D3.2 REPORT ON THE DEFINITION OF TECHNICAL AND FUNCTIONAL REQUIREMENTS FOR ENERGY INNOVATIONS

WP 3

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Summary Sheet

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Responsible Author(s)	TECNALIA: Amaia González Garrido, Eduardo García, Daniel Valencia Caballero, Elena Turienzo, Ander Zubiria Gómez, Ana Huidobro; LEITAT: Natalia Rey, Eduard Borras, Daniele Molognoni; Going Green: Chikondi Khonje; Make It Green: Martin Karlsson; RISE: Susanne Paulrud, Kent Davidsson
Contributing Partner(s)	Elisabeth Bieber (Siemens), Geoffrey Gasore (UR), Kasper Rodil (AAU), Sanket Puranik (SIN), Zakarie Ouachakradi (GEP)
Peer Review	Charles Ogalo (WeTu), Edmund Teko (UEMI), Maria Yetano (WI), Magdalena Sikorowska (ICLEI ES), Sanket Puranik (SIN)
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Abstract	Deliverable D3.2 provides a guideline of the desired functional requirements of the main energy technologies (energy innovations) that could possibly be deployed in the Living Labs. The functional requirements are identified, based on international standards (when applicable), and cover: system description, technical constraints, advanced functionalities, expected performance, operation and maintenance, reliability and expected costs of the solutions. When possible and relevant, these functional and technical requirements are provided ordered from lower to higher degree of innovation. Additionally, the potential local users and communities for each energy technology are presented. Each end-user group represents a set of individuals (i.e., households, rural communities, drivers, or municipality) or different sector

	activities (i.e., small business, agriculture sector, fishing sector, health sector, education sector or e-mobility. The targeted audience of this deliverable are the responsible entities of the Living Labs and project development partners, who will drive the implementation plans, and are responsible to select the appropriate technologies, systems, or solutions; and at the end, successfully deploy the demonstration actions in the Living Labs. A questionnaire (checklist) summarizes all functionalities in a brief and concise manner. This guideline and checklist can be used to track which energy solutions are needed by local users, which functionalities and features are considered, and what is the degree of innovation they reach. Beyond the SESA project, this information could be of support also for public and private sector professionals, such as equipment providers, project developers and local authorities

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TABLE OF CONTENTS

List of figures

List of tables

List of abbreviations

Acronym	Meaning
AC	Alternative Current
AD	Anaerobic Digester
AMI	Advanced Metering Infrastructure
BES	BioElectrochemical System
BMP	Biochemical Methane Potential
BMS	Battery Management System
BOS	Balance of System
CH4	Methane
CO	Carbon Monoxide
CO2	Carbon Dioxide
COD	Chemical Oxygen Demand
CPO	Charge Point Operator
CT	Current Transformers
CVR	Conservation Voltage Regulation
DC	Direct Current
DSO	Distributed System Operator
EMS	Energy Management System
eMSP	e-Mobility Service Provider
EV	Electric Vehicle
H2	Hydrogen
HAN	Home Area Network
HMI	Human Machine Interface
HRT	Hydraulic Retention Time
HV	High Voltage
ICT	Information and Communication Technologies
IP	Internet Protocol
LASN	Local Area Network
MaaS	Microgrid-as-a-Service
MASN	Medium Area Network
MDC	Microbial Desalination Cell
MDM	Measurement Data Management
MEC	Microbial Electrolysis
MEMS	Microgrid Energy Management System
MES	Microbial Electrosynthesis
MFC	Microbial Fuel Cell
MG	Microgrid

MMCS	Microgrid Monitoring and Control System
MU	Merging Units
NAN	Neighborhood Area Network
O&M	Operation and Maintenance
OLR	Organic Loading Rate
OPF	Optimal Power Flow
OSA	Operating Services Agreement
PAYG	pay-as-you-go
PCC	Point of Common Coupling
PCM	Power Control Mode
PCS	Power Conversion System
PDC	Phasor Data Concentrators
pH	Acidity
PM	Particulate Matter
PMU	Phasor Measurement Units
PPA	Power Purchase Agreement
PSA	Purchase and Sale Agreement
PV	Photovoltaics
RO	Reverse Osmosis
SCADA	Supervisory Control and Data Acquisition System
SLB	Second Life Battery
SM	Smart Sensors
SOC	State Of Charge
SOH	State Of Health
T&F	Technical and Functional
THD	Total Harmonic Distortion
TMS	Thermal Management System
TSO	Transmission System Operators
V2H	Vehicle to everything
V2G	Vehicle to Grid
V2V	Vehicle to Vehicle
VCM	Voltage Control Mode
VFA	Volatile Fatty Acid
VSI	Voltage Source Inverters
VT	Voltage Transformers
WAN	Wide Area Network
WP	Work Package
Wp	Watt peak

Executive summary

Deliverable D3.2 provides a guideline of the desired **functional requirements** related to the main energy technologies that could possibly be deployed in the SESA Living Labs, with special attention to the innovation degree, technology costs, expected performance, and their **local end-users**, covering households and rural communities, small businesses, tertiary sector, municipalities, the fishing and agricultural sector, educational and healthcare facilities, and e-mobility companies.

The **targeted audience** of this deliverable, behind the SESA project, are the responsible entities of the Living Labs and project development partners, who will drive the implementation plans, and are responsible to select the appropriate technologies, systems, or solutions. Beside this primary target audience, the document can be of interest also for public and private sector professionals, such as equipment providers, project developers and local authorities beyond the SESA project.

The '**energy innovations'** (energy technologies of interest) covered in this Deliverable D3.2 have been specially selected from the draft implementation plans and actions which are planned to be deployed in the SESA Living Labs, including: solar photovoltaics, smart mini/microgrids, electric mobility, second life EV batteries, biomass to biogas (biodigester), and waste to energy for cooking (BioCooker), as well as the transversal topic of climate proofing.

Figure 1 summarizes the main stages and outputs of the methodology followed in this deliverable to select the key energy innovations and describe their technical and functional requirements, ordered by the degree of innovation (from lower to higher) and relevance for the Living Labs.

