Report September 2014. Retrieved the 22th March, 2015 from https://www.bot-tz.org/Publications/Fin-stability/Financial%20Stability%20Report%20%20Sept%202014.pdf
- BMWi 2015 – [Bundesministerium für Wirtschaft und Energie] (2015): Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland, Retrieved the 11th March, 2015 from http://www.umweltbundesamt.de/sites/default/files/medien/384/bilder/dateien/2_abb_entw-install-leistung_2015-02-19.pdf
- Bronski et al. 2015: Peter Bronski, Jon Creyts, Mark Crowdis, Stephen Doig, John Glassmire, Leia Guccione, Peter Lilienthal, James Mandel, Bodhi Rader, Dan Seif, Helen Tocco, Hervé Touati. THE ECONOMICS OF LOAD DEFECTION HOW GRID-CONNECTED SOLAR-PLUS BATTERY SYSTEMS WILL COMPETE WITH TRADITIONAL ELECTRIC SERVICE, WHY IT MATTERS, AND POSSIBLE PATHS FORWARD. Rocky Mountains Institute & Homer Enerrgy. 2015, Boulder, USA.
- ESA 2011: [Electricity Storage Association] USA: Electricity Storage Association- power quality, power supply (2011). http://www.electricitystorage.org/ESA/technologies.
- EWURA 2015 [Energy and Water Utilities Regulatory Authority] (2015): PUBLIC NOTICE ON CAP PRICES FOR PETROLEUM PRODUCTS EFFECTIVE WEDNESDAY, 4th February 2015. Retrieved the 10th April, 2015 from http://www.ewura.go.tz/newsite/attachments/article/231/Cap%20Prices%20WEF%2001%20April%202015%20-%20English.pdf
- GIZ 2013 – [Gesellschaft für Internationale Zusammenarbeit] – Diaz Stark. C., Fricke, D., Guzman de Bay, J., Santos, D., Werler, S. & Y. Wu (2013): Energy Storage in Kenya and the Philippines - A Sub Sector Analysis of Market Opportunities for German Companies.
- GIZ 2015 - [Gesellschaft für Internationale Zusammenarbeit] – Project Development Programme 2015: Inception Workshop Results: "Tanzanian-German Cooperation of Solar Businesses and Associations" 5th November 2014, Hotel Protea Courtyard, Dar es Salaam.
- GSMA 2012– [Groupe Sepciale Mobile Association] (2012): Powering Telecoms: East Africa Market Analysis Sizing the Potential for Green Telecoms in Kenya, Tanzania and Uganda.
- GSMA 2015a – [Groupe Sepciale Mobile Association] (2015): Tanzania key statistics. Retrieved the 18th March, 2015 from http://www.m4dimpact.com/data/countries/country-details?iso=TZA
- GSMA 2015b – [Groupe Sepciale Mobile Association] (2015): Data, Statistics. Retrieved the 18th March, 2015 from http://www.m4dimpact.com/data/statistics/gsm-coverage-population-
- GSMA 2015c – [Groupe Sepciale Mobile Association] (2015): Network coverage. Retrieved the 18th March, 2015 from http://www.m4dimpact.com/data/networks-coverage-

