Global Gateway

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ELECTRICITY STORAGE ADAPTED TO THE MINI-GRIDS

Collaborative study on the battery sector in Sub-Saharan Africa

RÉPUBLIQUE FRANÇAISE
Liberté Égalité Fraternité

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Electricity storage adapted to the mini-grids

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GLOSSARY AND ACRONYMS

AFD: French Development Agency

IEA: International Energy Agency

AMP: Africa Minigrids Program

AfDB: African Development Bank

BESS (Battery Energy Storage System): Refers not only to BES (Battery Energy Storage) batteries but also to all the systems necessary for operation, such as converters, battery management systems (BMS), safety devices, and software infrastructure for intelligent storage management.

WB: World Bank

BMS (Battery Management System): an integrated electronic system that provides battery management, protection and optimization in an energy storage system.

CAPEX: Capital Expenditure or Investment Cost

CEI: International Electronic Commission

WEEE: Waste Electrical and Electronic Equipment

Energy density: The amount of energy stored per unit volume or weight; important for transport or confined spaces.

EMS (Energy Management System): software and hardware platform that allows you to supervise, control and optimize the production, consumption and storage of energy in a facility (residential, industrial or large-scale).

EPC (Engineering Procurement and Construction): a form of contractual agreement used between two parties, the industry and the contractor. The contractor takes care of the entire project, the installation, the necessary materials and then the realization either directly or by subcontracting part of the work. He bears responsibility for the project.

ESMAP: Energy Sector Management Assistance Program

GEF: Global Environment Facility

Islanding: The ability of a mini-grid to operate autonomously when disconnected from the main grid.

IRENA: International Renewable Energy Agency

LCOS (Levelized Cost of Storage): Levelized cost of energy storage (€/kWh stored), used to assess the cost-effectiveness of storage technologies.

LFP: Lithium-Iron-Phosphate

M2M: Machine to Machine

Interconnected mini-grid: Mini-grid that can be connected to the national grid, with the ability to switch between stand-alone and connected mode.

Metro-grid: Mini-grid deployed in urban areas, connected but capable of operating in an island system in the event of a failure of the national grid.

NAS: Batteries sodium-soufre

NiCD: Batteries nickel-cadmium

NiMH: Nickel-Metal Hydride Batteries

NiZn: Batteries nickel-zinc

OPEX: Operational Expenditure

PAYG: Pay As You Go

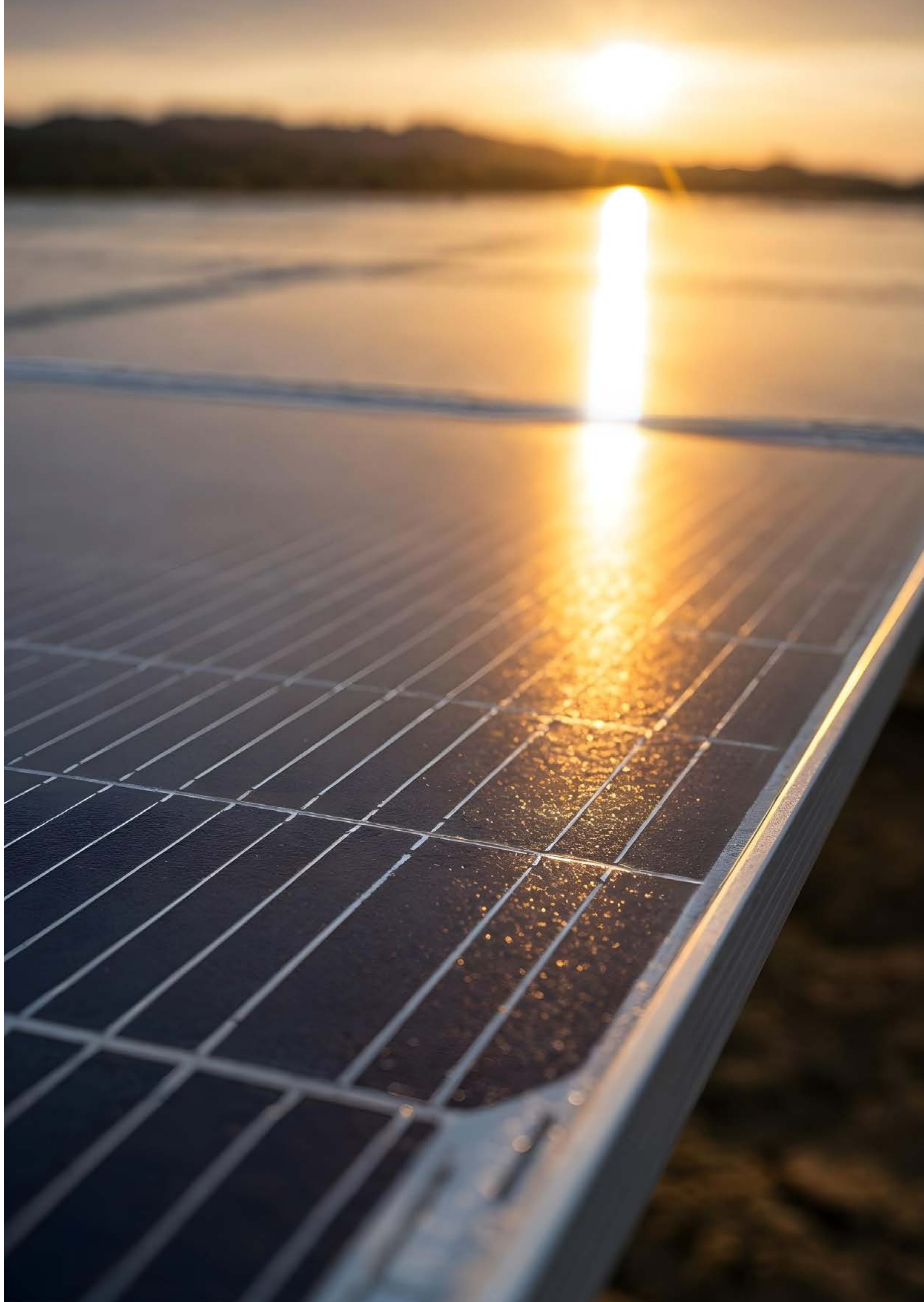
PBG: Performance Based Grant

PPP: Public-Private Partnership

UNDP: United Nations Development Programme

EPR: Extended Producer Responsibility

EU: European Union



INTRODUCTION

PRESENTATION OF THE ACTORS

The **Agence Française de Développement (AFD)** is a key player in France's international development and solidarity policy. As a public financial institution, it supports projects that contribute to improving living conditions, strengthening social cohesion and responding to climate challenges. Its management style is based on strategic governance articulated around ecological and social transition objectives, while promoting sustainable partnerships with public, private and civil society actors in partner countries. AFD relies on geographical and sectoral directorates, as well as on a network of local representations.

The **MEDEE cluster** brings together an ecosystem of research, industry and institutions around electrical technologies and the energy transition. As a catalyst for innovation, MEDEE supports collaborative R&D projects with high added value in the fields of energy efficiency, decarbonization of uses and the development of low-carbon industrial solutions. In recent years, MEDEE has also initiated or supported several technological cooperation projects in Africa, particularly around access to energy, the integration of renewable energies and the strengthening of local skills.

As a design and engineering firm dedicated to the energy and environmental transition, **Setec énergie environnement** supports local authorities, manufacturers and donors in designing and implementing sustainable projects. Thanks to a multidisciplinary team, Setec supports complex missions in the fields of industrial decarbonization, waste management and the development of renewable energies. The setec group is present in several African countries, and actively contributes to energy access projects in close collaboration with local players and technical and financial partners.

BACKGROUND TO THE STUDY

Digital Energy is a program of the Agence Française de Développement (AFD) that finances innovation and entrepreneurship in the energy sector in Africa funded by the European Union (EU). Digital Energy supports energy operators and start-ups in their digitalization process through the financing of technical assistance projects, the organization of calls for projects or the animation of a community of actors.

This study, launched in July 2024, is part of this framework and focuses on stationary energy storage in sub-Saharan Africa and more specifically energy storage for mini-grid applications. It was developed collaboratively with the contribution of a dozen companies in the sector.

Setec énergie environnement and the MEDEE cluster were mandated to conduct this study, in partnership with AFD and Onepoint, as part of the mission to lead the Digital Energy community entrusted to the latter.

OBJECTIVES OF THE STUDY

In sub-Saharan Africa, electrification remains a major challenge: despite a fast-growing population and increasing energy demand, the rate of access to electricity remains low, particularly in rural areas where it stood at only 30.7 % in 2023, compared to more than 80 % in urban areas according to World Bank statistics. To meet these needs, the development of mini-grids is a major lever. Indeed, the International Energy Agency (IEA) estimates that to guarantee access for all to reliable, sustainable and modern energy services at an affordable cost by 2030, 3 % of new electricity connections will have to be provided by mini-grids. The development of mini-grids must go hand in hand with the development of renewable energies in order to constitute a sustainable solution to meet energy needs while limiting greenhouse gas emissions.

the rate of access to electricity remains low, particularly in rural areas where it stood at only 30.7 % in 2023.

However, the generation of renewable electricity in mini-grids remains variable and they are generally not connected to national grids. It is then necessary to store the energy produced during periods of low demand in order to release it during peak consumption, thus ensuring a continuous supply in isolated areas. This is the role of stationary storage solutions that is the subject of this study.

This collaborative paper reviews dominant and emerging technologies by analysing their relevance in the context of sub-Saharan Africa. It also seeks to map the main challenges as well as the obstacles to the deployment of stationary storage while focusing on solutions that can address them. Finally, this study is intended to serve as a tool for the mobilization of a community of actors by facilitating exchanges and networking. As such, it contains a directory of the stakeholders who have been involved in its implementation.

METHODOLOGICAL APPROACH

The study is based on a bibliographic analysis of existing studies on stationary storage for mini-grids. On the other hand, and this is what makes it original, the content of this document is based on a series of working sessions with a «core group» of actors in the sector, whose experiences, positions and concerns it reflects from the experience in the field.

This «core group» is made up of a dozen companies working in Africa and covering the entire battery value chain, from manufacturing to reuse, including operation. These companies, including key players in the sector, were consulted to share their expertise and their current issues – whether they are logistical difficulties, economic constraints or technical challenges in sometimes complex environments.

They met four times throughout the conduct of the study between October 2024 and January 2025. The members of the «core group» were not only consulted, as is the case in other studies, but also played a fundamental role in the framing and management of the work. The present study is therefore not only a theoretical document, but a truly practical document that is directly useful to the actors of the sector.

Working group member companies

Company name	Geographical area of intervention	Nature of the activity	Origin company
SLS Energy	Rwanda	Builder and service provider	Rwanda
Lagazel	Senegal, Mali, Burkina Faso, Benin, Niger	Manufacturer, distributor and recycler	France
PAM Africa	Rwanda, Kenya, Burundi, DRC, Tanzania, Uganda	Manager	Nigeria
Aress	Senegal, Benin, Togo, Burkina Faso	Builder and operator	Benin
Engie energy access	East Africa mainly, and a few countries in the west	Manager	France
CEGASA	Benin, Ethiopia	Constructor	Spain
John Cockerill	Chad, Burundi, DRC...	Manager	Belgium
Catalyst Energy	Mozambique, South Africa, Malawi, Zambia, Zimbabwe, Namibia and Botswana.	Service Provider	Mozambique
Exide Technologies	Sub-Saharan Africa	Constructor	France
SAFT - TotalEnergies subsidiary	South Africa, Ivory Coast, Kenya	Utility scale	France
Evolve BGS	South Africa	Service Provider	South Africa
Vittoria Technology	South Africa	Service Provider	South Africa

Additional interviews with companies outside the core group

Company name	Geographical area of intervention	Nature of the activity	Origin company
Tailor	South Africa, West Africa, Central Africa, etc.	Technology Provider, System Integrator	France
Zembo	Uganda	Electric mobility	Uganda

The publication is therefore intended to provide food for thought, feed existing initiatives and inspire future concrete actions. Workshops to present the results, time for discussion with stakeholders and thematic events may be organised to extend the discussion and promote the appropriation of lessons learned.

THE IMPORTANCE OF BATTERIES FOR MINI-GRIDS IN THE CONTEXT OF ACCESS TO ELECTRICITY IN SUB-SAHARAN AFRICA

The African Development Bank and the World Bank are also committing to an unprecedented collaboration at the African Energy Summit held in Dar Es Salaam (Tanzania) in January 2025, as part of the «Mission 300», whose objective is to connect 300 million people in Africa to electricity by 2030.

The two levers of action of this program are the expansion of the electricity grid and the development of connections in underserved areas, as well as the deployment of mini-grids and standalone solar solutions to provide electricity to communities living in remote and off-grid areas.

THE ENERGY ACCESS DEFICIT IN SUB-SAHARAN AFRICA

According to the World Bank, between 1996 and 2020, the rate of access to electricity increased globally, from 73.4% to 90.5%. However, the COVID-19 pandemic slowed electrification programs in 2020 and 2021, leading to a potential delay in universal access to electricity targets for 2030 in several developing countries. Under the current scenario, about 800 million people are expected to get electricity between 2021 and 2030, leaving another 560 million without access. To achieve universal electrification by 2030, about 1.3 billion households must be electrified, including 800 million households in rural areas, which requires an annual growth in electrification of 6.5%.

The share of the population in sub-Saharan Africa with access to electricity was 48% in 2020 (World Bank 2020b). However, these figures mask significant disparities between countries: while some, such as Niger, Chad or the Democratic Republic of Congo, have electrification rates of less than 20%, others – such as Ethiopia, Ghana, Kenya, Nigeria, Rwanda and Senegal – have ambitious national plans to achieve universal access to electricity by 2030.

The share of the population in sub-Saharan Africa with access to electricity was 48% in 2020.

This lack of access to electricity can be explained by a combination of structural and economic factors. In many rural areas, the low population density and geographical isolation of villages make network extensions expensive and complex. In addition, the often fragile financial health of public electricity companies limits their ability to invest in new infrastructure. In addition, some households have difficulty in releasing part of their budget to access an electricity service. Finally, the sector suffers from a lack of capital investment, slowing down the development of alternative solutions such as mini-grids or decentralized solar systems. To close the electricity access gap, current policies must therefore encourage both national grid extension projects and the development of decentralized solutions, such as mini-grids.

DEFINITION AND ROLE OF MINI-GRIDS

A mini-grid is a decentralized electricity system powered by renewable or non-renewable energy sources and often coupled with storage systems. It operates independently of the main grid and represents a cheaper alternative for access to electricity for rural or remote communities. Mini-grids also have advantages over other decentralized solutions such as solar kits, including better quality supply and stronger support for productive uses.