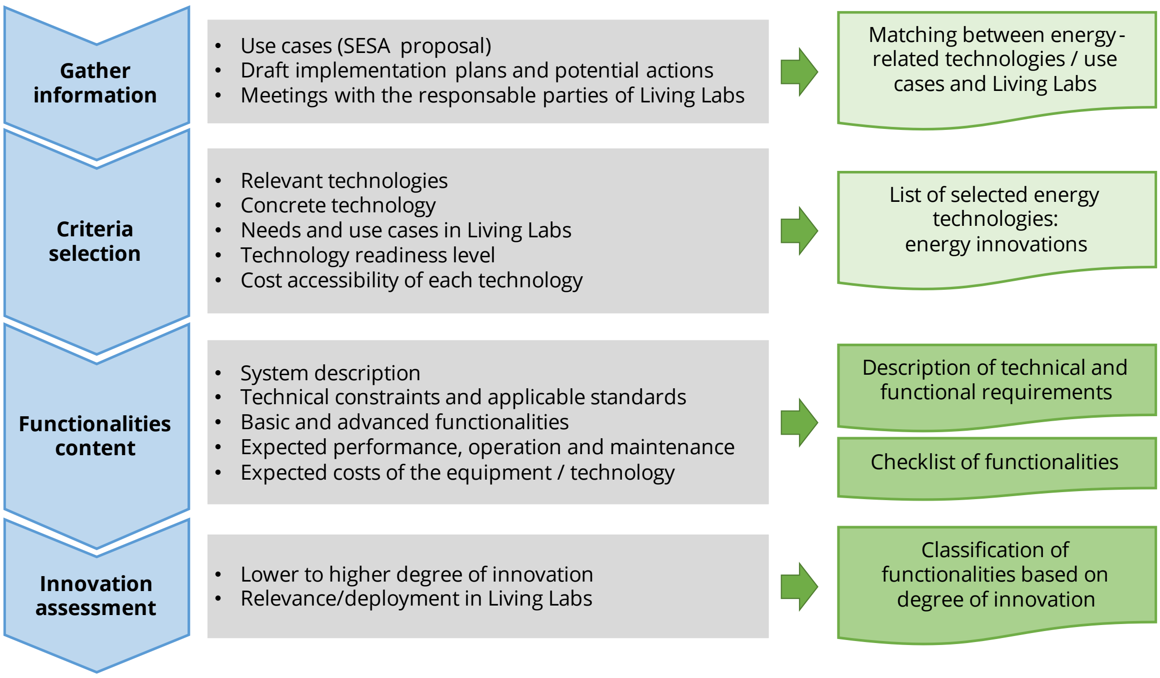


Figure 1. Main stages and outputs of the technology innovation roadmap.

The functional requirements of each energy innovation are identified and briefly described, based on international standards (when applicable) as well as expert know-how and technology innovation trends.

The functional requirements of each energy technology mainly cover the following aspects: **system description, technical constraints, basic and advanced functionalities, expected performance, operation and maintenance, reliability and expected costs of the solutions**.

When possible and relevant, these functional and technical requirements have been provided arranged **from lower to higher degree of innovation**, following the criteria of the responsible authors, technology experts, and research community trends. This distinction based on the degree of innovation of the solution will allow Living Labs to evaluate the innovation and novelty reached in the deployed solutions, compared to the guideline of functional and technical requirements.

Therefore, the purpose after its release is to provide useful information to Living Labs and support them in the decision-making process toward the identification of the **most technically suitable** (available technology which satisfies the user needs) **and economically affordable** (within the cost margins and budget) energy solution to be deployed in the Living Labs, also considering the perspective of high level of novelty of advanced energy innovations.

Solar photovoltaics (PV)

Solar PV is a key enabler for energy access increase and economic transformation by means of the electrification, and one of the predominant renewable energy resources in Africa. Solar PV would be one of the most feasible ways for generating electricity at local level. In fact, PV systems range from small rooftop-mounted or building-integrated systems with capacities from a few to several tens of kilowatts, to large utility-scale power stations of hundreds of megawatts.

The following figure summarizes the functionalities of PV systems per level of novelty, oriented to small-scale and off-grid applications. For additional functionalities oriented to energy and control and electric network-wise management systems, see subchapter 3.6 "Smart Microgrids".

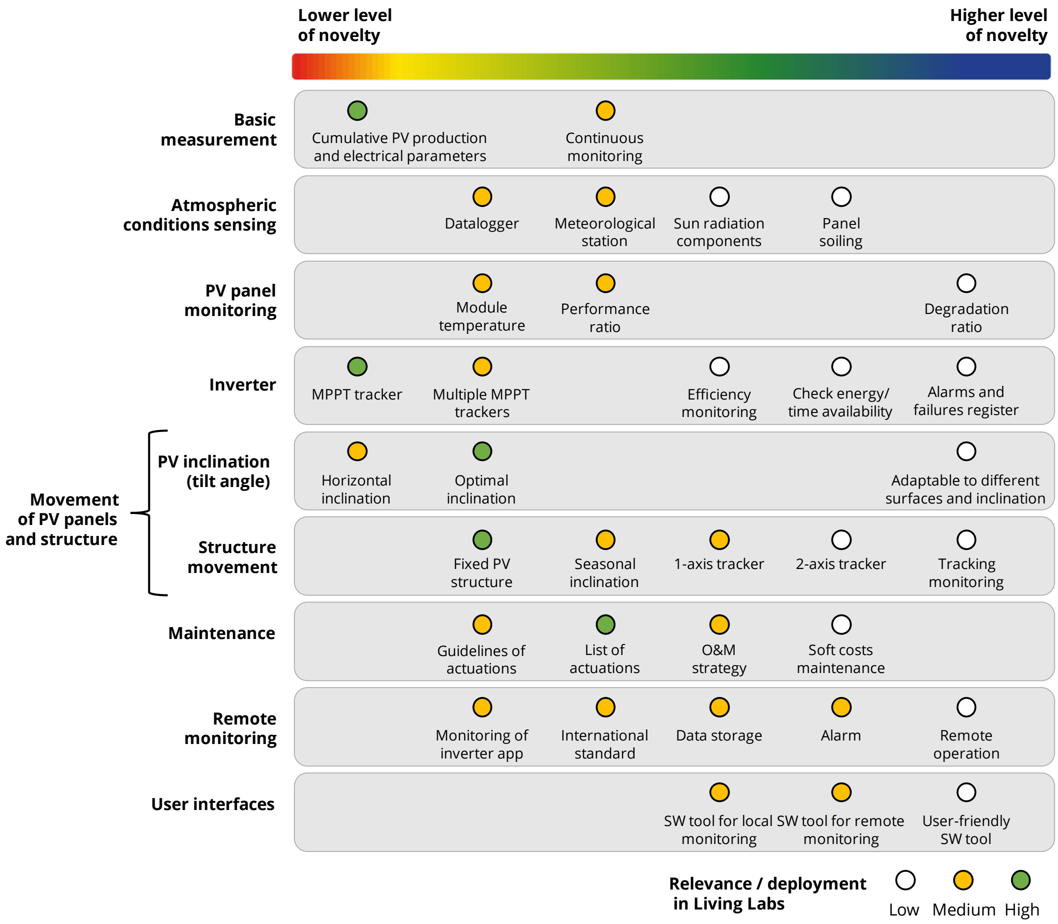


Figure 2. Classification of PV plants functionalities from lower to higher degree of novelty (from left to right) and relevance/deployment (low -white-, medium -yellow-, and high -green-) in African Living Labs.

The progressive cost decrease of solar PV makes this technology one of the most promising and attractive options, for a wide range of applications in rural and urban sites. PV systems are key for delivering reliable, secure, clean, sustainable, and cost-efficient electricity to households, businesses, and the primary sector (agriculture and fishing activities) as well as infrastructures from basic to critical such as schools and hospitals in many African countries.