- GTAI- 2014 a [Germany Trade and Invest] (2014): Energy Storage in Germany. Stationary Battery Manufacturers and Storage System Integrators. Retrieved the 11th March, 2015 from http://www.gtai.de/GTAI/Content/EN/Invest/_SharedDocs/Downloads/GTAI/Info-sheets/Energy-environmental/info-sheet-energy-strorage-stationary-battery-manufacturer.pdf
- GTAI- 2014 a [Germany Trade and Invest] (2014): Energy Storage in Germany. Certification and Safety Testing. Retrieved the 11th March, 2015 from http://www.gtai.de/GTAI/Content/EN/Invest/_SharedDocs/Downloads/GTAI/Info-sheets/Energy-environmental/info-sheet-energy-storage-batteries-certification-safety-testing-en.pdf
- Hadjipaschalis et al. 2009: Hadjipaschalis, I., Poullikkas, A., & Efthimiou, V. (2009). Overview of current and future energy storage technologies for electric power applications. Renewable and Sustainable Energy Reviews, 13(6-7), 1513-1522.
- Hall et al. 2008: Hall, P. J., & Bain, E. J. (2008). Energy-storage technologies and electricity generation. Energy Policy, 36(12), 4352-4355.
- Hensley et al. 2012: Battery technology charges ahead. Hensely, R., Newman, J., Rogers, M. Shahinian, M. McKinsey & Company 2012.
- Hummel et al. 2014: Patrick Hummel, Philippe Houchois, Joe Dewhurst, Alberto Gandolfi. Q-Series Global Utilities, Autos & Chemicals. Will solar, batteries and electric cars re-shape the electricity system? 20 August 2014. Retrieved the 17th June, 2015 from http://knowledge.neri.org.nz/assets/uploads/files/270ac-d1V0tO4LmKMZuB3.pdf
- Huyskens, H. & Blechinger, P. 2014. Techno-economic optimization of a hybrid mini-grid using a one-minute time step approach. In 7th International Conference on PV-Hybrids and Mini-Grids April 10th/11th (pp. 10–11). Bad Hersfeld.
- Ibrahim et al. 2008: Ibrahim, H., Ilinca, a, & Perron, J. (2008). Energy storage systems—Characteristics and comparisons. Renewable and Sustainable Energy Reviews, 12(5), 1221-1250.
- IEA-PVPS 2014 [International Energy Agency – PV power systems program: PV systems for Rural health facilities in developing areas. from Retrieved the 14th April, 2015 from http://www.iea-pvps.org/index.php?id=313
- Ilskog 2011: The Zanzibar Blackout - a case study on consequences from an electricity power crisis. Retrieved the 17th March, 2015 from http://www.diva-portal.org/smash/get/diva2:450394/FULLTEXT01.pdf
- IMF 2014 [International Monetary Fund] (2014): IMF Country Report No. 14/12 United Republic of Tanzania. Retrieved the 22th March, 2015 from http://www.imf.org/external/pubs/ft/scr/2014/cr14120.pdf
- Kaldellis et al. 2009: Kaldellis, J. K., Zafirakis, D., & Kavadias, K. (2009). Techno-economic comparison of energy storage systems for island autonomous electrical networks. Renewable and Sustainable Energy Reviews, 13(2), 378-392. doi:10.1016/j.rser.2007.11.002
- Kondiziella et al. 2013: Kondiziella H., Brod K., Bruckner T., Olbert S., Mes F.: Stromspeicher für die „Energiewende“ – eine akteursbasierte Analyse der zusätzlichen Speicherkosten. Z Energiewirtsch (2013) 37:249–260 DOI 10.1007/s12398-013-0115-7
- Mathematica 2011: Tanzania Energy Sector Impact Evaluation: Findings from the Zanzibar Baseline Study. Retrieved the 17th March, 2015 from http://www.mathematica-mpr.com/~/media/publications/PDFs/international/zanzibar_baseline.pdf
- MEM 2013a – [Ministry of Energy and Minerals] (2013): Power System Master Plan 2012 – Update. Retrieved the 13th March, 2015 from http://www.tanzania.go.tz/egov_uploads/documents/0062_10072013-Power_System_Master_Plan_2012_sw.pdf
- MEM 2013b – [Ministry of Energy and Minerals] (2013): Joint Energy Sector Review (JESR) 2012/13 for Tanzania. Author: Pöyry SwedPower AB. Retrieved the 13th March, 2015 from http://www.tzdpg.or.tz/fileadmin/documents/dpg_internal/dpg_working_groups_clusters/cluster_1/Energy_and_Minerals/Key_Documents/JESR/JESR_Final_Report_2012-2013.pdf
- Mini-Grid 2015: Mini-Grid Policy Toolkit. European Union Energy Initiative Partnership Dialogue Facility (EUEI PDF). Available online: http://minigridpolicytoolkit.euei-pdf.org/downloads (accessed on 12 May 2015)