This study focuses on the use of batteries in the context of mini-grid development and rural electrification, without claiming to exhaustively cover existing battery markets and associated technological developments.

In the geographical case of Sub-Saharan Africa, and although the majority of mini-grids serve isolated areas and cannot be connected, some mini-grids could in the future be connected to the national grid. The development of a «third generation» of mini-grids confirms this trend: they are solar-hybrid, incorporate new technologies such as smart meters and remote monitoring systems, and are generally designed to interconnect to the main grid[1].

[1] *Mini-grids for half a billion people, executive summary Sector Management Assistance Program (ESMAP)*

THE IMPORTANCE OF MINI-GRIDS IN ACCESS TO ELECTRICITY IN SUB-SAHARAN AFRICA

Mini-grids are the international and national initiatives to accelerate their deployment in sub-Saharan Africa. Their strategic importance is recognised by Mission 300 (see box), whose goal is to connect 300 million Africans to electricity by 2030. Mission 300 intends to mobilize more than $90 billion to achieve its electrification goals, including massive support for decentralized solutions. Five levers Promoting the expansion of mini-grids are identified by the ESMAP in its publication *Mini Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers*:

1. Reduce the cost of electricity from solar hybrid mini-grids to $0.20/kWh by 2030
2. Accelerate the pace of deployment to 2,000 mini-grids per country each year
3. Providing reliable electrical service to customers and communities
4. Mobilize financing from development partners and public investment to «attract» private financing.
5. Establish mini-grid-friendly business environments in key countries with limited access

Liam Murphy (COO of Vittoria Technology) mentions that the Alliance for Rural Electrification is working on guidelines for the management of the end of life of equipment, but that their implementation depends largely on the country of operation due to the wide variations.

The challenges faced by start-ups in moving from grant funding (from €100,000 to €300,000) to larger amounts (around €500,000) remain significant, as there are few funders in this bracket. Foundations such as AKUO or philanthropic funds are in this intermediary funding space.

Since 2022, the World Bank has also been developing the DARES (Distributed Access through Renewable Energy Scale-Up) platform, which calls for collaboration between governments, private investors and development organizations in order to develop decentralized solutions that can be transposed to the international. This major initiative is based on off-grid solar, mini-grids and other solutions to promote universal access to electricity through the decentralization of electricity generation from renewable energy.

Other examples include the Africa Minigrids Program (AMP), a $50 million country-led technical assistance program designed to boost the market for solar mini-grids with battery storage to improve access to electricity in 21 countries, and the EU's ElectriFI investment vehicle that aims to Accelerate the development of clean energy businesses.

In general, mini-grids account for a significant share of international energy investment in sub-Saharan Africa. Over the past five years, the Africa Mini Grid Developers Association reports that $9 billion in concessional capital has been committed to the mini-grid sector. By way of comparison, the «SDG7 Tracking» database maintained by the IEA and the World Bank indicates that international investments in renewable energy in sub-Saharan Africa represent $20 billion between 2019 and 2023.

THE STRATEGIC ROLE OF STORAGE IN THE DEVELOPMENT OF MINI-GRIDS

Mini-grids must guarantee continuous access to electricity for the population, but since they are autonomous and run on renewable energies, it is necessary to use systems to compensate for intermittency. To compensate for the intermittency of production, they must be supplemented by auxiliary diesel generators or by battery energy storage systems.

As of 2023, approximately 21,500 mini-grids were operational worldwide, serving more than 4.8 million people. In addition, an additional 29,400 mini-grids are currently planned, 95% of which are located in Africa and South Asia. These have the potential to connect 35 million people. (IEA and WB, 2025).

Three scenarios for the development of electrification and batteries are envisaged for 2022–2030, according to the report «Energy Storage for Mini-Grids, status and projections of battery deployment[2]»:

- **Optimistic scenario:** The share of rural electrification by mini-grids increases from 30% to 50% from 2022 to 2025, then remains at 50% until 2030. In this scenario, the annual demand for mini-grid batteries is projected to increase from around 180 MWh in 2020 to more than 3,600 MWh in 2030.
- **Base scenario:** Mini-grid penetration remains stable at 30%, and annual storage demand would exceed 2,200 MWh.
- **Pessimistic scenario:** Mini-grid penetration drops to 20%, with an increase in other methods of accessing electricity such as grid expansion and solar lighting systems. Annual demand is estimated to be around 1,500 MWh.

By 2030, the demand for energy storage systems is therefore expected to increase by a factor of 8 in the most pessimistic scenario, depending on the scenario, and up to a factor of 200 in an optimistic scenario of deployment of mini-grid electrification solutions. These scenarios evoking an increase in storage systems are confirmed by the "Mini-grid partnership" report (2024) which states that in sub-Saharan Africa, the number of connections installed almost doubled between 2019 and 2021, from 40,700 to more than 78,000. The main leading countries in terms of installed MW are Nigeria, Sierra Leone and Senegal. However, other countries, including Uganda and Ethiopia, are also developing several ongoing projects.

[2] *ESMAP RPT_Energy Storage for Mini Grids_WEB.pdf*

SEVERAL USE CASES DEPENDING ON THE MINI-GRID CONFIGURATIONS

There are different configurations of mini-grids depending on their energy source, whether or not they are connected to the national grid. Of these, the stand-alone configuration is the most common in sub-Saharan Africa, as it can supply isolated rural areas not connected to the main grid. Each of these configurations, described below, corresponds to a specific energy storage use case:

Off-grid solar mini-grids

Entirely independent of the national grid, stand-alone solar mini-grids are based on local production from photovoltaic panels and systematically integrate battery storage systems. Indeed, the latter make it possible to accumulate the excess energy produced during the day to release it during hours of high demand. Despite a high initial cost (PV infrastructure and storage devices), this configuration remains the most suitable for non-electrified rural areas, offering a reliable, ecological and sustainable solution.

Stand-alone hybrid mini-grids (solar + diesel, sometimes wind)

In hybrid mini-grids, battery storage is still necessary, but it is sized differently. These systems typically combine solar PV with a diesel generator (and sometimes a wind component) to ensure continuity of power without oversizing storage (see Figure 1). The batteries here mainly serve as an energy buffer, stabilizing the system, smoothing out peak demand, and reducing fuel consumption. This configuration optimizes costs: it has a lower CAPEX than a 100% renewable system and a lower OPEX than a pure diesel network. Hybridization can be implemented at the design stage of the project or by converting an existing diesel mini-grid. It maximizes the use of renewable energies while maintaining power reliability.

Interconnected mini-grids (connected to the national grid)

Interconnected mini-grids, still rare in Africa, represent an emerging configuration that combines local autonomy and interaction with the national grid. In this model, the use of storage is not systematic: it can be reduced, shared or targeted at specific uses. This is because the mini-grid can feed excess energy into the main grid or, conversely, draw electricity in the event of a production deficit, which limits the need for large battery capacities. When storage is present, it is used to ensure local continuity in the event of a grid failure (island mode) or to provide ancillary services (frequency regulation, reserve, load management). This type of configuration, which is more complex to implement, is suitable for underserved semi-rural or urban areas and paves the way for new business models that integrate storage as a tool for flexibility in the electricity system. It is promoted in particular within the framework of the DARES programme.

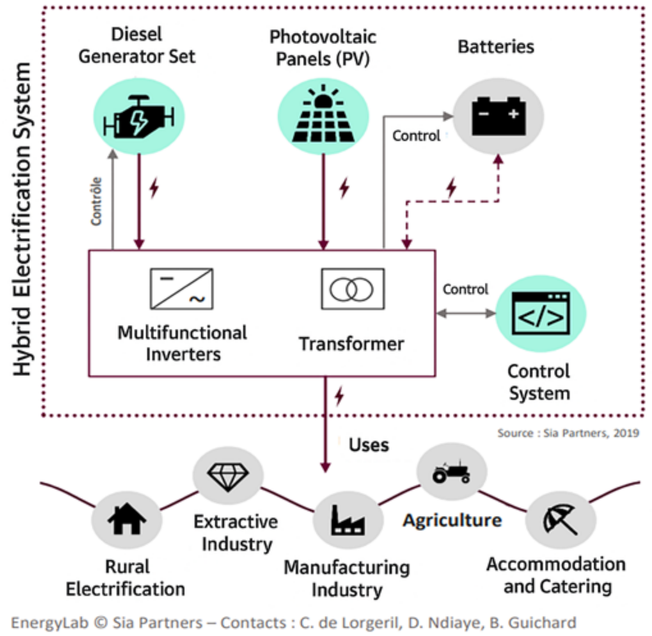


Figure 1 - Schematic plan of a hybrid system

SUMMARY TABLE OF ENERGY STORAGE ACCORDING TO MINI-GRID CONFIGURATION

Mini-grid	Battery storage required/not	Comment
Standalone solar mini-grid	Yes	
Standalone hybrid mini-grid	Yes but dimensioned differently	Reduced storage as diesel can cover peaks
Interconnected mini-grids	Sometimes shared / Not mandatory	Still rare in sub-Saharan Africa

Finally, there are mini-grids powered exclusively by diesel generators represent a transitional solution, historically the easiest to deploy in isolated areas. As they do not require battery storage, they are highly dependent on fuel costs and supply logistics, which are often restrictive in rural areas. Their efficiency decreases rapidly when operating under low load, leading to overconsumption and premature aging of equipment. Although their maintenance is perceived as simple and controlled, these mini-grids suffer from low economic and environmental sustainability, which is gradually pushing their hybridization with renewable sources and the integration of storage solutions to reduce their impact and operating costs.

ADVANTAGES AND LIMITATIONS OF BATTERY STORAGE

The advantage of battery storage in mini-grids can be seen in comparison with mini-grids powered exclusively by diesel generators and therefore not requiring battery storage:

- **Immediate responsiveness:** The batteries offer an extremely fast response time, making them particularly effective for stabilizing the voltage and frequency of the grid.
- **Lower maintenance requirements:** Unlike diesel generators, batteries do not have moving mechanical parts, which reduces the need for maintenance (oil changes, filters, wear parts) and significantly reduces operational costs.
- **Quiet operation:** Battery systems are noise-free, which is an advantage in dense urban or residential environments, where noise pollution is an issue.
- **Reduced emissions:** Batteries do not emit greenhouse gases or local air pollutants (NO_x, particulate matter), contributing to improved air quality and the fight against climate change.
- **Logistical simplicity:** The absence of fuel reduces the need for logistics, storage and transport, which is particularly advantageous in remote or unsecured areas.

Despite these advantages, battery storage has several technical and economic constraints:

- **High cost of storage:** the battery storage system can represent up to 50% of the total cost of the energy system as illustrated by the theoretical comparative case based on our estimates (see table below). This is all the more true when you are looking for long-term storage (several days of autonomy).
- **Limited autonomy:** These systems are usually designed to provide a few hours of electricity. In the event of low production for an extended period of time, they do not guarantee a continuous supply unless they are greatly oversized.
- **Regulatory and safety constraints:** In some countries, critical infrastructure (hospitals, data centers, pumping stations) must provide an autonomous power supply for several days. Batteries alone are rarely sufficient to meet these requirements without thermal support.
- **Rural economic viability:** In rural Africa, in the absence of public support mechanisms (CAPEX grants, subsidized tariffs, payment facilities), projects are often considered unprofitable.

Element	Scenario 1: No Storage	Scenario 2: Solar + battery	Scenario 3: Solar + Diesel
PV capacity	500 kWp	500 kWp	500 kWp
Storage capacity	—	2 MWh Li-ion	250 kVA group (back-up)
CAPEX PV (500 kWc, 700 $/ kW)	**350 000 $**	**350 000 $**	**350 000 $**
Li-ion battery ($250/kWh installed)	—	**500 000 $**	—
Generator set ($250/kVA)	—	—	**$62,500**
LV/MV local network (lines, poles)	**$200,000**	**$200,000**	**$200,000**
Inverters / Converters	**$50,000**	**$100,000**	**$70,000**
Balance of System (BOS, IT, sécurity...)	**$50,000**	**$70,000**	**$60,000**
TOTAL	**$650,000**	**$1,220,000**	**$742,500**
Delta with system without storage	**0%**	**88%**	**14%**

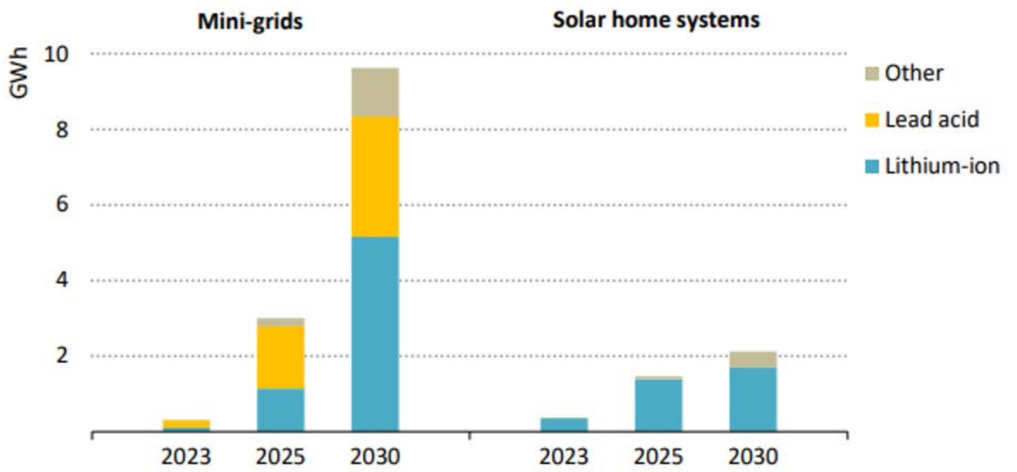
Source: Internal calculations based on cost data presented in the study.

ENERGY STORAGE TECHNOLOGIES

Battery energy storage is based on different technological solutions: lead-acid batteries, lithium-ion batteries, nickel-metal hydride (NiMH) batteries, nickel-cadmium (NiCD) batteries, nickel-zinc batteries (NiZn), flow batteries, sodium-sulfur batteries (NAS)[3].

The main technologies used today in sub-Saharan Africa, especially in mini-grids (see chart), are lead-acid and lithium batteries. Trends and exchanges with market players do not allow the institution to conclude that solutions will emerge that will replace these two technologies on a large scale. Lithium-ion technology is set to dominate the market in 2030 according to IEA analyses.