Second-life energy storage systems

Batteries are energy storage devices that can convert chemical energy and store it as electricity by means of internal electrochemical reactions. Batteries allow a wider and more efficient electricity usage for existing activities for multiple end-user groups (households, rural communities, agriculture and fishing sector, health sector, or e-mobility) and multiple uses (lighting, e-mobility, small appliances), by storing excess solar power during the day for night-time or peak periods. Moreover, batteries can harness transport electrification and enable new business opportunities (i.e., battery swapping, rechargeable lanterns, and battery-powered devices and systems).

Their lower costs, portability and easy integration with intermittent renewable energy generation resources make second-life batteries (SLB) another attractive technology for the Living Labs.

This figure summarizes the main functionalities per level of novelty of second-life batteries.

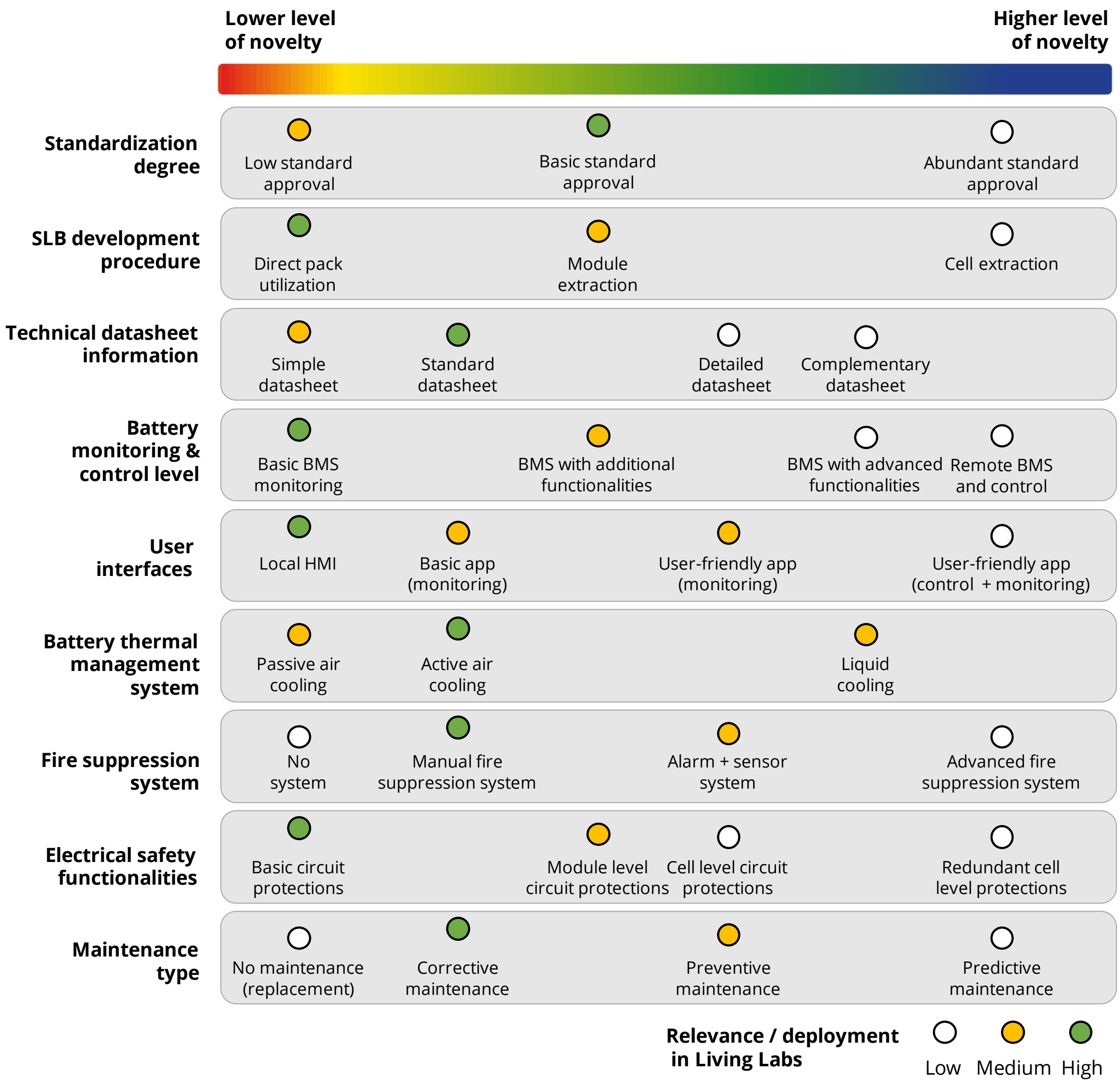


Figure 3. Classification of SLB functionalities from lower to higher degree of novelty (from left to right) and relevance/deployment (low -white-, medium -yellow-, and high -green-) in African Living Labs.

E-Mobility

Two-wheeled and three-wheeled electromobility along with e-micromobility will be the fastest electrification segments in Africa. Two- and three-wheelers are essentially electrified scooters and small vehicles. E-mobility represents a powerful transformation tool for many end-user groups. Indeed, apart from enabling individual transportation, by means of acquiring e-mobility services as private passenger cars or owning electric vehicles, it can create job opportunities for individuals and small companies (i.e., delivery services, means of transport for workers, and commercial use).

The considered functionalities per level of novelty are summarized in the following figure. The functional requirements are oriented to the electric vehicles and their charging infrastructure.