- Neupert et al. 2009:Neupert U., Euting T., Kretschmer T., Notthoff C., Ruhlig K. & Weimert B. 2009: „Energiespeicher – Technische Grundlagen und Energiewirtschaftliches Potenzial“, Fraunhofer Institut INT, Stuttgart: Fraunhofer IRB Verlag, 2009.
- Nykvist & Nilsson 2015. Nykvist, Bjorn., Nilsson, Mans. 2015. Rapidly falling costs of battery packs for electric vehicles. Nature Clim. Change 2015/04//print Vol. 5. Nature Publishing Group, http://dx.doi.org/10.1038/nclimate2564
- Practical Action, “Poor People's Energy Outlook 2013,” Practical Action Publishing., UK, 2013.
- REA 2014 [Rural Energy Agency] (2014): National Electrification Program Prospectus. Retrieved the 10th April, 2015 from http://rea.go.tz/Resources/E-Library/tabid/132/Default.aspx
- Sauer et al. 2013: Sauer D. U., Lunz B., Magnor D. : Marktanreizprogramm für dezentrale Speicher insbesondere für PV-Strom. BMU 2013
- Schott et al. 2010: Schott, B., C. Günther und A. Jossen, Batterie-Roadmap 2020+, ZSW-Studie, April 2010
- Serban & Marinescu 2014: I. Serban, C. Marinescu, Battery energy storage system for frequency support in microgrids and with enhanced control features for uninterruptible supply of local loads, International Journal of Electrical Power & Energy Systems, Volume 54, January 2014, Pages 432-441, ISSN 0142-0615, http://dx.doi.org/10.1016/j.ijepes.2013.07.004.
- Sterner 2009: Sterner, M.: Bioenergy and renewable power methane in integrated 100% renewable energy systems. Transformation. Kassel University Press GmbH, Kassel.
- Sterner et al. 2015: Sterner, M.; Eckert, F; Thema, M.; Bauer, F. 2015: Der positive Beitrag dezentraler Batteriespeicher für eine stabile Stromversorgung, Forschungsstelle Energienetze und Energiespeicher (FENES) OTH Regensburg, Kurzstudie im Auftrag von BEE e.V. und Hannover Messe, Regensburg / Berlin / Hannover.
- Strauch N. 2011: „Einsatz von Energiespeicher-Technologien in Inselsystemen mit hohem Anteil Erneuerbarer Energien“. Shaker, 1 edition, 2013. 26, 44, 45
- Szabo et al. 2011: Szabo S., Bodis K., Huld T. & Moner-Girona M. 2011: Energy solutions in rural Africa: mapping electrification costs of distributed solar and diesel generation versus grid extension. Environ. Res. Lett. 6 034002.
- TANESCO 2015 [Tanzania Electric Supply Comapany] (2015): Patrice Tsakhara Principal Engineer Small Power Projects. PRESENTATION ON THE TANZANIAN SOLAR PV-HYBRID WORKSHOP HELD IN BERLIN, GERMANY, 16TH MARCH 2015.
- Tanzania Tourist Board 2015 [TTB] (2015): List of accommodation. Retrieved the 18th March, 2015 from http://www.tanzaniatouristboard.com/accomodation/view.php
- UN Comtrade Database (2015): Statistics for trade data. Retrieved the 11th March, 2015 from http://comtrade.un.org/data/
- World Bank 2015: The World Bank: World Development Indicators: Health systems http://wdi.worldbank.org/table/2.15
- World Bank Group (2013): Tanzania country profile 2013 – Enterprise surveys. Retrieved the 17th March, 2015 from http://www.enterprisesurveys.org/~/media/GIAWB/EnterpriseSurveys/Documents/Profiles/English/tanzania-2013.pdf
- WTTC 2015 – [World Travel & Tourism Council] (2015): Travel & Tourism Economic impact 2015 Tanzania. . Retrieved the 20th July, 2015 from http://www.wttc.org/-/media/files/reports/economic%20impact%20research/countries%202015/tanzania2015.pdf
- WTTC 2014 – [World Travel & Tourism Council] (2014): Travel & Tourism Economic Impact 2014Tanzania. Retrieved the 18th March, 2015 from http://www.wttc.org/-/media/files/reports/economic%20impact%20research/country%20reports/tanzania2014.pdf
- ZCT 2015 [Zanzibar Commission for Touris] 2015: List of hotels. Retrieved the 14th April, 2015 from http://www.zanzibartourism.net/hotels.php

Appendices

Appendix 1 – Battery characteristics

Energy density

The energy density describes the amount of energy (Wh, kWh) that can be stored per mass (kg) or volumes (l). The specific energy density of a battery is commonly provided in Wh/kg or Wh/l

Power density

The power density describes the level of power (W, kW) that can be provided per mass (kg) or volumes (l). The specific power density of a battery is commonly provided in W/kg or W/l

Energy storage capacity

The storage capacity provides the total amount of energy which can be stored. The storage capacity is usually provided in kilowatt per hour (kWh).