Figure 2.28 ▹ Battery storage by type for new electricity access with decentralised systems in the NZE Scenario, 2023, 2025 and 2030



Lithium-ion batteries dominate in decentralised systems, though lead-acid batteries continue to play a role in mini-grids and the share of other battery types rises

Notes: Other includes sodium-ion, flow batteries and other battery chemistries/technologies. Technology mix can vary drastically depending on market evolution.

Sources: IEA analysis based on the IEA access database and model, and ESMAP (2023) and GOGLA (2023) resources.

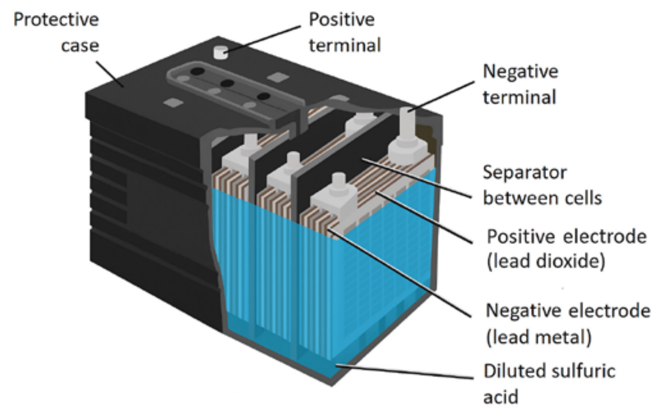
[3]https://www.mordorintelligence.com/fr/industry-reports/battery-market

LEAD-ACID BATTERIES

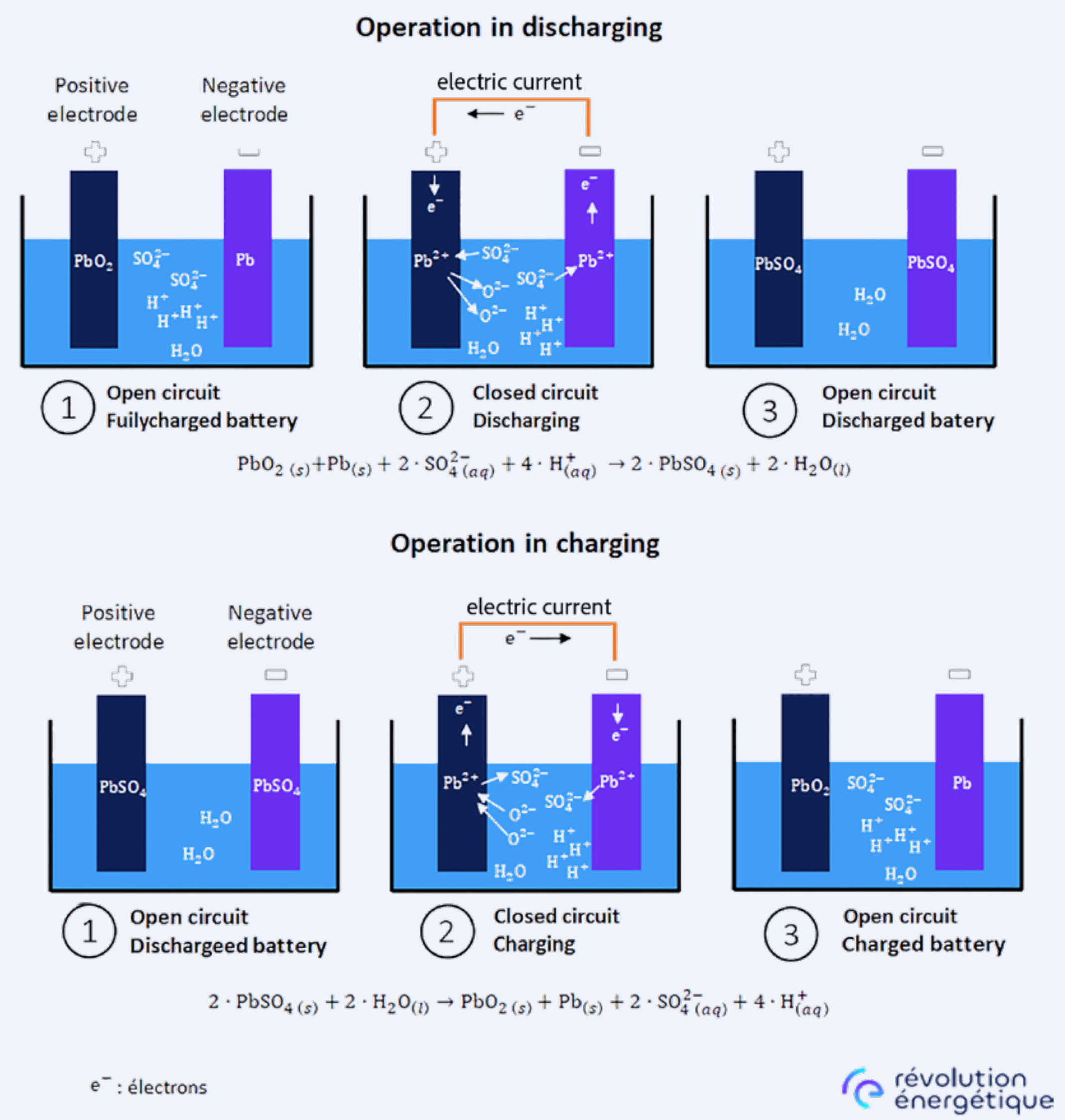
Working principle

A lead-acid battery stores electricity in a chemical form, which means that the charge/discharge process will involve chemical reactions that lead to several elements interacting with each other: hydrogen (H), oxygen (O), lead (Pb) and sulfur (S). As a result, a lead-acid battery falls into the category of «electrochemical accumulators», which includes the vast majority of electricity storage systems.

When the battery is discharged, it is a source of energy, so chemical reactions are spontaneous. To do this, the positive electrode must be connected to the negative electrode by an external electrical circuit, connected to the devices that are being supplied with electricity. The ions in the electrolyte are used to transmit the current inside the battery. The overall electrical circuit is therefore closed, allowing the current to circulate (see diagram below).



OPERATING PRINCIPLE OF A LEAD-ACID BATTERY



Lifespan and Cost of Lead-Acid Batteries

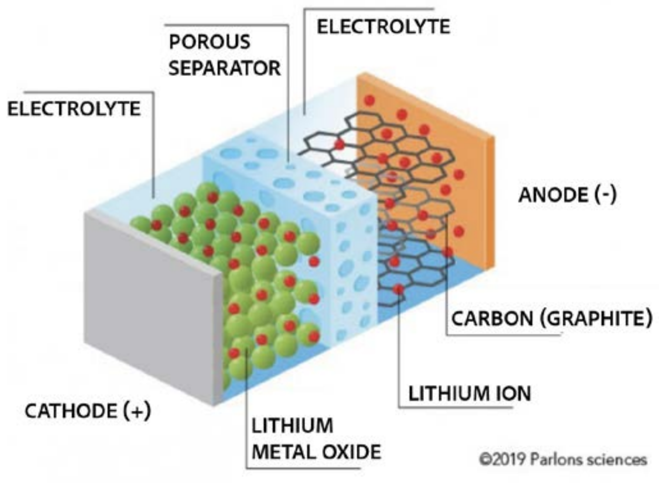
The lifespan, called the number of cycles, of a lead-acid battery is directly related to its discharge rate: as the depth of discharge increases, its «lifetime» decreases. In other words, the deeper the battery is discharged each cycle, the faster it wears out, and the fewer cycles it will be able to complete in total. The other important factor for this type of batteries is the outside temperature, which is usually recommended below 20°C.

Current estimates give a lifespan for lead-acid batteries of between 300 and 1500 cycles. However, they have a relatively short lifespan in Africa, especially due to climatic conditions. Thermal management is a crucial aspect of battery maintenance. A well-ventilated and, if possible, air-conditioned installation can significantly extend the life of the batteries.

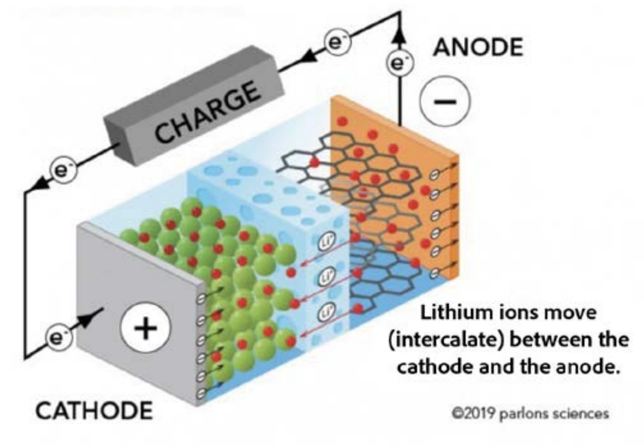
Current estimates give a lifespan for lead-acid batteries of between 300 and 1500 cycles.

According to the ESMAP study in 2022, the initial investment cost of these batteries, which depends on its power output and energy capacity, is around $70 to $100/kWh.

Components of a lithium-ion battery



Discharge



BATTERIES LITHIUM-ION

Operating Principle

In the same way as for lead-acid storage systems, lithium-ion batteries fall into the category of «electrochemical accumulators». The charge/discharge process will therefore involve chemical reactions leading to several elements interacting : lithium (Li), cobalt (Co), oxygen (O) and carbon (C).

Li-ion batteries are composed of a set of cells enclosed in a protective envelope. Each cell contains an accumulator, which is the very component where energy is stored. An accumulator consists of a positive electrode and a negative electrode between which is inserted a separator, the function of which is to prevent short circuits between the two electrodes. The whole thing is immersed in an electrolyte.

The manufacture of these batteries requires the use of strong and structurally stable materials that can absorb and release lithium in both the positive and negative electrodes.

- **Boxes:** aluminum/steel
- **Anode :** graphite
- **Cathode:** mixture of different metals - cobalt, nickel, manganese, lithium, iron, aluminium (the material often varies and its choice has a great influence on the characteristic performance of the battery)

The cells (anode, cathode, separator) represent 50% of the weight of the batteries and 90% of their value.

The main advantages of these batteries are high energy density and longer life compared to traditional lead-acid batteries, for minimal maintenance.

Lifespan and Cost of Lithium Batteries

Current estimates now give a lifespan for lithium batteries that can range from 3000 to 6000 cycles, according to feedback from companies in the core group. However, these figures vary greatly depending on the conditions of use of these batteries, the quality of manufacture, etc.

According to the same ESMAP study, the investment cost of lithium batteries was on average $250/kWh in 2021. When we interviewed the companies participating in the study, they told us that in 2025 the price has already dropped to around $200/kWh, thanks in particular to the massive production of batteries to meet the demand for electric vehicles, which leads to economies of scale

Mr. Saint-Sernin, co-founder of the start-up Zembo, shares the four elements to maximize the life of a battery:

- **Correctly assess the energy requirement and choose the battery technology accordingly**
- **Select a reliable supplier, respecting quality standards and offering traceability on manufacturing**
- **Adapt the use of the battery:**
    - **Cycle monitoring: avoid full charge/discharge too frequently, keep the battery within an ideal charging range (20-80%)**
    - **Temperature control, as lithium batteries are sensitive to extreme temperatures. As mentioned above, exposure to excessive heat accelerates battery wear**
    - **Favor a slow load to limit stress on the cells**
- **Use a battery management system (BMS) with built-in sensors to monitor key parameters (temperature, charge cycles, depth of discharge) in real time, which allows for adjustment of operating conditions.**

Lithium-ion batteries in mini-grids

The use of this type of battery for stationary storage has been increasing significantly in popularity for several years. In 2019, 29% of batteries used in sub-Saharan Africa ran on lithium-ion.

In the mini-grid sector, while lead-acid batteries were dominant before 2018 because the technology was mature and inexpensive, they are now in decline in favor of lithium batteries. An ESMAP survey of 211 mini-grids under construction or commissioned in 2020 and 2021 revealed that 69% of them used lithium-ion batteries and 31% used lead-acid batteries (ESMAP 2022), reflecting the transition from the appetite of the lead-acid battery market to lithium batteries.

Their market share is expected to reach 70% by 2030, up from 55% in 2021 according to analysis by Customized Energy Solutions (CES, a consulting firm specializing in energy markets) cited in the report.

Li-ion batteries are also widely used in other areas and their possible reuse in the mini-grid sector is an additional advantage. This is particularly the case for the e-mobility sector. For example, electric vehicle batteries are associated with a «state of health» to track their aging over time. When it is around 80%, the batteries can no longer be used in vehicles but still work (the power output and range of the vehicle decrease). However, they are still efficient enough to be used as a renewable energy storage system. Indeed, for an energy storage application, lithium batteries can be used up to a state of health of 50% before they need to be recycled.

EMERGING TECHNOLOGIES

Flow batteries

Redox Flow Batteries (VRFBs) are a type of rechargeable batteries that store energy electrochemically in two separate liquid electrolytes, often referred to as electrolyte solutions. These solutions are contained in external tanks and are pumped through an electrochemical cell that converts the chemical energy into electrical energy. The energy is returned by carrying out the opposite reaction.

Although this technology is of technical interest, it is still very rare in practice, with only about ten use cases identified to date.

Among the favorable points of this technology for use in mini-grids, we can note:

- Robust performance in a variety of temperatures.
- Long life (up to 20 years and 10,000 cycles), ability to fully discharge and operation for six hours or more.
- The vanadium and zinc components are relatively easy to recycle, which makes these batteries interesting from an environmental point of view.

However, their initial cost is high, between $350 and $450/kWh and these batteries have a low energy density (20-40 Wh/kg, compared to 150-250 Wh/kg for lithium batteries), as well as more complex maintenance. Their initial investment cost is also higher due to the complexity and size of the systems, compared to lead-acid and lithium-ion batteries.

The main manufacturers are[4]:

- RedFlow Ltd (Australia);
- Primus Power Corporation (United States);
- VRB Energy (Canada);
- Invinity Energy Systems Plc. (Merger of UK-based RedT Energy and North American-based Avalon Battery);
- ESS Tech Inc. (USA)

[4] *Spring: Flow Battery Market – Size, Share and Growth*

Batteries nickel-cadmium (NiCD)

Although representing a small share of the installations, this technology was mentioned by Mr. LIPPERT - Director of Innovations and Solutions for Energy, at SAFT. According to him, this technology is particularly suitable for the weather conditions on the African continent.