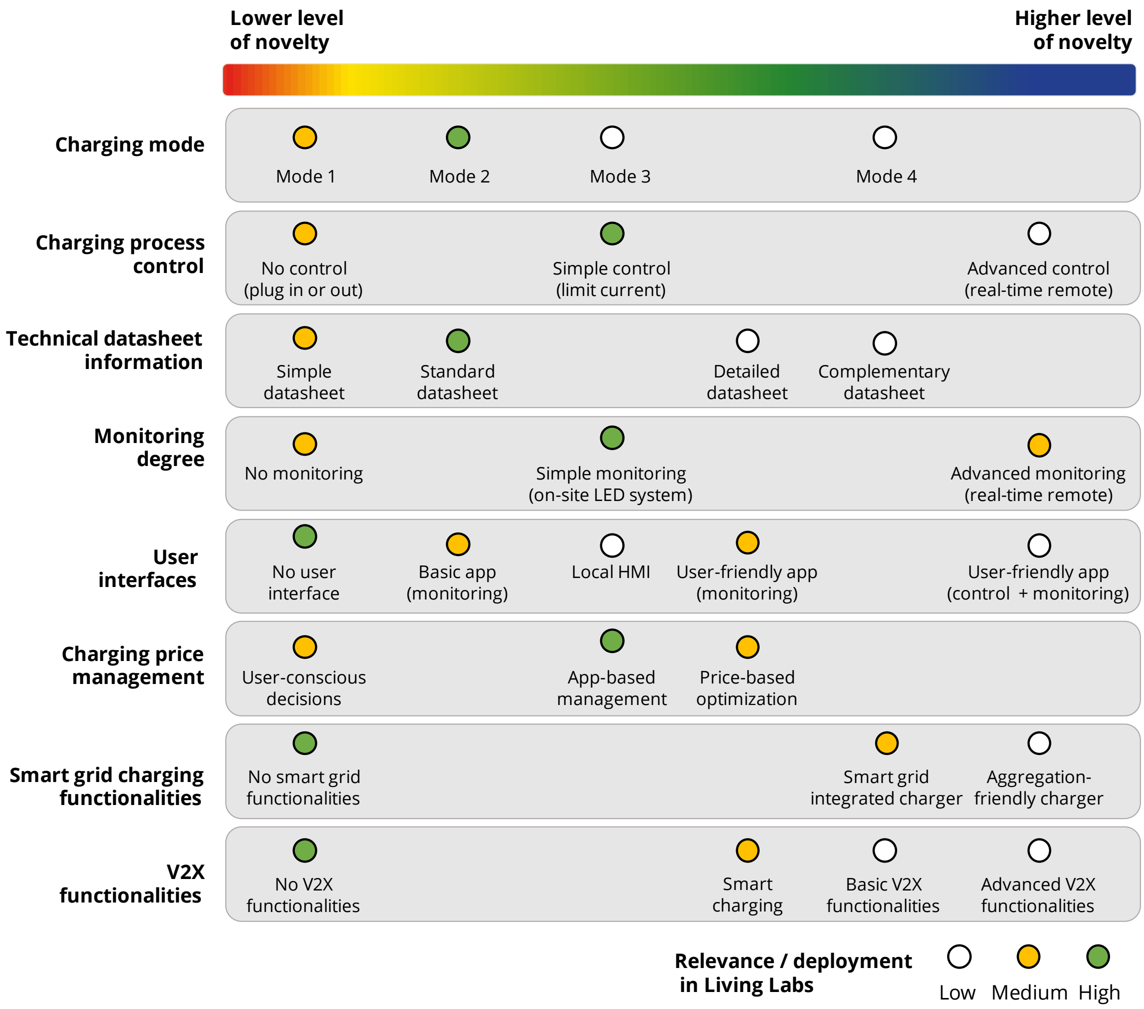


Figure 4. Classification of e-mobility functionalities from lower to higher degree of novelty (from left to right) and relevance/deployment (low -white-, medium -yellow-, and high -green-) in African Living Labs.

BioCooker (biomass for clean cooking)

The BioCooker utilizes traditional wood-based fuel (a type of feedstock from biomass) to provide heat for cooking and produces biochar as a byproduct. BioCookers shall be affordable especially in regions where clean cooking solutions are needed the most. Households and rural communities are the primary end-users of BioCookers in Africa, and women in particular, being often times in charge of cooking-related activities.

The biochar obtained from the use of BioCooker is used as an affordable water purification system and to enrich soil for agriculture. Moreover, it has been seen as an efficient means of carbon sequestration.

This figure summarizes the considered functionalities per level of novelty for the BioCooker.

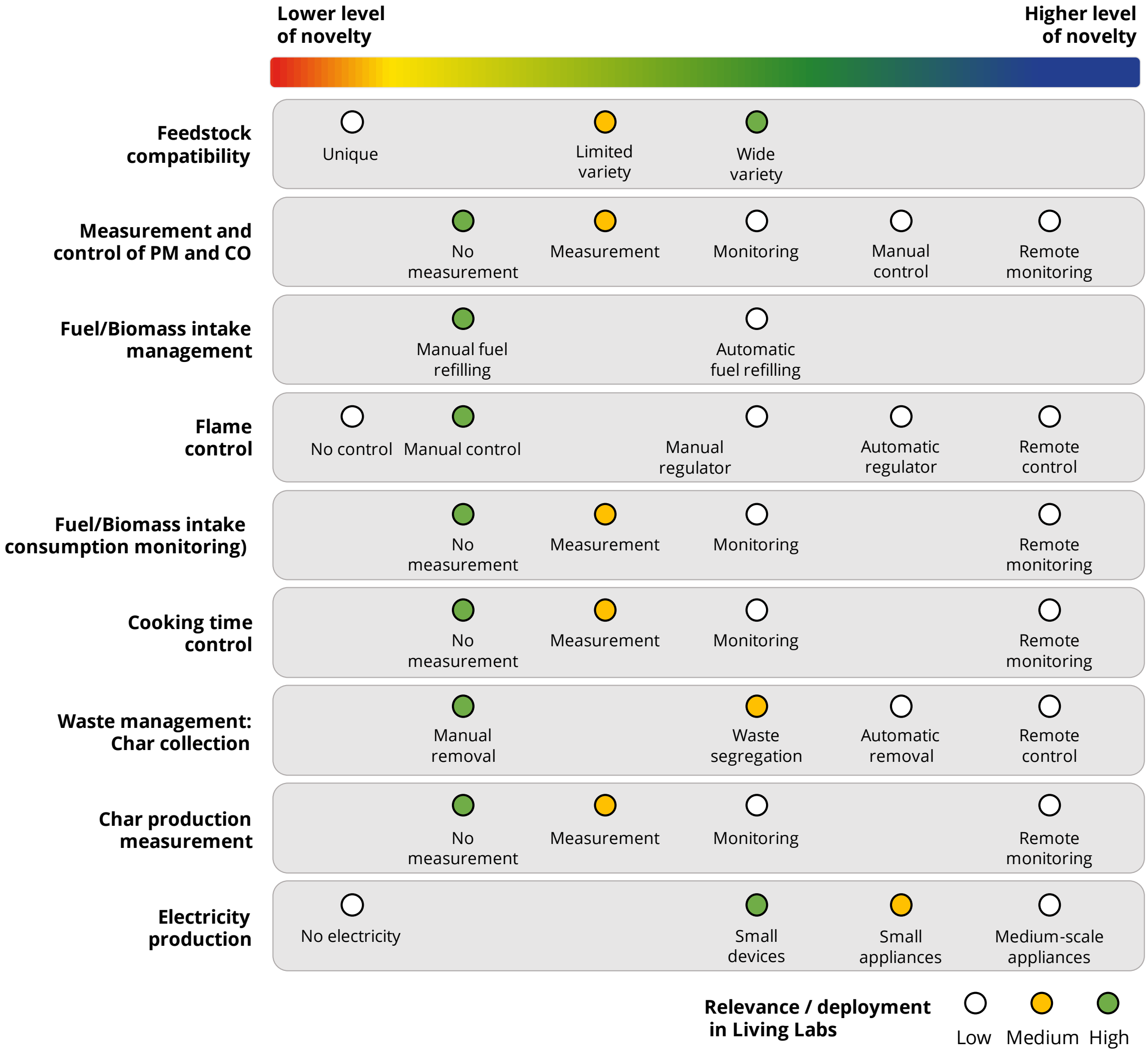


Figure 5. Classification of BioCooker functionalities from lower to higher degree of novelty (from left to right) and relevance/deployment (low -white-, medium -yellow-, and high -green-) in African Living Labs.

Biodigesters (organic waste to biogas and electricity)

A biodigester consists of an airtight, high-density polyethylene container within which organic waste materials are diluted in water flow and are fermented by microorganisms.