Energy storage power

The storage power describes the maximal power by which the battery can be charge or discharge energy. The power capacity is usually provided in kilowatt – (kW).

State of charge (SoC)

The state of charge defines the stored energy which is available for discharge. The SoC is usually provided in per cent (%) of the energy storage capacity.

Depth of discharge (DoD)

The depth of discharge provides the battery capacity that has been discharged related to the total capacity. Thus, the DoD represents the counterpart of the SoC. The DoD is usually provided in per cent (%).

Charging rate (C-rate)

The C-rate provides information in which ratio power is given to the total storage capacity. The C-rate is commonly provided in power per capacity (kW/kWh).

Round cycle efficiency

The amount of energy which a battery can deliver in relation to the energy injected. Thereby, the charging and discharging efficiencies are combined into one. The round cycle efficiency is provided in per cent (%).

Lifetime

The lifetime of a battery can be described in two different ways, either by the calendric lifetime given in years, or by maximum number of full-cycles, i.e. times the battery can be charged and discharged totally.

Self-discharge

The self-discharge describes the internal losses of energy over time. The self-discharge is usually provided in per cent per month (%/month).

Appendix 2 – List of companies within the German battery sector

Battery manufacturer
Accurate GmbH
Accusysteme Transwatt GMBH
Akasol GmbH
Albert Seine GMBH
Atec Batterie
BAE
BBS-Industriebatterien Brenner Batterie Systeme
Deutsche ACCUmotive GmbH & Co. KG
Diehl & Eagle-Picher GmbH
Dispatch Energy Innovations GmbH
Dynamis Batterien GMBH
EAS Germany GMBH
ECC Repenning GmbH
EnerVault Corporation
Exide
F.X. Mittermaier & Söhne GMBH & CO. KG
GAIA Akkumulatorenwerke GmbH
Hawker GMBH
Hoppecke Accumulatorenwerke / Batterien
InnoPower
Leclanche
Li-Tec Battery GmbH
Moll Batterien
NEC Europe
PROSOL Invest Deutschland GmbH
RRC Power Solution GmbH
Samsung SDI Europe GmbH
Tadiran
VARTA Microbattery GmbH
Varta Storage GmbH
VRI Batterietechnik

Battery management and energy management solution providers
ads-tec GmbH
Enpla GmbH
EnWi-Etec GmbH
Gildemeister Energy Solutions
Heliocentris Energy Solutions AG
OHP Automation Systems GmbH
P21 GmbH
Refu Elektronik
RKB electronic AG
RWE Fuel Cells
Sia Energy GmbH & Co. KG
Stuba
Voltwerk

Component suppliers for battery manufacturing and system solution providers
aleo solar AG
ArevaGmbH
BBT Thermotechnik Junkers Deutschland
Bosch
Büttner Energie- und Trocknungstechnik GmbH
CAEstorage GmbH
Clariant Produkte GmbH
Comemso
Custom Cells Itzenhoe GmbH
dfm-select gmbh electronics & power-protection
Dhiel
Digatron Industrie-Elektronik GmbH
e-Wolf GmbH
GP Joule GmbH
Grenzebach Maschinenbau GmbH
Gustav Klein GmbH & Co. KG
IMB Stromversorgungssysteme GMBH
Industrieelektronik Brilion GMBH
Kaco
KBA-MetalPrint GmbH
KBB Underground Technologies GmbH
KEW GmbH
Kostal Industrie Elektrik GmbH
Linde AG
M+W group
Mack Electronic Systems GmbH
Manz AG
Mastervolt GmbH
McPhy Energy Deutschland GmbH
Mitsubishi International GmbH
Platinum GmbH
Power-One
Q3 Energieelektronik
RauEE
Rena GmbH
Rittal GmbH & Co. KG
Roth&Rau
SafetytestGmbH
Schmid Group
Schneider Electric GmbH
Schüco
Scienlab
SGL Carbon GmbH
SMA Solar Technology AG
Solarworld
Solutronic
Spitzenberger & Spies GmbH & Co. KG
Stirling Sun Power International GmbH
Stornetic GmbH
TALIS Deutschland GmbH & Co. KG
Umicore
Werner Mathis AG