Nickel-cadmium batteries are suitable for small, stand-alone photovoltaic systems, especially in regions with hot climates. These batteries stand out for their ability to store several days of energy consumption, providing reliable backup power for critical equipment such as pumps or electronic systems, even in the prolonged absence of solar power.

Their relatively low cost, their fairly long lifespan (1500-2000 cycles) as well as the ease of storage regardless of the charge level make them a fairly good ally in remote environments.

However, they contain dangerous substances, in particular cadmium (a heavy and toxic metal) and must therefore be collected at the end of their life to be recycled, which remains a major constraint.

Other technologies

- **Sodium-ion batteries** developed by the British company **Faradion**, as a more economical alternative to lithium-ion batteries. These batteries are less expensive and the materials are more abundant.
- **Iron-to-air batteries**, still in the development phase, promise a large storage capacity at a lower cost, adapted to the needs of mini-grids in Africa.
- **Flywheel storage systems** offer a robust and sustainable solution for energy storage, although their initial cost is higher. They are especially useful for applications that require frequent charge and discharge cycles.

According to ESMAP's study, *Energy Storage for Mini Grids Status and Projections of Battery Deployment*, these technologies are used in less than 0.5% of mini grid installations. Their market share by 2030 is expected to remain below 1% of annual installations.

TECHNOLOGY COMPARISON: COST, PERFORMANCE, LIFETIME

In this study, we will focus on the main technologies, which are lead and lithium. We will also discuss nickel-cadmium batteries, which are of particular interest in the climatic conditions on the African continent, while taking into account the recycling difficulties specific to this technology[5].

Storage cost

CAPEX (upfront investment cost) is the tool most often used to financially determine which storage technology is more advantageous than another.

However, using CAPEX primarily does not allow for other factors such as project lifetime, efficiency, or operational and maintenance cost. These parameters are included in the calculation of another indicator: the Levelized Cost of Storage (LCOS). The latter refers to the total cost of storage over the entire life of an energy storage system and takes into account different cost elements and their timing over time, the time value of the money and the opportunity cost of the capital invested. The LCOS also allows the cost of managing the end of life of a system to be taken into account:

$$LCOS = \frac{CAPEX + OPEX - Net\ Residual\ Value}{Energy\ stored\ over\ lifetime}$$

Where the following parameters are considered:

- **CAPEX:** the investment cost of the storage system
- **OPEX:** the cost of operating, maintaining and replacing the storage system
- **Net residual value:** the monetary value of the storage system at the end of its use – the cost of managing the end of life (i.e. collection, recycling, etc.)
- **Energy stored over the lifetime:** the result of the following equation: number of cycles X storage capacity X Efficiency round trip

The LCOS would therefore allow a more complete comparison of the costs of the different storage systems and go beyond the mere consideration of CAPEX. For illustrative purposes, a comparison between lithium and lead-acid battery storage is presented below for a fictitious 1 MW / 4 MWh system with the following parameters:

[5] *The use of nickel-cadmium batteries, for example, is regulated in Europe: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:266:0001:0014:fr:PDF*

Element	Lithium-ion	Lead-acid
BASIC SETTINGS		
CAPEX	\$250/kWh × 4,000 kWh = **\$1,000,000**	\$100/kWh × 4,000 kWh = **\$400,000**
Annual OPEX	2% × CAPEX = **\$20,000**	4% × CAPEX = **\$16,000**
Lifetime (years)	10	5
Cycles/year	300	300
Depth of Discharge	90 %	60 %
Yield	92 %	75 %
Energy stored over lifetime	9,936 MWh	2,700 MWh
NET RESIDUAL VALUE		
Gross residual value	\$200,000	\$40,000
End-of-life costs	\$150,000	\$10,000
Net residual value	\$50,000	\$30,000

Source: Internal calculations based on cost data presented in the study.

We then obtain:

$$LCOS_{Li} = \frac{(1000000 + (20000 * 10) - 50000)}{9936} = 115.7\$/MwH$$

$$LCOS_{Pb} = \frac{(400000 + (16000 * 5) - 30000)}{2700} = 166.7\$/MwH$$

This simulation explains the interest of using LCOS to measure the real cost of a storage system over its entire lifespan and reveals that lithium batteries are now 30% cheaper than lead-acid batteries if we go beyond the immediate investment cost and that the full cost of the system is considered.

However, market players such as SAFT and SLS Energy point out that LCOS is not yet a common operational indicator in tenders or short-term business decisions. Indeed, the extremely volatile nature of battery life in the context of sub-Saharan Africa, particularly with regard to the challenges of maintenance and use practices (deep charging and deep discharge), makes the calculation of the LCOS and its consideration in the business models of the players difficult.

Instead, LCOS is used in macroeconomic analysis, to compare technologies in investment studies, public policies or energy roadmaps and is relevant in the case of large-scale stand-alone storage systems.

To allow the calculation of the LCOS, these actors therefore suggest that for each technology and each use, a "standard" of number of load cycles should be set by independent bodies on which they could rely.

Batteries performances

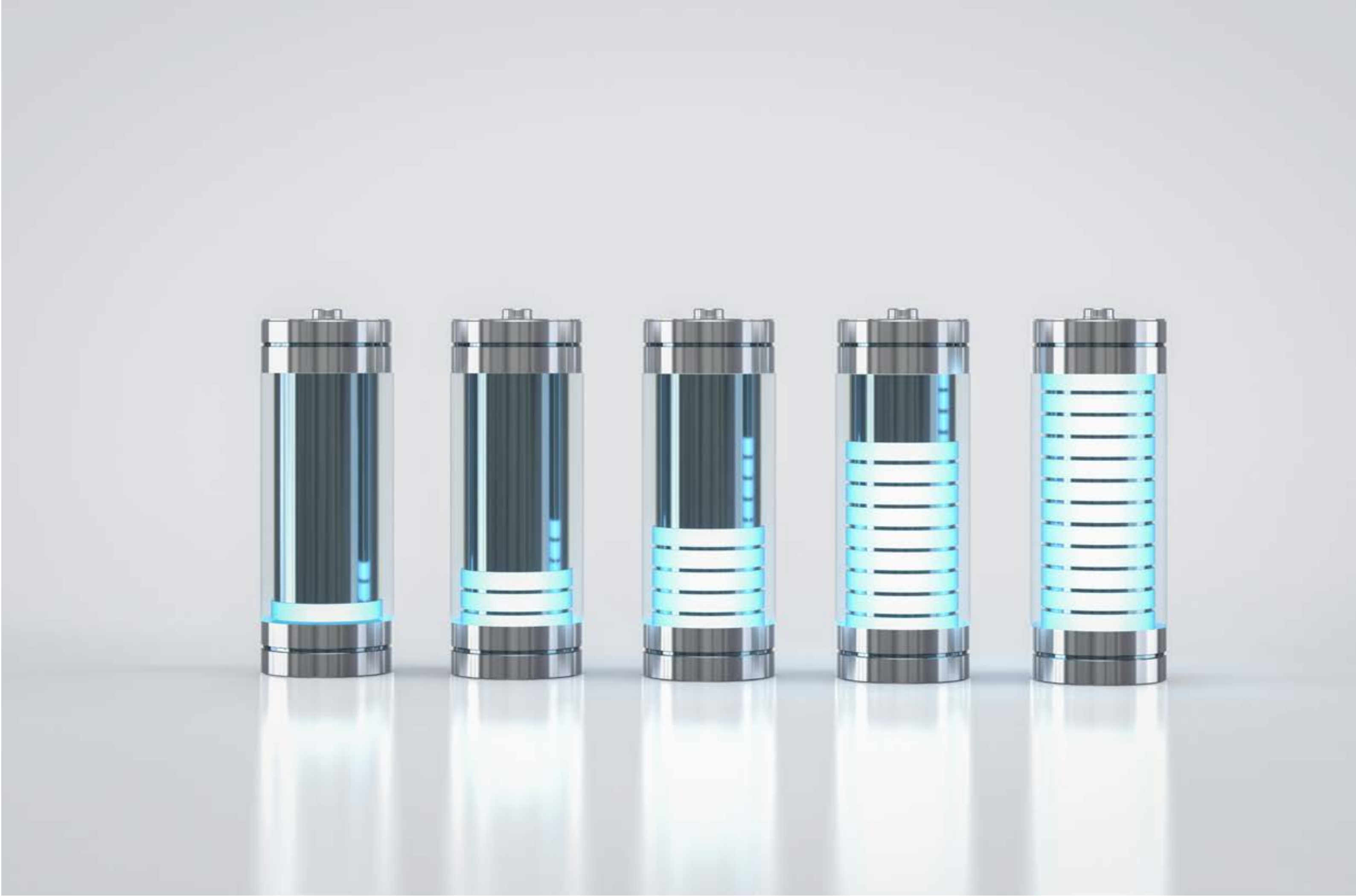
In addition to CAPEX, the following players are considered by investors:

- **Battery life** (or number of cycles): A longer life reduces replacement costs, which include labor and battery.
- **Depth of discharge:** Batteries with a better depth of discharge offer more energy available, reducing storage costs.
- **Charging Type:** Lead-acid batteries are not suitable for high inductive loads that can damage them.
- **Energy density:** High-density batteries are preferable for their energy capacity and ease of transport.
- **C-rating:** C-rating is a measure of the maximum current that a battery can charge or discharge. Most mini-grids use lead-acid batteries with aC/ 10 rating, which means that in the event of a discharge, the battery can provide a current level that would completely discharge it in 10 hours. These batteries are not intended for heavy-duty applications requiring a high discharge current. When used for such applications, they discharge quickly. Lithium-ion batteries and redox flow batteries often have higher C-ratings
- **Maintenance:** Batteries that require less maintenance, such as lithium-ion, are preferred. Lead-acid and redox flow batteries require more maintenance.
- **After-sales service:** Essential for troubleshooting, especially in remote areas.
- **Integrated solution:** Integrated systems can reduce tax costs through lower import duties compared to individual components in some African regions
- **Maturity:** Mature storage technologies are perceived as more reliable, with well-developed supply chains and after-sales service.
- **Capital and operational cost:** Developers can prioritize the upfront cost over the total cost of ownership.
- **Battery degradation:** Technologies with higher degradation rates result in more frequent and higher replacement costs.

TABLE 3.2: **Pugh Matrix Ranking of Storage Technologies in Mini Grid Applications**

Parameter	Weight (Percent)	Li-Ion	Lead Acid	Advanced Lead Acid	VRFB	Zn-Br	Nickel Sodium Chloride
Battery life	25	8	5	7	9	8	9
Heavy-duty usage (higher C-rate)	15	9	5	7	7	7	7
Maintenance	10	9	6	8	7	7	6
After-sales service	15	8	9	8	6	6	5
Maturity of technology	10	8	10	6	7	7	6
Cost	25	9	10	8	6	6	5
Weighted-average score		8.5	7.5	7.4	7.1	6.9	6.5

Source: CES.



This storage technology comparison table is used to make recommendations for storage technologies. Each parameter is scored on a scale of 1 to 10, and is equally weighted: some criteria count more than others in the final score. In the table, the two main criteria are battery life and cost, respectively to ensure storage durability and economic viability.

The battery's ability to withstand intensive cycles, maintenance, after-sales service and the maturity of the technology were also taken into account.

A total efficiency score is calculated (last row of the table) by performing a weighted sum.

The conclusions of this comparison are as follows:

- Lithium-ion remains the optimal solution for most mini-grids because it combines longevity, reliability and reasonable costs.
- Lead-acid batteries remain affordable, at least during the initial investment, which is less expensive. On the other hand, their lifespan is shorter.
- Emerging technologies such as zinc-bromine batteries and vanadium redox batteries are under development and show promise, but at present their use would depend solely on subsidies given their high costs to be deployed on a large scale.

INDUSTRY PLAYERS AND BUSINESS MODELS

Here are the main players in the sector. These lists are not exhaustive but provide an overview of the players and identify the most representative solutions in the territory. The companies shown **in blue** are part of the core group of this study.

BATTERY MANUFACTURERS FOR STATIONARY STORAGE

Presentation of the main manufacturers and suppliers

Batteries lithium

- **Panasonic Corporation:** The company not only specializes in the manufacture of batteries for electric vehicles, but also provides large-scale systems for both homes and grids.
- **LG Energy Solution (LGES):** The world's second-largest producer of lithium-ion batteries, with a global market share of around 20%. It supplies some of the largest electric car manufacturers, but also has significant interests in major battery energy storage systems, which provide residential and grid-scale applications.
- **Samsung SDI:** Solutions for Residential and Network-Wide Customers
- **Pylontech:** This Chinese company is a provider of specialized energy storage systems, bringing together skills in electrochemistry, power electronics and system integration. It offers commercial and industrial solar systems, as well as residential battery energy solar (BESS) systems.
- **Solar® :** Solar® specializes in lithium-ion battery storage for residential and commercial applications. It designs intelligent battery management systems, enabling monitoring, protection and control at the cell level. The solutions are manufactured in a factory in Cape Town, South Africa.
- **CEGASA:** CEGASA is a European company with 90 years of experience in energy storage. It focuses on the local assembly of batteries based on Lithium-Iron-Phosphate (LFP) cells imported from China, integrating its own battery system management (BMS) and energy management (EMS).
- **SAFT:** A subsidiary of TotalEnergies since 2016, is a world leader in the design and manufacture of batteries. The company offers energy storage solutions for the industrial, transportation, energy and defense sectors. SAFT is developing lithium-ion and nickel-cadmium batteries.

Lead-acid batteries

- **Exide Technologies:** one of the world's leading manufacturers of lead-acid batteries. In addition to automotive batteries, they also manufacture considerable volumes of industrial batteries. These batteries are used in backup systems and other miniature energy storage solutions.

  To guarantee the durability of the systems, Exide collects as much information as possible from its customers on the expected conditions of use of the batteries (temperature, charge profile, use, etc.) in order to size the equipment as closely as possible to the real needs. The company also offers technical training to prevent premature end of battery life, considering that it is the responsibility of the manufacturer to provide users with the knowledge necessary for optimal use.

Blackridge Research & Consulting and Grand View Research also cite the following players:

- **Clarios** (USA, formerly Johnson Controls): specialized in batteries for use in electric vehicles
- **GS Yuasa** (Japan): various applications, including automotive batteries, industrial batteries, and high-performance batteries for offshore research and space development
- **East Penn** (USA): particularly specialized in uses for the automotive industry
- **EnerSys** (USA): specialized in stationary energy storage solutions for telecoms, data centers, backup systems, as well as heavy industrial applications.
- **Leoch International Technology Ltd (China):** batteries for the telecom, off-grid solar, UPS systems, and automotive sectors, with a strong presence in emerging markets

Supplier channels – example of the core group companies

The supply of batteries for energy systems deployed in Africa is based on a largely internationalized supply chain, marked by a strong dependence on Asia for lithium components, a predominance of Europe for lead-acid batteries, and a gradual emergence of local second-life sectors. The analysis of the companies in the core group shows that the structuring of these sectors depends not only on the technology used, but also on the economic model, local manufacturing capacities and the degree of integration desired by the operators.