In addition to the biogas, rich fertilizer is produced, which contains macro and micronutrients. The biogas can be used as a renewable energy source for cooking, heating, or generating electricity, while the fertilizer can be used to improve soil health and crop yields. Biodigesters are considered a sustainable solution to waste management and renewable energy production.

The anaerobic digester can be coupled to a bio electrochemical system (AD-BES). The integrated AD-BES system shows potential for versatile applications, including AD effluent polishing, biogas upgrading, biosensor, and nutrient recovery.

Being a quite specific and complex technology, the targeted end-users in Africa are small business oriented to this energy technology (Agro-industrial companies, food processing companies, industrial heating applications, waste management companies, and the tertiary sector) and the agriculture sector (small farmers which convert animal manure and agricultural waste into biogas).

The following figure summarizes the functionalities per level of novelty of the biodigester.

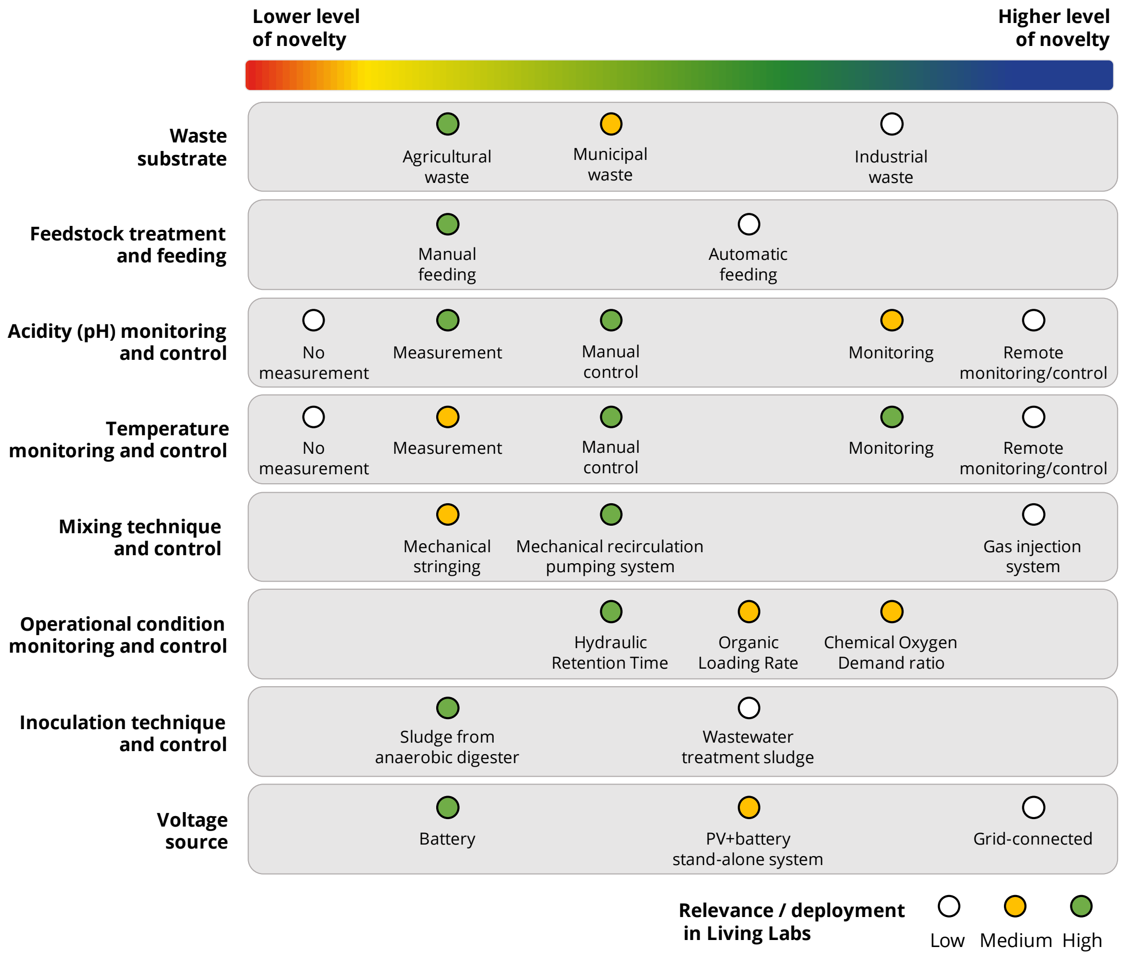


Figure 6. Classification of biodigester functionalities from lower to higher degree of novelty (from left to right) and relevance/deployment (low -white-, medium -yellow-, and high -green-) in African Living Labs.

Smart Microgrids

Compared to an isolated PV installation, smart microgrids are modern electricity distribution systems that use digital technology to monitor, control, and manage the flow of electricity. They enable more efficient and reliable energy distribution, integration of renewable energy sources, and improved demand response. Microgrid (MG) is defined as a group of interconnected loads, storage devices and distributed energy resources (preferably renewable technologies), which act as a single controllable entity with respect to the external grid. In that sense, microgrids can operate, both, grid-connected (i.e., in rural and peri-urban areas) and off-grid (during main grid outages, as well as in rural or remote areas without access to the main external grid).

The main objective of the deployment of microgrids in SESA project is to enable the access and use of a more reliable, secure, clean, sustainable, and cost-efficient electricity to the users (including residential and educational buildings, productive sector, and critical facilities such as hospitals) through an adequate energy management regarding the energy exchange between the main grid, the local renewable resources, energy storage assets and the manageable demand.

The following figure shows the covered functionalities per level of novelty of microgrids. Among functional requirements covered in this section, microgrid scheduling module is studied in detail identifying and describing the design and planning, energy dispatch optimization, market trading, forecasting (renewable, load and electricity price), maintenance (corrective/reactive, preventive, and predictive). More advanced functionalities are presented along demand-side management module (payment methods, collective self-consumption, demand-response mechanisms), and the (micro)grid monitoring and control system (including protection and power quality issues).