System solution providers and integrators
a+f GmbH (Gildemeister)
AS solar
ASD Sonnenspeicher
Aton-Solar
Autarsys
b+w Electronic Systems
Batterie365
BayWa r.e. Solarsysteme GmbH
BeBa Energie GmbH
Centrosolar AG
Conergy
Conergy AG
cronimet power solutions
Deutsche Energieversorgung GmbH
DG Licht
dibu-energie
Durion GmbH
e3 dc
Energiebau Solarstromsysteme
ET Solar Power GmbH

ETOGAS GmbH
eva technology GmbH & Co. KG
Frankensolar
Gehrlicher
General Electric Deutschland Holding GmbH
Green Store AG
HID-Europe GmbH + Co. KG
Hitzler Energiesysteme GmbH
Hitzler Energiesysteme GmbH
IBC solar
Interprojekt Ingenieurgesellschaft mbH
JMS Solarhandel
J-ON Power GmbH
Juwi
KAUFEL GMBH & CO. KG
Krannich solar
Lokavis Energietechnik GmbH
Martin Walz Elektro + Solartechnik GmbH & Co. KG
Mederer Energie + Technik e.K.
Multiwatt Energiesysteme GmbH
OneShore
Pfenning Elektroanlagen GmbH
Qinous
SBWW GmbH
Schmitz Gebäudetechnik
Siemens AG
SiG Solar GmbH
Solartechnik Stiens GmbH & Co. KG
Solarwatt
Soleos
Sumec Europe GmbH
Tritec
Vanadis Power GmbH
VR ENBEKON eG -
Wagner Solar
Younicos AG

Consultant and project management services
Apricum GmbH
Björnsen Beratende Ingenieure
ce energy consulting
Cetecom ICT Services
Clean Horizon Consulting
Currenta GmbH & Co. KG
DMT GmbH & Co. KG
e3 eins e-energie gmbh
EHG Energie Handel GmbH
enervis energy advisors GmbH
Enrag GmbH
Fichtner GmbH & Co. KG
Hartwig-Technik Ing.-Büro
Hochtief Solutions AG
JBO Ingenieure GmbH

Research institutes and industry associations
Baden-Württemberg International Gesellschaft für internationale wirtschaftliche und wissenschaftliche Zusammenarbeit mbH
Brennstoffzellen + Batterie-Allianz Baden-Württemberg
Deutscher Wasserstoff- und Brennstoffzellenverband
ELG Sonnenstrom eG
energy2hub
Europapartner-Solar GmbH & Co. KG
Fachhochschule Köln Institut für Landmaschinentechnik und Regenerative Energien
Fraunhofer-Institut für Siliziumtechnologie ISIT
Fraunhofer-Institut für Solare Energiesysteme ISE
Fraunhofer-Institut für Umwelt-, Sicherheits- und Energietechnik Umsicht
Fraunhofer-Institut für Werkstoff- und Strahltechnik IWS Dresden
Fraunhofer-Instiut für Physikalische Messtechnik IPM
Industrie- und Handelskammer zu Düsseldorf
International Solar Energy Research Center
Israel Trade Center - Büro Berliner Botschaft
Kompetenznetzwerk Lithium-Ionen Batterien e.V.
MEET Battery Research Center / Universität Münster
OTTI Ostbayerisches Technologie- Transfer-Institut e. V. Bereich Erneuerbare Energien
StoRegio Energiespeichersysteme e.V.
ZAE Bayern

Insurance, law and financial services
Aon Versicherungsmakler Deutschland GmbH
Beiten Burkhardt
Enernovum GmbH & Co. KG

Utilities
EnergieSüdwest AG
ewmr - Energie und Wasserversorgung Mittleres Ruhrgebiet GmbH
Ewz
Greenpeace energy eG
Naturstrom AG
Next Energy EWE Forschungszentrum für Energietechnologie e.V.
Pumpspeicherwerk Einöden GmbH
RWE
RWE AG
Schluchseewerk AG
Stadtwerke Schwabach GmbH
Stadtwerke Troisdorf GmbH
SWT Stadtwerke Trier Versorgungs- GmbH
Vattenfall Europe Generation AG