New lithium batteries – the Chinese sector remains in the majority

PAM africa, which assembles some of its systems in Nigeria, sources mainly from China for critical components. Despite some attempts to localize assembly, limited economies of scale and lack of infrastructure are holding back industrialization on the continent.

In the case of **Engie Energy Access**, the strategy differs according to the segments. For solar home systems (SHS), the supply chain is entirely based in China, while for mini-grids, Engie is collaborating with South African manufacturer Solar MD, indicating a willingness to favor African partners when available.

The company **ARESS**, for its part, imports its LFP (lithium-iron-phosphate) batteries directly from China, like the majority of integrators. Evolve BGS is not involved in the initial selection of batteries but notes that the majority of its customers' equipment is of Chinese, sometimes Italian or German origin.

Finally, **Cegasa** illustrates a hybrid sector: although its lithium cells are also imported from China, all assembly and development of management systems (BMS and EMS) are carried out in its factories and laboratories in Europe, thus ensuring enhanced quality control. In fact, the company has its own laboratories, which allows them to carry out extensive tests at every stage of manufacturing: from cells to modules, to the complete system. They have laboratories that specialize in characterizing cells and evaluating them under extremely demanding conditions. In addition, their dedicated approval and safety laboratories ensure optimal quality and reliability, both at the cell and module levels. Each complete system is finally rigorously tested before being sent to its installation site.

Lead-acid batteries: a European anchor

Unlike lithium batteries, the lead sector in sub-Saharan Africa is still largely based on European production. **Exide** illustrates this industrial model: all its lead-acid batteries are manufactured in Germany, France or Portugal, then shipped to African projects at the request of customers (integrators or developers).

ARESS completes its portfolio with lead-acid batteries from Germany and Japan, in particular from the **Okaya** brand, which shows that this technology remains a sought-after solution for certain uses, often for reasons of cost or compatibility with existing systems.

Second-life batteries: innovation for more circularity

SLS Energy stands out for its circular sourcing strategy, recovering components from e-waste or used batteries, often of Chinese origin. The main challenge lies in the heterogeneity of the cells, which requires adapted battery management systems (BMS), mainly sourced in China as well.

To get around the lack of standardized BMSs for remanufactured batteries (they are designed for new batteries), SLS Energy is working with European partners on *open source* platforms, particularly in Germany to improve supply chain traceability and BMS customization. The company also relies on technical partners for the diagnosis and sorting of recovered batteries, an essential condition for their reuse.

DISTRIBUTION AND EXPLOITATION STRATEGIES

Developers are increasingly inclined to choose areas where some level of economic activity or anchor load is present within rural communities, allowing mini-grids to operate to their full potential. Anchor load refers to a load or customer with stable, predictable energy demand and sufficient power to serve as an economic and technical basis for the development and viability of the mini-grid. This is the customer whose request ensures the minimum economic viability of the system. Mini-grids are therefore less and less intended to supply only households, but also other economic activities.

These different strategies are at the heart of the servicing of energy access systems with storage.

Prepayment

This business model is based on the installation and use of a communicating meter. The latter works with a prepaymentt system for gas or electricity consumption via the internet or a charging point. It therefore allows energy to be consumed according to the amount charged on the individual meter.

This system of purchasing an electricity credit in advance makes the energy storage system viable by reducing the risk associated with the initial investment cost in two way

- Reducing the risk of business losses and chargebacks, which promotes the generation of stable and anticipated revenue
- By making users more attentive to their consumption, which reduces cases of deep discharge, increases the lifespan of batteries and therefore their profitability

In Benin, this is the business model deployed by Engie Energy Access. At present, a power plant with a capacity of 134 kW is installed, and mini-grids with capacities of 50, 75 or 100 kW are also being set up. The energy is stored using lithium batteries for the night. A low-voltage distribution network has been installed in the surrounding villages, as well as individual meters for individuals, operating with the prepayment system. Consumers can buy as many units as they want, with one unit corresponding to 1 kWh.

The two types of consumers targeted are households and small businesses.

All the installations belong to Engie, which only sells energy to consumers. This model is so far a success in Benin for Engie, which is expected to commission 20 new production sites by January 2025.

Pay-as-you-go

Unlike the prepaid meter model, in which the user buys a fixed credit of electricity (in kWh or currency) in advance and consumes it until it is exhausted, the pay-as-you-go (PAYG) model is based on a system of progressive and flexible payments, made as theuse, usually via mobile payment platforms. It is therefore a more dynamic model, which combines digital tools (GSM chips, M2M communication, online payment platforms) to remotely activate or deactivate access to electricity depending on the payments made.

This innovative business model is now one of the most promising levers to meet the growing energy demand of rural African households, by facilitating the financing of access to energy. It mainly targets areas covered by mobile networks but not connected to the electricity grid, making it possible to provide basic energy services at low cost, before moving upmarket to more powerful uses (household appliances, pumps, refrigeration, etc.).

In concrete terms, the PAYG system is based on communication between the consumer, the payment platform and the electricity supplier. The solar equipment is equipped with GSM chips and Machine-to-Machine (M2M) modules, allowing the supplier to remotely monitor the performance of the system and unlock the service upon receipt of payment. The data transmitted by the mobile network allows real-time monitoring of the use and condition of the batteries, thus improving the technical and commercial management of the installed base.

Like the prepaid model, PAYG strengthens the economic viability of battery storage systems by:

- allowing users to pay in small amounts, expanding the customer base;
- ensuring recurring and more predictable revenues for the operator;
- facilitating the remote control of storage, while promoting more economical and responsible user behaviour, which helps to extend the life of the batteries.

Finally, several players in the sector express their wish to see this model evolve towards even more flexible solutions, allowing in the long term payment after use, which is currently limited by technical and contractual constraints.

ARESS was the first company to set up such a system in Benin, so far more than 8000 solar kits have been distributed in Pay-as-You-Go.

PAM Africa's So-Cool project is based on energy storage by LifePO4 lithium-ion batteries to provide energy to several small businesses in villages in Nigeria. To solve the cost of the battery, the company also uses the PAYG system, allowing consumers to pay only for what they need and thus making this technology more accessible.

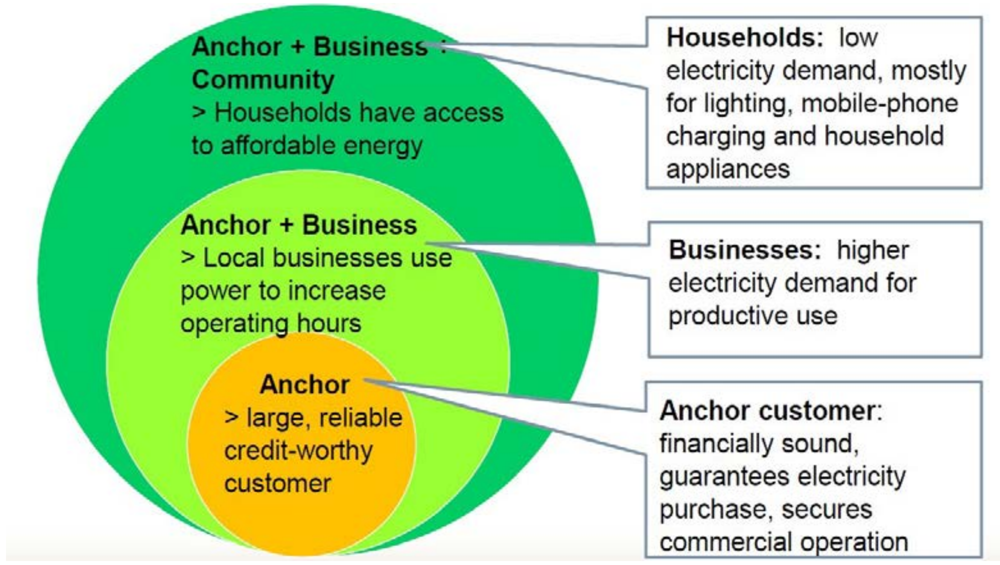
The ABC Model

To compensate for the low profitability of mini-grids based solely on supplying rural populations, and to meet the growing demand from donors to prove the economic viability of projects after they are commissioned, a new model — the Anchor-Business-Community (ABC) — is emerging in Africa.

In this model, the energy production facility is first designed to meet the needs of a local productive actor whose consumption is predictable and able to pay the market price (e.g. a small agricultural processing unit or a fish farm). This client, called the "anchor client", ensures the economic stability of the project.

Once the anchor customer is reliably fed, the distribution area of the system gradually expands. It can first serve other small local economic players, such as shops, before extending access to the population via a mini-network that is gradually being deployed.

This model can be summarized graphically as follows:



Source: "The ABC Model: anchor customers as core clients for mini-grids in emerging economies", GIZ

In Cameroon, the ABC model is being deployed through the "production communes" project, led by the Association of Municipalities (CVUC). Several local authorities wish to equip themselves with a municipal energy production infrastructure intended to:

- **to supply small local economic actors as a priority,**
- **stimulate the creation of new business through reliable supply,**
- **and then gradually extend the supply of electricity to the population.**

In Madagascar, the company Anka is also developing several electrification projects using mini-grids with storage, based on the same ABC model.

Regarding the servicing of power generation and battery storage systems, the ABC model has its own advantages over prepayment and PAYG by:

- Helping to amortize the investment cost of batteries thanks to a customer with regular and large-scale consumption
- Reducing financial risk, as private customers have a lower risk of non-payment
- Reducing the risk of deep discharge and the need for oversizing thanks to a stable demand provided by the anchor customer that avoids the stress of batteries during the day and a distribution of demand that allows for the smoothing of peaks (anchor and business customers consuming during the day and "consumer" households in the evening).

SLS Energy

SLS Energy is an innovative Rwandan company specializing in the optimization and reuse of batteries, especially those from electric vehicles and electronic waste. The company stands out for its ability to extend the life of batteries by reusing them until they reach the end of their useful life.

It develops on-demand energy storage systems using second-life batteries. These systems are designed to optimize setup, estimate health, and protect batteries, through remote control via IoT sensors and cloud technology. This approach ensures safety and enables predictive analysis of battery performance.

Vittoria Technology

This South African company is active in battery reuse through its innovative Battery Bank Africa initiative. This digital platform makes it possible to rent used batteries for mini-grids, which offers an effective solution to extend the life of batteries.

PROCESSES AND ACTORS OF BATTERY END-OF-LIFE

According to the GIZ study "Exploration of Market Potentials in Battery Recycling and Refurbishment in Africa", there are several options for the treatment of end-of-life batteries: they can be reused, reconditioned or recycled.

Battery reuse

First of all, the batteries can be simply **reused**. This is the case, for example, with used batteries for electric vehicles (this process is already being developed in Europe). The battery is thus used as is, without dismantling or modifying it but in a different application from the original one , even if it only has 80% of its capacity left.

Batteries that are unusable for electric vehicles can then still be useful for stationary applications, such as energy storage for backup systems or supporting renewable energy. This may require changes to the battery management system (BMS) or repair of damaged cells.

Reconditioning

The battery is dismantled in order to test, repair or replace certain components (such as defective modules or cells), then it is reassembled.

In order to reduce the impact of the end-of-life of storage systems and considering that a battery regularly reaches the end of its life due to the wear and tear of a single or a few cells, several companies are developing battery storage solutions that allow reconditioning. We are thus seeing the emergence of "modular" solutions such as the French company Tyva Energie with its "Tyva Refill" solution. According to this model, the battery is designed to allow the removal, testing, and individual replacement of defective or worn cells within the original pack.

Case of the Lagazel company

The company is setting up partnerships for the collection of used lithium batteries from solar home equipment and electric mobility devices. The batteries are then sorted according to their state of health, using specific tests to assess their residual capacity and safety. Cells in a satisfactory state of health are reassembled into new battery packs for stationary use.

Lagazel's business model around the end of life of Li-ion batteries is still being defined. One of the preferred options is based on positioning as a service provider, exclusively focused on the repair and reuse of used batteries, without owning them: Lagazel does not buy or resell the batteries supported. The company is also involved in the assembly of cells, and can offer new or second-life batteries for sale.

By setting up battery manufacturing and refurbishment workshops directly on the African continent, Lagazel promotes the creation of local jobs and supports regional industrial development, while limiting the costs associated with importing new equipment. The company also has a dismantling unit dedicated to the local reconditioning of batteries, thus strengthening its anchoring in a local circular economy logic.

Recycling

Finally, the third option at the very end of the chain is recycling: the battery is completely dismantled to extract the materials (lithium, nickel, cobalt, copper, etc.), which will then be reused to make new batteries or other products.

Recycling by pyrometallurgy

Based on the heat and melting of materials, this treatment makes it possible to separate the metals used in batteries and then recover and recover them. Thanks to this technique, a mixture of copper, nickel and cobalt can be recovered, which will then be processed so that it can be reused in future batteries.

Positives	Negatives
• No need for dismantling manpower • Low costs • Metal processing procedure already common in Africa	• Chemical and process engineering needed to be more efficient • Energy-intensive method • Lithium and aluminium are lost in waste and therefore cannot be recycled

Recycling by hydrometallurgy

The battery is first dismantled and shredded, the cathode is then chemically separated from the other materials. The resulting product is called BAMM (mixture of active materials for batteries), the metals contained in it are dissolved with the use of acids and then crystallized. The materials can then be reused in new batteries.

It costs €3000 to €5000 to recycle a tonne of lithium-ion battery (includes storage, sorting and processing).

Positives	Negatives
• Almost the entire process is automated • The chemical process is already in use in Africa	• Need to dismantle batteries • Chemical, mechanical and process engineering needed to be more efficient • Viable only at scale

Direct recycling

After the battery has been physically crushed and the materials separated, the components can be reused directly in production. The treatment consists of relithiation (replacing the missing lithium ions in the structure).

For the moment, this method has only been tested in the laboratory, which makes it complicated to deploy on a large scale.