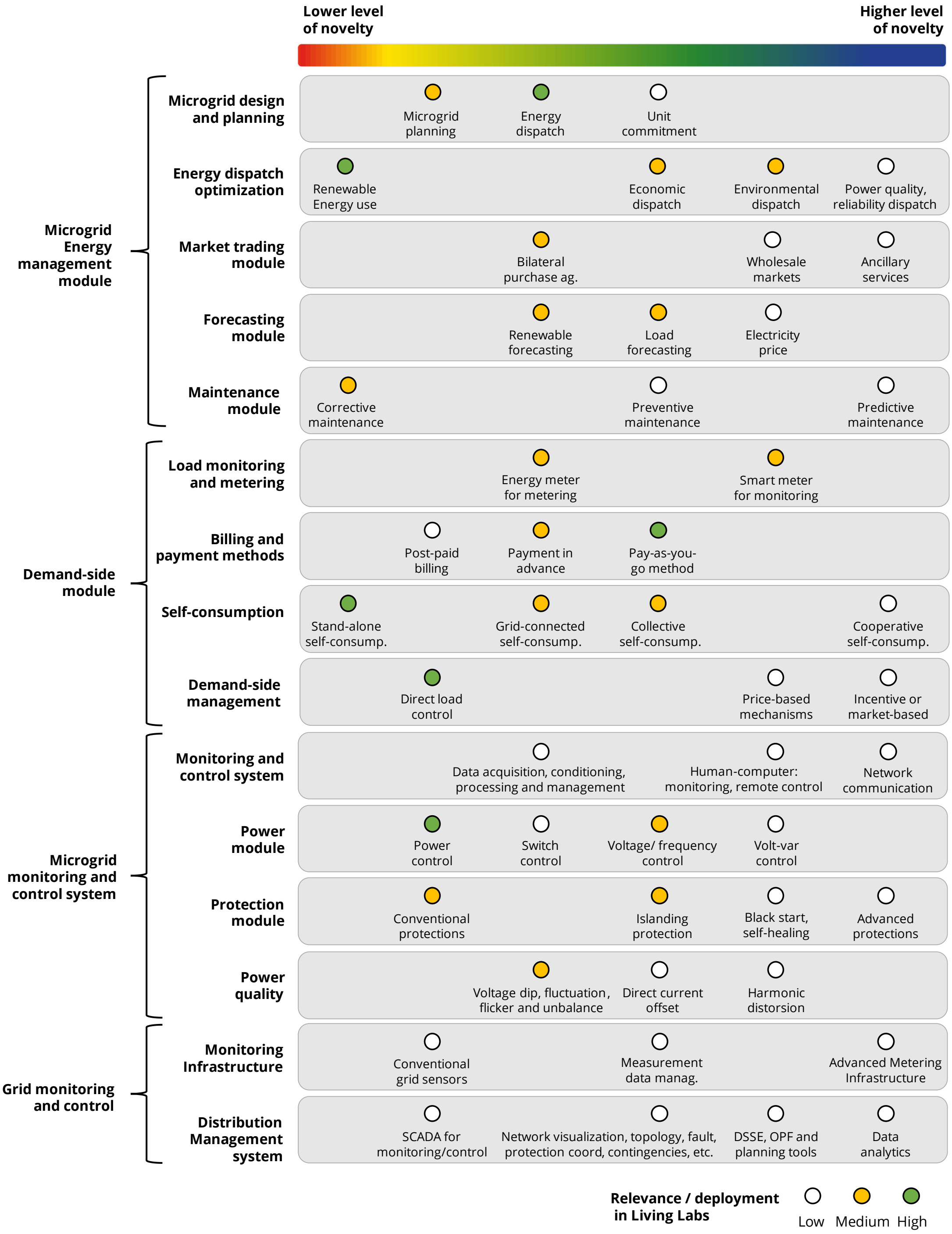


Figure 7. Classification of Smart Microgrids functionalities from lower to higher degree of novelty (from left to right) and relevance/deployment (low -white-, medium -yellow-, and high -green-) in African Living Labs.

Climate Proofing

Climate proofing is a term that refers to a process of mainstreaming climate change into mitigation and/or adaptation strategies and programs. The goal of climate proofing is to ensure that climate-related risks and opportunities are integrated into the design, operation, and management of the infrastructure with the objective of reducing them to acceptable levels through long-lasting and environmentally sound, economically viable, and socially acceptable ones. It involves taking proactive steps to minimize the negative effects of climate change and ensure that a particular system can perform effectively under changing climatic conditions.

1 Introduction

1.1 SESA project

SESA is a collaborative project between the European Union and nine African countries (Kenya, Ghana, South Africa, Malawi, Morocco, Namibia, Tanzania, Rwanda, and Nigeria) that aims at providing energy access technologies and business models that are easily replicable and generate local opportunities for economic development and social cohesion in Africa. Through several local Living Labs, the project will facilitate the co-development of scalable and replicable energy access innovations, to be tested, validated, and later replicated throughout the African continent.

These solutions will include decentralised renewables (solar photovoltaics), innovative energy storage systems including the use of second-life electric vehicle batteries, smart microgrids, waste-to-energy systems (biomass to biogas), climate-proofing, resilience and adaptation, and rural internet access.

With this background, **the project's overall objective is to provide innovative energy access technologies and business models that are easily replicable and generate local opportunities for economic development and social cohesion.**

1.2 Objectives and scope of the document

Deliverable D3.2 provides a **guideline of the desired functional requirements** related to the main energy technologies that could possibly be deployed in the Living Labs, with special attention to the innovation degree, technology costs, expected performance and potential end users.

The '**energy innovations'** covered in this Deliverable D3.2 have been specially selected from the draft implementation plans and actions which are planned to be deployed in the Living Labs, including: solar photovoltaics, smart mini/microgrids, electric mobility, second life EV batteries, biomass to biogas (biodigester), and waste to energy for cooking (BioCooker). The document covers also the additional and transversal topic of climate proofing which involves taking proactive measures to minimize the negative effects of climate change and ensure that a particular system or infrastructure can perform effectively under changing climatic conditions along its lifetime.

The functional requirements of each energy innovation are identified and briefly described, based on international standards (when applicable), expert know-how and technology innovation trends. The functional requirements of each energy technology mainly cover the following aspects: **system description, technical constraints, basic and advanced functionalities, expected performance, operation and maintenance requirements, reliability and present and expected costs of the solutions**.

The **level of detail** of each energy technology depends mostly on the complexity of the equipment and systems which comprise each energy technology, the functionalities that can be covered by the energy technology, and the level of standardization of the technology, system, or device. For example, solar photovoltaics, biodigesters, or BioCookers are more self-contained systems or specific equipment, while e-mobility applications, batteries or smart microgrids comprise multiple equipment, devices, control systems, and has more standards in place which extend the required information and functionalities to be described.

When possible and relevant, these functional and technical requirements are provided ordered **from lower to higher degree of innovation**, following the criteria of the responsible authors, technology experts, and research community trends. This distinction based on the degree of innovation of the solution will allow Living Labs to evaluate the innovation and novelty reached in the deployed solutions, compared to the guideline of functional and technical requirements.

The **targeted audience** of this deliverable, behind the SESA project, are the responsible entities of the Living Labs and project development partners, who will drive the implementation plans, and are responsible to select the appropriate technologies, systems, or solutions; and at the end, successfully deploy the demonstration actions in the Living Labs. Out of the scope of this Deliverable D3.2, the responsible entities of the Living Labs should clearly analyse their needs of local users and communities from a technical and energy point of view; gather relevant information to the potential energy-related infrastructure and equipment; identify available system providers, developers and stakeholders; refine or adjust their implementation plan; and select the energy solutions and the corresponding features (functionalities) to be deployed in those Living Labs. All these activities (covered within the WP4) will be carried out with the support of other partners and experts of the technical, socioeconomic, and environmental domains.