Source: GIZ 2013

Appendix 3 – List of existing standards and certificates for battery systems

List of existing standards and certificates for battery storage solutions

Certificate/ Standard	Content
CE	The CE marking is required for many products. It states that the product is assessed (with procedures like hazard analysis and risk assessment) before being placed on the market and meets EU safety, health and environmental protection requirements.
UN 38.3	Norm contains criteria and electrical, mechanical and thermal tests for the safe transport of Li-ion batteries. The tests are in part very sophisticated and reveal a certain robustness and basic safety of the system. Only by passing these tests and receiving this certificate, Li-ion-batteries are allowed to be transported.
DIN EN 50272—1/2	„Safety requirements for secondary batteries and battery installations - Part 1: General safety information, Part 2: Stationary batteries“ Standard is related to electrical engineering (e.g. isolation, separation) and battery safety issues (e.g. transportation, installation site, charging, protective measures).
DIN EN 61427—1/2	„Secondary cells and batteries for renewable energy storage - General requirements and methods of test - Part 1: Photovoltaic off-grid application, Part2: on-grid applications “ Standard contains e.g. capacity and cycle life tests, but few aspects concerning safety.
DIN EN 61850—3	„Communication networks and systems for power utility automation - Part 3: General Requirements“
DIN EN 62133	„Secondary cells and batteries containing alkaline or other non-acid electrolytes – Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications“
DIN EN 62619 (Draft)	„Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for large format secondary lithium cells and batteries for use in industrial applications“ Requirements and tests for a safe running.
DIN EN 62620 (Draft)	„Secondary cells and batteries containing alkaline or other non-acid electrolytes - Large format secondary lithium cells and batteries for use in industrial applications“ Performance tests and measuring methods for Li-ion cells and batteries.
VDE-AR-E 2510-2 (Draft)	„Requirements for the design, construction, operation, dismantling and disposal of fixed electrical energy storage systems“
VDE-AR-N 4105	„Power generation systems connected to the low-voltage distribution network - Technical minimum requirements for the connection to and parallel operation with low-voltage distribution networks“

Source: GTAI 2014 b

Appendix 4 – Table of tourism facilities

Table 18: Licensed tourism facilities according to Tanzania Tourism Board

Region	Hotel	Lodge	Tented camp	Sum
Arusha	9	25	18	52
Coast	4	2	3	9
Dar-es-salaam	29	0	2	31
Iringa	2	0	0	2
Katavi	0	0	1	1
Kilimanjaro	3	1	0	4
Lindi	0	0	1	1
Manyara	0	1	0	1
Mara	0	0	1	1
Morogoro	2	0	1	3
Mwanza	2	0	1	3

Source: Tanzania Tourism Board (TTB 2015)

Appendix 5 – Table of medical facilities

Table 19: Distribution of medial infrastructure per region in Tanzania

Region	Hospital	Clinic	Health centre	Dispensary	Sum
Arusha	1	1	11	43	56
Dar-es-Salaam	3	4	5	51	63
Dodoma	1	0	6	96	103
Iringa	2	0	7	54	63
Kagera	2	4	7	87	100
Kigoma	3	0	3	44	50
Kilimanjaro	0	2	8	42	52
Lindi	4	0	7	113	124
Manyara	2	0	5	31	38
Mara	2	1	8	36	47
Mbeya	3	0	9	80	92
Morogoro	13	0	19	245	277
Mtwara	3	0	3	52	58
Mwanza	4	5	6	113	128
Pemba North	0	0	2	0	2
Pemba South	0	0	1	0	1
Pwani	8	2	13	148	171
Rukwa	2	1	8	32	43
Ruvuma	2	0	5	29	36
Shinyanga	2	0	13	75	90
Singida	3	0	4	63	70
Tabora	3	0	6	77	86
Tanga	6	2	29	195	232
Zanzibar North	0	0	1	0	1
Zanzibar South/Central	0	0	2	0	2
Zanzibar West	0	0	2	0	2

Source: National Electrification Prospectus (REA 2014).

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