Positives	Negatives
• Reuse of certain materials • Process automation • Energy-efficient	• Chemical and process engineering needed to be more efficient • Existing only in the laboratory phase

Some companies operating in sub-Saharan Africa

In sub-Saharan Africa, the battery recycling sector is still emerging and poorly structured in most regions, in particular due to the lack of local supply of used batteries and organized e-waste collection systems. On the other hand, in the coming years, the continent is expected to see an increase in the quantity of used batteries, which are currently in use and will reach the end of their life. The informal sector is still very present at present, particularly in the collection of waste electrical and electronic equipment (WEEE). As a result, few companies have significant activities in this sector. The list of actors involved in battery recycling in Africa below is therefore indicative and not exhaustive, with initiatives that vary according to country and local context.

Cwenga Technologies

Cwenga Technologies is a South African company that aims to recover some of the battery components using a chromatographic separation technique of battery metals by leaching using reusable and inexpensive reagents, at room temperature and atmospheric pressure. This reduces the electrical energy requirements associated with pyrometallurgical processes, which are costly and energy-intensive. The recycler supplies ion exchange resins and activated carbon, with input materials supplied by industrial partners Lanxess and Chemviron.

The aim is to recover and separate the metals contained in batteries at a level of quality that allows them to re-enter the market as raw materials.

Enviroserve

Founded in the United Arab Emirates, Enviroserve is a major player in the field of e-waste management and material recycling. Now, having expanded its operations to Rwanda in particular, Enviroserve is collaborating with various solar companies and the government to collect, test, recondition and recycle used batteries. The recovered batteries are tested, recharged, reconditioned and reintroduced to the market for a second life.

This company focuses on testing and reusing functional cells to reduce the amount of batteries that need to be recycled. They support local entrepreneurs and collaborate with partners to rebuild batteries adapted to different energy needs.

Hinckley Recycling

Pioneer company in electronic waste (e-waste) recycling in Nigeria and the first registered e-waste recycler in the country. They work closely with the Ministry of Environment, the National Environmental Standards and Regulations Enforcement Agency (NESREA) and the Lagos State Environmental Protection Agency (LASEPA) to ensure responsible management of e-waste. Hinckley Recycling offers solutions for the collection and recycling of electrical and electronic equipment, ensuring the secure destruction of confidential data and exceeding reuse, recycling and recovery targets.

ANALYSIS OF THE CHALLENGES AND OPPORTUNITIES SPECIFIC TO SUB-SAHARAN AFRICA

This part of the study is mainly the result of working sessions with the companies of the core group, which made it possible to feed the analyses by enriching them with their experiences, the problems they encountered on the continent as well as the solutions deployed.

TECHNICAL AND OPERATIONAL CHALLENGES

Reliability and Durability

Climatic conditions

Extreme weather conditions and limited infrastructure in sub-Saharan Africa pose challenges for the sustainability and maintenance of energy storage systems.

Mr. LIPPERT - Director of Energy Innovations and Solutions, at SAFT, believes that in Africa, high temperature is a 1st order factor in the degradation of batteries, especially lead-acid batteries. Increasing the temperature by 10 degrees halves the battery life. A battery designed to last 10 years at 25°C will only last an average of 5 years if used at 35°C.

In order to overcome this difficulty and adapt to the climatic conditions of the continent, the company has developed an air-conditioned container system, in which the batteries are located, in order to optimize their lifespan.

Maintenance and local ownership

In order to enable the systems to reach their maximum expected lifespan, it is important to ensure their proper use through appropriate trainning for local operators on site, online or in the manufacturers' factories. This is the case for the companies Exide, Cegasa, Aress and Lagazel.

- Exide: organisation of tailor-made training courses to optimise battery life.
- Lagazel: training of local technicians, although infrastructure limits implementation. The context in Burkina Faso makes the training of teams complex, as they cannot travel around the country. Lagazel therefore trains African students in France who then return to Burkina Faso to train the teams there.

As far as the training of local actors is concerned, the'enterprise Schneider Electric has developed an ambitious program: **EcoXpert**.

This program is a global initiative to train and certify partners in various fields related to energy, including mini-grids through the **"New Energy Landscape & Grid"** segment. With approximately 4,500 certified partners worldwide, this program allows Schneider Electric to support its partners in ensuring their skills development. It is based on three levers to guarantee the qualification of partners: (i) training, (ii) support for projects and (iii) evaluation based on the number of projects executed.

Role of digital technology

Digital technology plays a central role in improving battery management. The digital strategies deployed by the core group's companies reveal a convergence towards fine-tuned, dynamic and predictive management of battery farms. The use of the cloud, IoT, data science and AI not only increases the performance of systems, but also improves their resilience, while supporting users towards more sustainable consumption.

Intelligent Monitoring & Data Analysis

Digital systems enable proactive and granular monitoring of batteries. By collecting data (temperature, charge/discharge cycles, voltage, current, etc.), companies can:

- Detect non-optimal uses,
- Adapt the operation of the system (via automatic feedback loops),
- Propose corrective actions remotely.

At Engie, for example, battery systems are equipped with battery management systems (BMS), allowing software updates and remote monitoring of the use of their batteries (including the level of charge/discharge). This information makes it possible to better optimize the use of the energy that Engie produces through the mini-grid.

Centralized and dynamic energy management platforms

PAM Africa has developed a versatile digital platform that collects and analyzes users' energy consumption data in real-time. This processing of information makes it possible to segment customer profiles according to their consumption habits, their ability to pay and their level of energy dependence. An energy administration interface dynamically adjusts the tariffs applied taking into account individual consumption profiles, thus influencing user behaviour. With this dynamic pricing, the platform encourages more efficient use of energy, which in turn helps to extend the battery life of power systems.

Predictive Modeling and Digital Twins

SLS Energy is taking an innovative approach through the development of a digital twin of its batteries, i.e. a virtual replica modeled in real time by data from physical batteries. This architecture allows batteries to be monitored at the cell level, not just the pack level as is currently the case.

They can use the data collected to predict the future behavior of the battery: performance, aging, risks, and maintenance required. These analyses are crucial for minimising maintenance costs, which are central to SLS Energy's "battery-as-a-service" model.

Optimization algorithms and user training

ARESS implements a hybrid approach, combining various elements:

- Use of an algorithm to monitor battery usage and ensure that usage ranges are met. The durability of batteries is ensured differently depending on their use (stand-alone system, solar home system or mini-grid).
- Monitoring via sensors and digital platform of the batteries it operates
- When they are not system operators, ARESS is working to train local teams to optimize the use of the battery. The systems operated by ARESS are therefore monitored by people trained in-house
- Finally, they ensure control of environmental conditions by installing the batteries in temperature-controlled technical rooms, to avoid damage to the systems.

EMS cloud & real-time intelligence

Schneider Electric now offers the deployment of a cloud-based EMS (Energy Management System) layer, offering intelligent and predictive management of power grids.

This solution analyzes and models the network every 15 minutes, allowing real-time adaptation to variations in production and consumption. The EMS relies on a database from the previous six weeks, combined with two-day weather forecasts, to anticipate and optimize energy management. This proactive approach ensures better grid stability, optimal integration of renewable energies and reduced energy costs for users.

ECONOMIC BARRIERS AND REGULATIONS

Cost of storage technologies

The high upfront cost of storage technologies remains a major obstacle. Faced with this challenge, some players in the sector have begun negotiations with local authorities in order to adjust the financial models currently in place. PAM Africa wishes to bring to the attention of local authorities the weight of the cost of the storage system in the total cost of the system, which remains the first item of investment.

However, innovative financing models, such as microfinance and pay-as-you-go, can help overcome this barrier. Indeed, microfinance makes it possible to provide a range of financial services to people working with too small amounts of money to access these services through traditional banks.

Strengthening regulatory frameworks to support mini-grids

The development of mini-grids continues to be hampered by unstable or incomplete regulatory frameworks and the lack of institutional capacity of public authorities. The lack of clear regulations creates uncertainty for investors, while weak technical skills limit the effectiveness of public-private partnerships. Aware of these challenges, donors are now supporting technical assistance programmes aimed at strengthening governance and structuring the sector in a sustainable manner.

In Benin, the government has developed regulations that are favourable to the development of mini-grids, with the aim of providing access to energy to as many people as possible. The country's National Electrification Framework has also defined priority villages for the installation of production plants, based on villages that have not benefited from electrification projects for 15 or 20 years.

Also, the price per kWh is defined by the Benin Electricity Regulatory Agency. To define this price, the Agency analyses the standard of living of the population, as well as the investment and operating costs of the power plants.

Finally, the State and Engie have signed a concession agreement, meaning that Engie has the mandate to operate the plant and distribute energy over 20 years.

Standards and quality: how to control the quality of batteries?

Discussions with the company **CEGASA** confirmed that the batteries exported from Europe all follow different standards, which differ according to their use (storage, use for photovoltaics, etc.):

- **Regulation (EU) 2023/1542** of the European Parliament and of the Council of 12 July 2023 on batteries and waste batteries, Articles 6 / 7 / 8 / 9 / 10 / 12 / 13 / 14.

  This regulation aims to ensure that in the future, batteries will have a low carbon footprint, use a minimum of harmful substances, require fewer raw materials from non-European Union (EU) countries and will be collected, reused and recycled to a large extent within the EU.
- **EMS Standards:**
  - **EN 61000-6-2:** Generic Standards - Electromagnetic Compatibility Immunity Requirements applies to electrical and electronic devices intended for use in industrial environments.
  - **EN 61000-6-3:** Standard for the emission of electrical and electronic appliances intended for use in residential, commercial and light industrial environments
- **European directives:**
  - **2014/30/EU Directive (EMC, Electromagnetic Compatibility):** aims to ensure that electrical and electronic equipment meets an adequate level of electromagnetic compatibility in the European Union.
  - **2011/65/EU Directive (ROHS):** strengthens existing rules on the use of hazardous substances, such as lead, mercury and cadmium, in electrical and electronic equipment (EEE) to protect human health and the environment, including by enabling environmentally friendly recovery and treatment of EEE waste.
  - **2014/35/EU Directive (LVD):** creates uniform conditions in the EU for the sale of electrical equipment intended for use within certain voltage limits. It applies to electrical equipment designed to be used at a voltage between 50 and 1,000 V for alternating current and between 75 and 1,500 V for direct current.
- **UN 38.3 (Regulations for the Transport of Li-ion Batteries):** The United Nations standard that lithium batteries must comply with in order to be certified as safe transportable.
- **IEC 62619: 2022 Ed. 2022-05 (Battery safety):** specifies requirements and tests for the safe operation of lithium batteries used in industrial applications, including stationary applications.
- **IEC 62620:2014 Ed. 2014-01 Standard (Battery Technical Requirements):** Specifies the marking, testing, and requirements for lithium storage cells and batteries used in industrial applications, including stationary applications.

Quality Control Process

Several participants have in-house laboratories to test batteries according to IEC and UN 38.3 standards. This ensures compliance, especially for projects in West Africa.

As a supplier of second-life batteries, **SLS Energy** sets up individual tests, varying various parameters to find out the quality of the batteries. The results obtained are compared to the results provided by the manufacturer when it left the factory. The condition of the second-life battery is determined in this way, but battery degradation and aging cannot be anticipated through these results. To predict the behavior of batteries, it is necessary to have visibility into its first life and how it was degraded. To make this easier, **SLS Energy** uses U.S. asset management companies that collect solar home systems and consumer electronics. These companies sometimes have national agreements allowing them to determine previous use, in particular through the tracking of serial numbers. On the other hand, obtaining certification for the quality of the battery reused in second life, as SLS Energy could have, remains complex due to the battery models used that are constantly renewed. At present, the certifications relate directly to batteries as a finished product. One of the solutions that SLS Energy is working for is to obtain a certification that would focus on the battery rehabilitation process rather than the battery model itself, which would allow them not to need to renew their certification requests for each new battery version.

> **Obtaining certification for the quality of the battery reused in second life [...] remains complex due to the battery cells used that are constantly renewed. At present, certifications relate directly to batteries as a finished product.**

At **Exide Technologies**, batteries are tested before export in order to comply with the standards of the International Electronic Commission (IEC). The difficulty encountered concerns the different demands depending on the customer: the batteries can sometimes be considered non-compliant because they have to meet all the standards at the same time, sometimes incompatible.

Lagazel, for their part, are working with the CEA, which is supporting them to design a test process using inexpensive equipment while having maximum safety. The batteries are tested in their laboratory, to detect defective cells.

Procurement challenges:

According to Mr. Saint Sernin (Zembo), battery sourcing is a major challenge for African energy storage players. While Chinese suppliers dominate the market thanks to their competitive prices, the actual quality of the batteries remains uncertain, as the technical data do not reflect local conditions of use (heat, overloads, deep discharges). Without reliable testing tools and databases, African operators struggle to evaluate products. The implementation of standardised qualification protocols and tests is therefore essential to guarantee the durability and reliability of the installations.

Traceability

Traceability plays a crucial role in battery quality control, allowing each battery to be tracked from its manufacture to its end use, ensuring compliance with safety and performance standards. This transparency is essential to identify potential sources of failure quickly, and to facilitate recalls if necessary.

One solution mentioned by **Cegasa** to improve traceability includes a digital passport containing data on the state of health, remaining lifespan and carbon footprint (including the extraction of raw materials) of each battery.

Similarly, there are European certifications guaranteeing the proper compliance of the transport of lithium batteries.

One difficulty encountered by the companies of the core group in terms of compliance with battery standards in international tenders for African countries concerns certain requirements regarding the end of life or compliance with strict standards. While these requirements are realistic in European contexts, they may be difficult to achieve in Africa at present, due to a lack of resources and infrastructure in the countries concerned.

END OF BATTERY LIFE

According to a report by the International Energy Agency (IEA) titled " EV Battery Supply Chain Sustainability ", the global demand for lithium-ion batteries is expected to increase 4x by 2030 and 7x by 2035, mainly due to the increase in electric vehicle sales. Recycling will play a crucial role in securing the supply of metals to batteries, especially in regions with low primary metal production.

Access to finance

Access **to finance** remains a challenge for the sector. The investments needed to implement effective recycling technologies are high. However, the perceived risks and short-term profitability of battery recycling make financing difficult to obtain.

The **uncertain profitability** of battery recycling is also a deterrent. The costs of processing batteries, compared to the low margins generated on recycled materials, make the sector less attractive to investors. In addition, the prices of recycled raw materials, such as lead and lithium, can fluctuate, creating a climate of uncertainty that inhibits long-term investment.