Therefore, the final purpose of this Deliverable D3.2 is to provide useful information to Living Labs and support them in the decision-making process toward the identification of the **most technically suitable** (available technology which satisfies the user needs) **and economically affordable** (within the cost margins and budget) energy solution to be deployed in the Living Labs, also considering the perspective of high level of innovation and advanced functionalities. To this purpose, the Deliverable D3.2 also includes a questionnaire (**checklist**) in the Annex I, that summarizes the functionalities of all presented energy technologies in a brief and concise manner, to be used for responsible entities of the Living Labs to identify the most suitable solution. This guideline and checklist can be used to track which energy solutions are needed by local users, which functionalities and features are considered, and what is the degree of innovation they reach. The final functionalities implemented in the SESA Living Labs will be tracked within the WP2.

Finally, the SESA objective is "*to facilitate the co-development of scalable and replicable energy access innovations, to be tested, validated, and later replicated throughout the African continent*". The guideline of the desired functional requirements presented in the Deliverable D3.2 are described in a generic and technical way, to ensure better reliability, **replicability, and scalability**. Consequently, the content of this Deliverable 3.2 may be of interest beyond the SESA project for public and private sector professionals, such as *equipment providers* to compare their products regarding a level of innovation and check the functionalities provided; and *project developers* to deploy solar or e-mobility solutions with high level of innovation; and *local authorities* to be used as technical assistance in the preparation of bid specifications on a tender documentation.

The content of Deliverable D3.2 will be available for the material release of Task 1.1 (Toolbox), Task 3.1 (Sustainable Energy solutions catalogue) and Task 2.2 (Capacity tools and methodologies).

1.3 Structure of the document

Following the executive summary, in Chapter 1 an introductory section covers the main objectives and scope of the deliverable and structure of the document.

Chapter 2 describes the methodology that has been followed for the identification of the main energy technologies or domains, which might be possibly deployed in the Living Labs, and the definition of the functional requirements and classification regarding their degree of novelty. Chapter 2 presents the procedure of how to use this guideline of functional requirements by the responsible entities of the Living Labs (or any interested stakeholders and professionals) in order to track and evaluate which functionalities and features are being considered, and what is the degree of innovation they will reach. Additionally, the potential local end users and communities for each energy technology are identified and here presented:

- Households (residential users) and rural communities,
- Small businesses, manufacturing companies and tertiary sector,
- Municipalities and government facilities,
- The fishing sector,
- The agricultural sector,
- The educational institutions,
- The healthcare facilities,
- Transport (electric mobility) service companies.

Chapter 3 covers in detail the functionalities of each energy technology, including the following aspects: system description, technical constraints, basic and advanced functionalities, expected performance, operation and maintenance, reliability and expected costs of the solutions. Thus, the following subchapters are considered:

- Subchapter 3.1 presents solar photovoltaics,
- Subchapter 3.2 covers the second-life energy storage systems,
- Subchapter 3.3 covers the electric mobility application and charging infrastructure,
- Subchapter 3.4 presents the BioCooker (improved biomass cookstoves) technology,
- Subchapter 3.5 presents the biodigester technology,
- Subchapter 3.6 discusses the smart microgrids domain, and
- Subchapter 3.6 comprises the climate proofing concept.

Finally, some key remarks and final considerations of the technical and functional (T&F) requirements are presented in Chapter 44 and the consulted bibliography in Chapter 5. The document is completed with the Annex I that includes a list of all functionalities of energy innovations of Chapter 3, in a brief and concise manner, in a format of 'questionnaire' or 'checklist'.

2 Methodology for energy innovations

Chapter 2 describes the methodology for energy innovation, divided into two approaches:

Firstly, subchapter 2.1 describes the methodology followed to structure this Deliverable 3.2, as a ***'technology innovation roadmap',*** comprised of: 1) the identification and selection of key energy innovations to be potentially deployed in the Living Labs; 2) the definition of the main functional and technical requirements that need to be met by each energy innovation, as well as their economical parameters for cost-efficient selection; and, 3) the classification of each functional and technical requirement, regarding the degree of novelty (or innovation) and the relevance of each energy technology to be involved in SESA demonstration actions.

Secondly, subchapter 2.2 presents the procedure of how to use this guideline of functional requirements by the responsible entities of the Living Labs, in order to track and evaluate which functionalities and features are being considered, and what is the degree of innovation they will reach. The potential local users and communities for each energy technology are presented.

2.1 "Technology innovation roadmap" approach

Below it is described the methodology that responsible authors of this document have followed to design and structure it with the goal of creating a ***'technology innovation roadmap'***, which contains the main technical and functional requirements (ordered by the degree of innovation, if possible) for the all the energy innovations of interest. The diagram depicted in Figure 8 summarizes the main stages of this process:

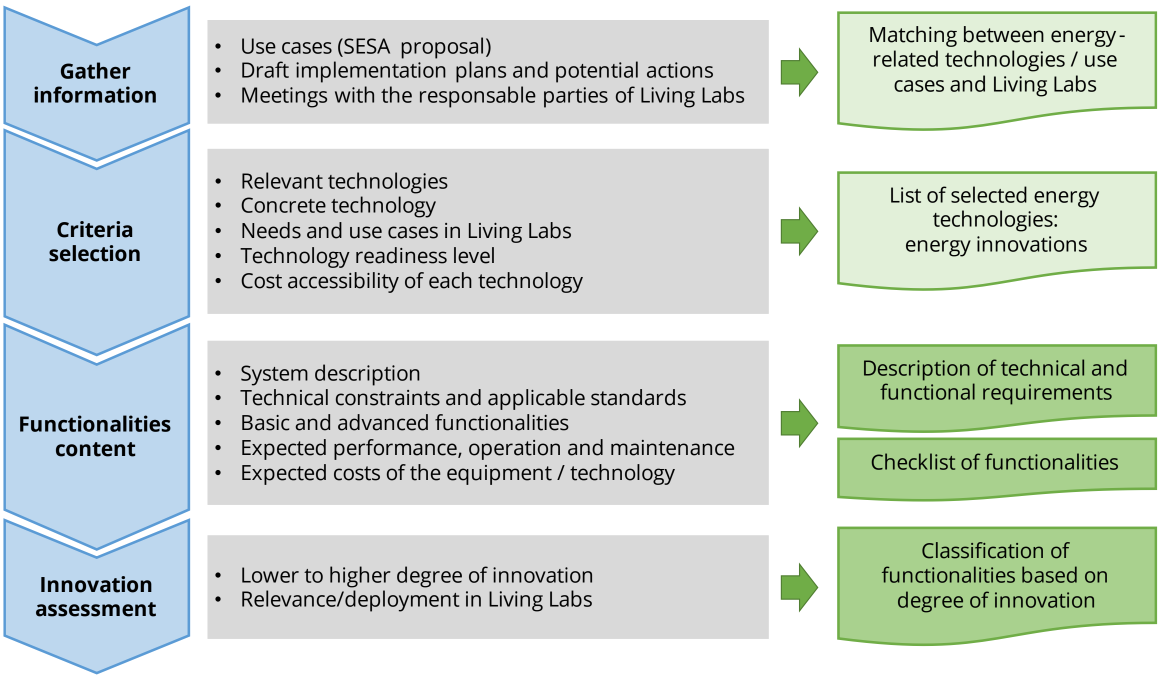


Figure 8. Main stages and outputs of the technology innovation roadmap.