In order to make end-of-life battery treatment sectors viable, a reflection on the implementation of tariff and tax mechanisms is emerging in several countries. These mechanisms could take three forms:

- The implementation of an Extended Producer Responsibility (EPR) system on batteries; systems under which marketers are responsible for the entire life cycle of batteries, from design to end of life. According to this system, the marketers would discharge their responsibility either collectively by setting up non-profit structures responsible for end-of-life management (eco-organisations) or individually by setting up their own system for the recovery and treatment of end-of-life batteries
- The introduction of an eco-contribution on the sale of batteries making those who put them on the market contribute financially to cover the cost of treatment.
- The introduction, in view of the fact that almost all batteries are imported, of a special excise duty on batteries whose revenues would be used to finance the processing sector.

In Togo, the NGO Moi Jeu Tri is receiving FISONG funding from AFD to set up a system for the management and local treatment of the end of life of WEEE from the solar sector. The post-grant servicing of the sector is based, according to the project, on the implementation by the Togolese authorities of an Extended Producer Responsibility (EPR). This principle implies that economic actors are responsible for the entire life cycle of the products they place on the market, from their eco-design to their end of life.

Moi Jeu Tri is working with the national authorities as part of the project to define the conditions for the implementation of this EPR.

Health challenges

The current ways of dealing with electronic waste in Africa (open dumping, combustion, landfilling) can be dangerous for the ecosystem and human health when it comes to batteries. This is mainly due to the heavy metals they contain.

The battery recycling sector also faces **competition from informal players**. In some African countries, informal battery recovery and processing networks exist, although often in conditions that are hazardous to health and the environment. This competition can make it difficult for formal companies to enter the market, which must comply with strict safety and environmental standards.

Operational and economic constraints

Lagazel underlines the difficulty of working on the end of life of batteries with low volumes of used batteries: this complicates the collection, transport and treatment efforts. Indeed, it is more difficult to justify the costs associated with setting up efficient recycling infrastructure, if the volumes are not large enough. The processing of small quantities of batteries is less profitable, and therefore disincentive to properly manage the end of life of used batteries. Transportation is also expensive, due to poorly maintained road infrastructure. The objective for the company is therefore for the moment to extend the life of lithium cells through reconditioning and reuse, in order to postpone the moment when they will have to be treated at the end of their life.

A lack of collaboration between countries limits development opportunities, especially for end-of-life management of batteries. The sharing of good practices and different recycling technologies is hampered, but it is mainly the lack of pooling between countries that poses a problem. The payment of customs duties, taxes and other fees associated with cross-border transport is a deterrent for players in the sector. Pooling could take two different forms, namely (i) that of used batteries from different border countries, which could be transported to a single recycling centre, and (ii) the pooling of the investments needed to develop adequate infrastructure.

This is Lagazel's bias, for which the volumes of end-of-life batteries are too low. They therefore add their waste to that of other organizations to have a sufficient volume of waste to process. The batteries are then transported to Europe, as there are currently no processing plants on the African continent.

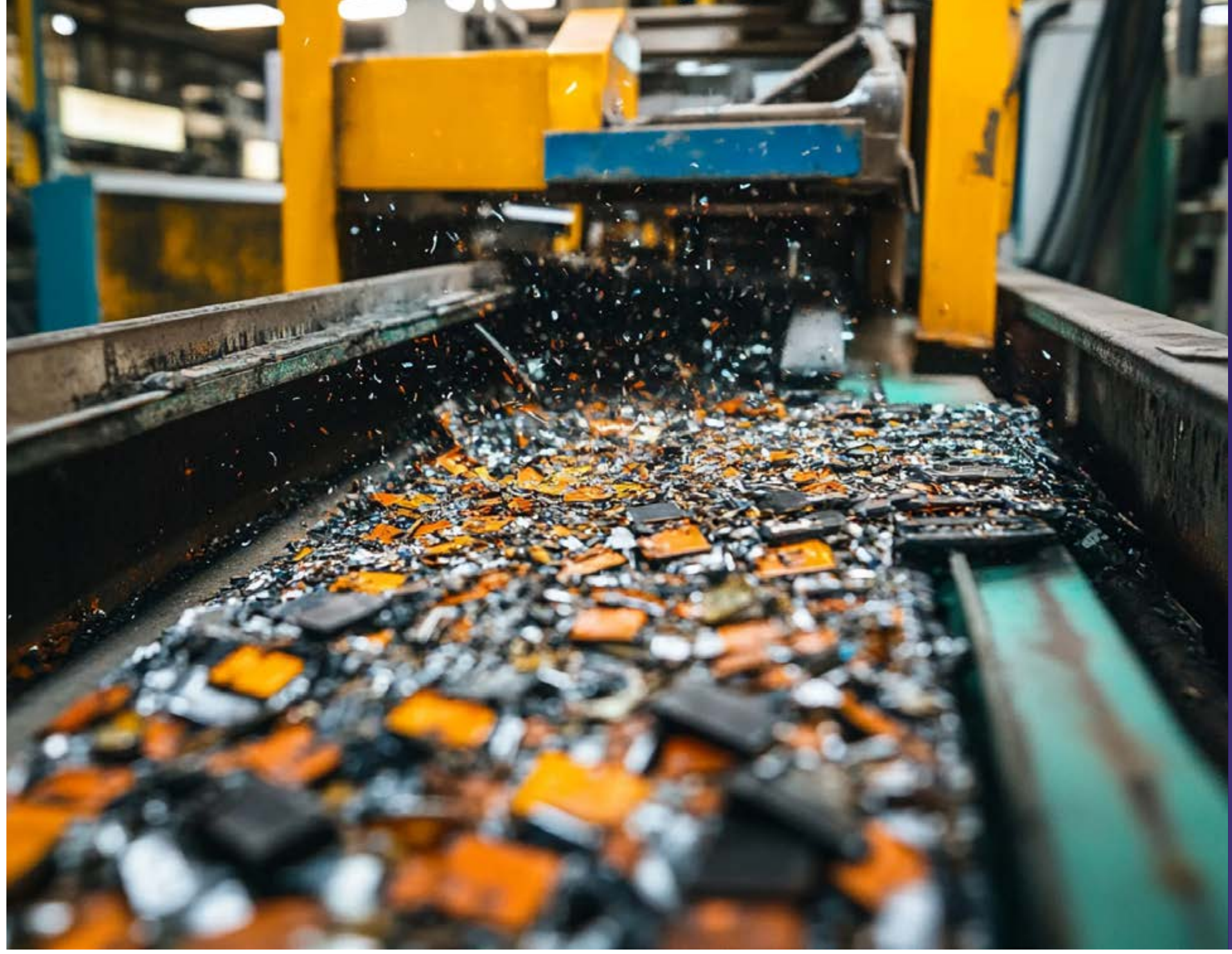
SLS Energy is working with research institutes, including the Massachusetts Institute of Technology (MIT), the University of Rwanda, and Carnegie Mellon University, to determine possible recycling levels, with a focus on direct recycling. While there are many recycling technologies available, their economic viability, especially for low volumes, remains a major issue. SLS Energy is focused on a dual objective: (i) validating the volume of supply and projections of energy storage needs that would make recycling efforts viable and (ii) how the company's battery-as-a-service infrastructure will help achieve the economies of scale needed to remain cost-competitive, while avoiding the constraints of initial investments.

Another question concerns the projected volumes, both on the supply side (availability of waste) and on the demand side (need for recycled materials and products on the markets). This analysis is essential to assess the potential for scaling operations in the future. The key question is whether these activities can be profitable in local markets. One way could be to pool waste flows over a set of larger territories.

This would make it possible to develop infrastructures that are still limited today. Battery **recycling** requires **sophisticated and expensive** facilities that can safely process the various components — including **lead** and **lithium**.

In Africa, this specialized infrastructure remains scarce, often leading to **the export of used batteries** to countries with adequate processing facilities.

In this context, innovative initiatives are emerging to improve battery lifecycle management. This is the case of Vittoria Technology, a social enterprise that is developing the Battery **Bank Africa digital platform**. It offers a **battery rental service for mini-grids**, integrating storage optimization, procurement, performance monitoring and reuse of batteries. This type of solution helps to **extend the useful life of batteries** while **reducing the costs and waste associated with** premature replacement.



The Alliance for Rural Electrification has developed a «best practice» guide for the end-of-life and circularity of batteries, which could contribute to their standardization.

These guidelines are based on 4 key points:

- **Quality and durability**
- **Warranties, maintenance and repair**
- **Recovery**
- **End-of-life management**

The full document is available here :

https://www.ruralelec.org/wp-content/uploads/2024/09/ProBaMet-Circularity-Guidelines.pdf

Hinckley Recycling announced in September 2024 a $5 million investment to establish Africa's first lithium-ion and lead-acid battery recycling and processing plant, located in Ogun State, Nigeria.

Regulatory challenge

The lack of a regulatory framework and environmental policy is one of the main obstacles. Indeed, many African countries do not have strict regulations on the collection, recycling and management of e-waste, including batteries. The lack of environmental standards and tax incentives makes investments in this sector less attractive.

Battery recycling involves the collection and transportation of used devices, which is complicated by a fragmented logistics network and high transportation costs, especially due to the toxicity of the materials.

Legislation on the transport of batteries remains unclear, especially across borders, as used batteries are often considered so-called "hazardous" waste. This classification means that they are subject to regulations concerning their transport. However, there are no single regulations in Africa to allow transport from one country to another: some are very strict, when they may not be present in other countries.

For example, in Mali, Order No. 2016-2637/MEADD-SG of July 22, 2016, strictly regulates the management of used batteries and other sources containing lead, while Cameroon does not have specific regulations governing the recycling industry of used lead-acid batteries. Faced with the rise of lithium batteries in recent years, replacing lead-acid batteries, new regulations will be necessary to regulate the end of life of these batteries in a few years.

There is still no strict rule on the continent on the structure responsible for battery recycling. In addition, accessible collection points remain insufficient, limiting the efficiency of battery waste management.

According to **Exide**, lithium recycling is about to start in Europe, but it is not completely under control at the moment. He points out that manufacturers are not responsible once their batteries are sold, but they can still help find solutions with the operator. It is up to the States to take care of the legislation around recycling to facilitate it.

This element is confirmed by the company **CEGASA**, for which the operator of the batteries should be responsible for the recycling of the battery, the manufacturer being there to ensure the correct sizing of the storage system as well as training.

Synergies between companies in the sector exist and must be developed.

In Benin, **Engie** is already considering the recycling of its batteries. With 20 sites whose operation will begin in December 2024, the issue of end-of-life will arise in about 5 years, and the company is actively looking for solutions until then.

From **Vittoria Technology**'s point of view, one of the solutions to this global problem is to engage with second-life players, to create a market and divert part of the waste stream.

CASE STUDIES: THE HEART GROUP'S PROJECTS IN SUB-SAHARAN AFRICA

MAHAMA REFUGEE CAMP, RWANDA – VITTORIA TECHNOLOGY

This project aims to improve access to electricity for the 58,000 people. In collaboration with MeshPower, 33 kWh of second-life lithium-ion batteries were installed in November 2023 on an existing solar mini-grid, initially deployed in 2019 to power a health clinic and community facilities. It allows the introduction of several innovations:

- An energy storage leasing model, which reduces costs for operators by financing new battery capacities.
- The use of second-life lithium-ion batteries, supplied by AceleAfrica in Kenya, illustrates their potential for off-grid markets.
- A hybrid battery bank architecture, combining lithium-ion batteries with existing lead-acid systems, thanks to the collaboration with the Ferntech team at Odyssey Energy Solutions. This approach doubles capacity while optimizing performance and reducing costs.

Expected impacts include a reduction in diesel use, cost savings from the rental model, and a decrease in e-waste. As a result, the camp will benefit from greener and more affordable electricity for services, businesses and residents.

THE ADDED BONUS
An innovative energy storage rental model

SO-COOL PROJECT, NIGERIA – WFP AFRICA

The So-Cool project aims to install solar kiosks in Nigeria to provide local traders with electricity, cooling and storage solutions, improving the conservation of agricultural products and reducing post-harvest losses. This off-grid electricity production is made possible by energy storage by LifePO4 lithium batteries, with a capacity of 2.56 kWh and a lifespan of 2500 cycles.

Merchants will pay monthly for these services, making them accessible and affordable.

This project is led by the Nigerian start-up PAM Africa, in collaboration with the Junia engineering school and JiroFrance, a subsidiary of the Malagasy company Jirogasy specializing in solar solutions.

They have 260 systems ranging from 1kW to 2.4kW. To date, more than 100 So-Cool batteries have been deployed.

THE ADDED BONUS
PAM Africa is a supplier of product and power solution to make it work. Turnkey solution

«PAM-AI» PLATFORM, NIGERIA – WFP AFRICA

PAM-Ai is an innovative AI-driven platform developed by PAM Africa designed to improve battery performance and profitability. PAM-Ai was integrated with the mini-grid system in a rural community to monitor energy production, storage, and consumption. The platform used real-time data to:

- Schedule battery charging during peak solar production hours
- Optimize discharge patterns to prioritize critical loads during periods of high demand.
- Align energy use with dynamic pricing, which enables cost-effective distribution of energy to end users.

The implementation of PAM-Ai has transformed the operation of the mini-grid. By optimizing battery charge and discharge cycles, operators have been able to extend battery life and reduce operating costs. Residents and businesses have benefited from more reliable access to energy, especially in the evenings when demand is highest. The system's ability to adjust energy tariffs based on real-time data encouraged users to change their consumption behaviour, further improving energy efficiency.

The success of the mini-grid project has demonstrated the potential of PAM-Ai to provide installers and local grid operators with advanced energy management tools. This approach has not only improved the sustainability of the mini-grid but has also highlighted PAM-AI's scalability for similar renewable energy projects across the region.

THE ADDED BONUS
The use of artificial intelligence allowing for greater battery performance.

SOLAR POWER PLANT IN CÔTE D'IVOIRE – SAFT

In 2022, Saft won a contract from Eiffage Energie Systems for the delivery of a 10MW energy storage system, with the aim of facilitating the integration of the Boundali solar photovoltaic power plant into the grid.

The 37.5 MWp plant is the first large-scale solar project in Côte d'Ivoire. It will use pure lithium-ion storage to stabilize and guarantee a local power supply, allowing optimal use of carbon-free energy. The system includes 6 Saft Intensium Max containers for a total capacity of 13.8 MWh.

The storage system quickly charges and discharges the lithium batteries to accommodate the intermittent production of the solar power plant. This helps to provide a steady generation profile that is equivalent to the plant's average 30-minute output, and can be easily accepted by the local electricity grid.

This solution makes it possible to compensate for the intermittency of solar production, and is adapted to the semi-arid climatic conditions of the region.

The operator Côte d'Ivoire Energies also plans to test the storage system in other grid support options such as controlling solar generation ramp-up, maintaining frequency and reactive power, and autonomous start-up. This will provide useful data on battery aging in different configuration scenarios in operation.

THE ADDED BONUS
An example of lithium battery energy storage for a networked application.

MINI-GRID ENERGY PRODUCTION IN BENIN – ENGIE ENERGY ACCESS

The solution proposed by Engie is composed of photovoltaic panels combined with lithium batteries. Smart meters have been set up to connect their customers and allow access to energy. The system is hybrid with a diesel generator that takes over in the event of a failure of the main system.

The economic model consists of a partnership between public and private actors. Partnerships are established with the government and international organizations, which facilitate their access to loans.

2 projects are under construction or modernization, for a total of 21 sites

- 1 project in the construction phase (OCEF): 1.2 MW and 68 km of network that will supply nearly 5900 households, and the scenario chosen has 5 people per household. To do this, Engie has worked with various EPCs: Sagemcom, Butec and Volta United.
- 1 in the modernization phase (Dohouè): 135 kW of energy and a network length of 1.8 km is underway, to supply about 280 people. The EPC is Sustain Solar, as well as a local company named Ego Technologie.

One of these projects is funded by the Millennium Challenge Account and complemented by private and own funds. Six sites are already operational, 14 are expected to start their activity in January 2025.

THE ADDED BONUS
The establishment of public-private partnerships to ensure the sustainability of the project.

MICRO-GRIDS AND DISTRIBUTION NETWORKS IN CHAD – JOHN COCKERILL

The electricity storage projects in Ati and Mongo, Chad, is an important initiative to improve energy access in the region. These projects, financed by the Development Bank of Central African States (BDEAC), provide for the construction of two micro-grids and distribution networks in the cities of Mongo and Ati. Specifically, the project includes the construction and maintenance of hybrid photovoltaic solar power plants-generator sets (PV-GE) with a capacity of 2.5 MW for the photovoltaic field, 1.5 MW for the backup source, and a 1.5 MWh battery storage unit.

John Cockerill supplied the various equipment (NAS batteries, Li-ion batteries, PCS, etc.) as well as the automation of the whole.

This project aims to support the economic and social development of the cities concerned, while reducing the carbon footprint through the use of solar energy. These projects aim to provide energy to more than 3,000 households, as well as local industries and government departments. In addition to reducing Chad's chronic energy deficit, this project will help improve the quality of health care and education through a continuous supply of energy.

THE ADDED BONUS
The use of hybrid renewable energy and generator solutions, for better stability.

MINI-GRID ENERGY STORAGE SYSTEMS IN GHANA – CEGASA

The challenge the company met was to provide electricity to three rural areas where expansion of the electricity grid was not possible due to orographic conditions.

The project was the construction of three photovoltaic power plants with energy storage for the Ghana Energy Development and Access Project (GEDAP), owned by the Ghanaian Ministry of Energy and Petroleum, to provide electricity to three islands located on the Volta River in the Accra region of Ghana. The electricity supply was distributed as presented in the table below.

The technology used was the Cegasa LFP Lithium Battery Energy Storage System (48 VDC) integrated with STUDER inverters, for the creation of the three microgrids. These have led to a significant improvement in the economic activity of the area and the living conditions of its inhabitants, who have had access to electricity where it did not arrive before.

The project was funded by the Swiss Confederation, through the State Secretariat for Economic Affairs (SECO), in consortium with STUDERINNOTEC, Switzerland, and NEW ENERGY, Ghana.

THE ADDED BONUS
Project carried out as part of a government program, marking the State's involvement in the development of batteries.

	Aflive	Azizakpe	Alorkpem
Photovoltaic Capacity (kWp)	110	73	73
Storage (kWh)	737	496	496
Distribution Network Users	295	187	127

SECOND-LIFE BATTERIES AND MINI-GRIDS IN ZAMBIA – SLS ENERGY

SLS Energy is working on the integration of second-life batteries into mini-grids in Zambia, in partnership with ENGIE Energy Access. The project, which could launch in the second quarter of next year, includes a 120 kWh system to increase mini-grid capacity. This model overcomes the financial difficulties associated with replacing used batteries, which are often not mentioned in the initial budgets. These initiatives are based on a "battery as a service" model, in which battery ownership and maintenance remain under the control of SLS Energy, helping to optimize battery performance, safety, and lifespan. This project also aims to validate how the SLS Energy model can improve the financial viability of solar mini-grids by reducing their capital expenditures by up to 40% and managing the technical, operational, and safety risks of battery assets through the integration of the company's battery optimization software.

In addition, the company implements mobile energy storage solutions to provide services in remote areas for productive use of energy, in partnership with One Acre Fund, without the need for transmission lines, which is particularly suitable for seasonal or decentralized use.

THE ADDED BONUS
Reconditioning of second-life batteries and « Battery as-a-service » model

RECONDITIONING AND PRODUCTION OF NEW BATTERY PACKS IN WEST AFRICA - LAGAZEL

Lagazel is implementing an innovative project to reduce waste in the solar sector in West Africa. With facilities in Burkina Faso, Benin and Senegal, the company focuses on the refurbishment, repair and production of new battery packs, mainly using second-life cylindrical lithium-ion batteries.

This project, developed in partnership with the French Atomic Energy Commission (CEA) in France, validates the feasibility of integrating second-life batteries through simple test tools, adapted to the African context. Lagazel is also training local partners, such as in Togo, to replicate this model and plans to expand its activities to other countries in the region via franchises or partnerships. However, the project faces several challenges:

- Limited access to used batteries, due to the recent nature of solar installations in Africa.
- The high costs of collection and the constraints related to the highly regulated international transport of batteries.
- The need to reduce costs to make second-life batteries competitive with imported batteries, which are often cheaper.

With this project, Lagazel aims to create a sustainable circular economy for solar batteries while strengthening local capacities.

THE ADDED BONUS

Local reconditioning solution, creating added value to waste

SOLUTIONS AND RECOMMENDATIONS

How can this study be useful to entrepreneurs in Africa?

KEY POINTS OF THE STUDY

1. Lithium is currently the preferred technology for battery energy storage in the development of new mini-grids. What for?

- This technology is very mature, and its cost is steadily decreasing thanks to increasing industrial production.
- Lithium batteries are more resistant to high temperatures than lead-acid batteries, which are crucial on the African continent. In addition, their lifespan is longer.
- International funding is now favouring mini-grid projects powered by lithium batteries, which are more efficient and better meet the objectives of the energy transition.

2. The most developed business models are pay-as-you-go (PAYG) and pre-payment methods. Why are they the most adapted to the realities on the ground in sub-Saharan Africa?

- As the initial investment costs are high, mini-grids are installed by operators, and PAYG allows payment by consumers based on actual consumption, and offers flexibility as needed.
- Both models allow flexibility for users, as they are often managed through digital solutions (payment via Orange Money, for example) that allow users to pay via mobile phones and are therefore adapted to current practices. In addition, these methods are already used in other sectors such as mobile communications, which promotes social acceptability.
- Prepayment also reduces the financial risk for operators, ensuring payment before consumption.

TECHNICAL ADVICE FOR THE SELECTION AND MANAGEMENT OF BATTERIES

The choice of storage technology is a central issue in the design of a mini-grid. It determines the performance of the system, its reliability, its short- and long-term costs, as well as its social acceptability. In this section, only the two main storage technologies will be compared, namely lead-acid batteries and lithium-ion batteries.

What are the criteria for making your choice?

- **Site profile (size, use, temperature, road access)**

Local conditions strongly influence the performance of the batteries. For example, in a warm, isolated area, lithium batteries (LFP type) are preferable: they tolerate heat better than lead-acid batteries, while requiring less maintenance. In addition, if the site is difficult to access, transporting heavy batteries or having to perform frequent maintenance can be complex.

- **Business model (energy sales, utilities, self-consumption, etc.)**

If the company plans to sell electricity on a pay-as-you-go model, ensuring continuity of service is essential to ensure customer satisfaction. Lithium batteries, which are more reliable, can make a difference here. Conversely, in a self-consumption model with little variability in use, well-sized lead-acid batteries may be sufficient, with lower initial costs.

- **Local maintenance capability**

Lead-acid batteries, for example, are generally better known to technicians in rural areas because they have historically been more widely used and easier to troubleshoot without sophisticated equipment. Conversely, lithium systems or refurbished batteries often require more complex management electronics (BMS), so the rapid availability of spare parts as well as training of local players are essential.

- **Desired system life**

If the project is thought of for the long term (10–15 years), it is better to choose a battery with a long life, even if it is more expensive at the beginning. Lithium takes the advantage here. But if the project is shorter (pilot phase, demonstrator, or transition zone), a more accessible technology such as lead, or a well-controlled second-life battery, may be sufficient.

- **Recycling or end-of-life channels**

Used batteries are hazardous waste, and their end-of-life management poses real challenges. In some regions, lead-acid batteries are already relatively collected, even if the sector remains very informal. For lithium batteries, the recycling sector is still under construction in many countries, which complicates their recovery.

Overview of the main technologies available

Lithium batteries (mainly LFP – Lithium Iron Phosphate)

Typical use case: medium to large mini-grids, for rural or peri-urban areas with a large load (small business, light industry, schools, healthcare, extended domestic use).

- **Advantages :**
  - Long service life (up to 10-15 years depending on conditions)
  - Good thermal tolerance (up to 45°C)
  - High depth of discharge (>90%)
  - Relatively low maintenance
  - Optimized size/weight → reduced transportation cost
- **Limitations :**
  - Higher initial cost than lead
  - Technologies often imported (especially China), customs complexity
  - Sizing sensitivity: overloading or underloading can accelerate aging

Practical advice: choose suppliers that offer a performance guarantee (number of cycles, maximum temperature), and make sure that the BMS (Battery Management System) is adapted to the operating conditions.

Lead-acid batteries

Typical use cases: small mini-grids with low consumption, remote or humanitarian sites, projects with a limited budget.

- **Advantages :**
  - Well-known technology, readily available
  - Lower purchase cost
  - Better locally organized recycling in some countries
  - Relatively simple maintenance
- **Limitations :**
  - Shorter lifespan (2 to 5 years)
  - Sensitive to high temperatures → reduced performance
  - High weight → more expensive logistics
  - Less suitable for variable loads and frequent deep discharges

Practical advice: provide adequate ventilation of the battery room, limit the depth of discharge (60% max) to extend the service life, and plan for regular replacement.

Second-life batteries (mainly lithium)

Typical use cases: pilot and small-capacity projects, urban or suburban areas, facilities with the need for flexibility, experienced technical partners.

- **Advantages :**
  - Reduced cost (up to 50% cheaper than the new)
  - Reduced environmental footprint
  - Potential for local recovery (diagnosis, assembly, reconditioning)
- **Limitations :**
  - Uncertain performance if reconditioning is not rigorous
  - Difficulty in obtaining bankable guarantees
  - Potential UPS/EMS compatibility issues
  - Regulatory frameworks that are not well adapted today

Practical advice: work with specialized partners with a real-time diagnostic and monitoring platform (**Vittoria Technology, SLS Energy**, etc.). Properly size systems to compensate for the heterogeneous performance of reconditioned cells.

INNOVATIVE SOLUTIONS IN THE SECTOR

- To overcome the challenge of battery end-of-life in storage, some companies have opted for new models, including **"storage as a service"** which allows customers to benefit from storage services without investing in the equipment themselves. This is particularly the case for **Vittoria Technology**, which offers turnkey storage solutions using second-life batteries. The company provides grid operators with access to flexible storage capacity optimized for intermittent energy management, without having to directly acquire storage capacity.
- This is also the model proposed by **SLS Energy,** which reconditions and deploys second-life batteries for high-performance, modular energy storage solutions. The company offers an integrated platform that optimizes the use of these batteries while facilitating reliable, sustainable and cost-effective energy access for its customers.
- Use of artificial intelligence for better performance. **PAM Africa** has developed PAM-Ai, an innovative AI-driven platform designed to improve battery performance and profitability. This platform leverages artificial intelligence to optimize battery usage, focusing specifically on influencing customer behavior through dynamic energy tariffs.
- Staying in the field of predictive management, Schneider Electric offers a cloud-based energy management system (EMS), designed to offer intelligent and predictive management of power grids. This system analyzes and models the grid at regular intervals, allowing real-time adaptation to variations in production and consumption. EMS relies on historical data and weather forecasts to anticipate and optimize energy management.

RECOMMENDATIONS FROM DISCUSSIONS WITH THE CORE GROUP

- Today, the certifications directly concern batteries as a finished product. A more optimal solution would be to obtain certification focused on the battery rehabilitation process (reuse, reconditioning or recycling) rather than on each specific model. This would avoid the need to renew certification applications with each new battery release.
- In addition to the regulatory framework, discussions have also emerged regarding better policy coordination between countries, particularly concerning the management of end-of-life batteries.

  Indeed, the current lack of coordination prevents the pooling of resources, as the transport of used batteries, considered waste, remains highly complex.

  This has a direct consequence: each country has too small a volume of batteries to allow for profitable recycling or recovery, as logistical costs remain far greater than potential revenue.

LIST OF COMPANIES AND CONTACTS

Working Group member companies:

Company name	Geographical area of intervention	Nature of the activity	Origin company
SLS Energy	Rwanda	Builder and service provider	Rwanda
Lagazel	Senegal, Mali, Burkina Faso, Benin, Niger	Manufacturer, distributor and recycler	France
PAM Africa	Rwanda, Kenya, Burundi, DRC, Tanzania, Uganda	Manager	Nigeria
Aress	Senegal, Benin, Togo, Burkina Faso	Builder and operator	Benin
Engie energy access	East Africa mainly, and a few countries in the west	Manager	France
CEGASA	Benin, Ethiopia...	Constructor	Spain
John Cockerill	Chad, Burundi, DRC...	Manager	Belgium
Catalyst Energy	Mozambique, South Africa, Malawi, Zambia, Zimbabwe, Namibia and Botswana.	Service Provider	Mozambique
Exide Technologies	Sub-Saharan Africa	Constructor	France
SAFT - filiale TotalEnergies	South Africa, Ivory Coast, Kenya	Utility scale	France
Evolve BGS	South Africa	Service Provider	South Africa
Vittoria Technology	South Africa	Service Provider	South Africa

Additional interviews with companies outside the core group

Company name	Geographical area of intervention	Nature of the activity	Origin company
Tailor	South Africa, West Africa, Central Africa, etc.	Technology Provider	France
Zembo	Uganda	Electric mobility	Uganda

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