Firstly, starting from the description and use cases presented in the proposal phase of the project, draft implementation plans and actions to be deployed in the Living Labs have been reviewed in light of context specific needs and conditions.

Table 1 shows the energy technologies considered by the Living Labs at proposal phase (P), to be potentially deployed (D) or to be reconsidered (C). This set of energy-related technologies have been the initial criteria for the identification of their related technical and functional requirements.

Table 1. Distribution of considered technologies per demo/validation Living Labs. Source: SESA WP4

Focus area	Energy-related technologies	Kenya	Morocco	South Africa	Ghana	Malawi
GENERATION	Solar photovoltaic	P, D	P, D	P, D	P, D	P, C
	Solar hubs / Microgrid (off-grid)	P, D	P, D	P, D		
CONSUMPTION	Rural household consumption	P, D	P, D		P, D	
	Public school consumption				P, D	
	Night lighting	P, D			P, D	
	Infospots	P, U		P, D	P, D	P, C
BATTERY	2life stationary batteries for household/community	P, D	P, D	P, D		
	2life stationary batteries for electric mobility	P, D		P, D		
	2life batteries for fishing activity	P, D				
	2life batteries for agriculture	P, D			P, U	
MOBILITY	Motorcycle-based electric mobility	P, D	P, D	P, D		
	Motorcycle-based mobility charging infrastructure	P, D		P, D		
PRIMARY SECTOR USES	Fisher lanterns charge	P, D				
	Agriculture products cooling	P, D				
	Fish products cooling	P, D				
	Fish drying	P, D				
WATER USES	Water pumping	P, D			P, D	P, C
	Water filtration systems	P, D			P, D	
	Water purification systems	P, D			P, D	P, C
COOKING/WASTE TECHNOLOGIES	BioCooker for cooking (biogas, biochar, biomass)	P, U			P, D	P, D
	Waste-to-energy/Biodigesters	P, U			P, D	

The matching between energy-related technologies / use cases and Living Labs has been assessed as reliably as possible at the date of the release of this deliverable, by gathering all the available information from each site responsible and LL implementation plans. Possible changes during project execution may be happen. As can be observed, the energy-related technologies considered by the Living Labs gather:

- Solar technology to feed multiple applications, such as public schools, lighting, communities, water-related equipment, to charge stationary batteries or motorcycles, etc.
- Energy storage systems also is considered for diverse applications, such as electric mobility, fishing, agriculture, stationary back-up for households, etc.
- The electric mobility is covered from the user (motorcycles) to the owner/operator of the electric mobility charging infrastructure.
- Small applications like night lighting or infospots are also covered.
- Many equipment or systems are oriented to specific use cases, such as fishing activities (fish drying, fish cooling, etc.) or agriculture uses (water pumping, vegetables cooling, etc.).
- Other systems involve more energy vectors (i.e., heat or biogas): BioCooker or biodigester.

In order to provide a **useful guideline of the technical and functional requirements** of the main energy technologies of interest for the partners and Living Labs involved in SESA project, the following criteria have been chosen to select the energy technologies covered in this D3.2:

- **Relevant technologies:** The selection will be made ensuring that relevant technologies, to be potentially deployed in several Living Labs of the SESA project, are considered.
- **Technology:** Any concrete technology, system or equipment may be selected, in order to describe their own technical and functional requirements, abstracting as much as possible from the final use case (i.e., solar for irrigation, solar for lighting, solar for households). Thus, the functionalities shall refer only to the energy technology, enabling to be applicable to any further use (that is, requirements not dependent on the use case).
- **Needs and use cases in Living Labs**: The needs and use cases of the Living Labs expressed by themselves in the different meetings held with WP3 are considered. As stated before, concrete technologies will be described, independent to the final use cases. So, these technical and functional requirements can be useful for all of them. The selection will ensure that all final use-cases, applications, and end-user groups are covered.
- **Technology readiness level:** The present state of the art and level of the maturity of the considered energy technologies is evaluated. Some mature technologies or commercial equipment which is not being researched within the project (i.e., water pump, cooling systems) will be dismissed to be selected as key energy technology innovations. The energy technologies which seem to have less technology readiness level, or a huge potential of innovation will be better candidates to be selected as energy innovations.
- **Cost accessibility of each technology**: The affordability of Living Labs in the African context is also evaluated, in order to select and propose energy technology (and innovative alternatives) which will be technically suitable and economically affordable.

Considering these criteria, the selected '**energy innovations'** are the following:

- **Solar photovoltaics (PV).**
- **Second-life energy storage systems (SLB).**
- **Electric mobility application.**
- **BioCooker (waste to energy for cooking).**
- **Biodigester (biomass to biogas).**
- **Smart microgrids (covering solar hubs).**

All energy innovations selected here are exposed to climate change. Therefore, an additional and transversal topic is covered: **climate proofing**, which involves taking proactive measures to minimize the negative effects of climate change and ensure that a particular system or infrastructure can perform effectively under changing climatic conditions along its lifetime.

The functional requirements of each energy innovations are identified and briefly described, based on international standards (when applicable), expert know-how and technology innovation trends. The functional requirements mainly cover the following aspects: **system description, technical constraints, basic and advanced functionalities, expected performance, operation and maintenance, reliability and expected costs of the system or technology**.

When possible and relevant, these functional and technical requirements are provided ordered **from lower to higher degree of innovation**, following the criteria of the responsible authors, technology experts, and research community trends. This classification is fair, whose objective is to show advanced and innovative functionalities. This distinction based on the degree of innovation of the solution will allow Living Labs to evaluate the innovation and novelty reached in the deployed solutions, compared to the guideline of functional and technical requirements.

Along Chapter 3, the main functionalities of each energy innovation are summarized as depicted in Figure 9, including their degree of novelty/innovation and relevance in African Living Labs. Each functionality may have basic features and/or more advanced features. On the one hand, basic features have lower level of novelty (i.e., all commercial devices or systems include this functionality) and they are set at the left side of the slidebar. On the other hand, advanced functionalities have high level of novelty (i.e., functionality under research, advanced control systems, high-end product, etc.) and they are place at the right side of the slidebar.
Additionally, each feature of the functionality is coloured in white, yellow, or green, according to the relevance or deployment in African Living Labs. This classification is made based on the criteria of the responsible authors and information found from responsible entities of Living Labs on their draft implementation plans and actions which are planned to be deployed in the Living Labs.

For example, a white feature (low relevance or deployment) means that this functionality or feature will not be covered at all in the energy innovation to be deployed in the Living Labs, both for being too basic or too advanced; or because this feature has no interest for local end users, communities, or Living Lab entities. A yellow feature means medium relevance or deployment i.e., a functionality that may be interesting to be considered. A green feature means high relevance or deployment i.e., current state of the art of the technology or a feature which have been explicitly indicated in the draft implementation plans that will be considered in the Living Labs.

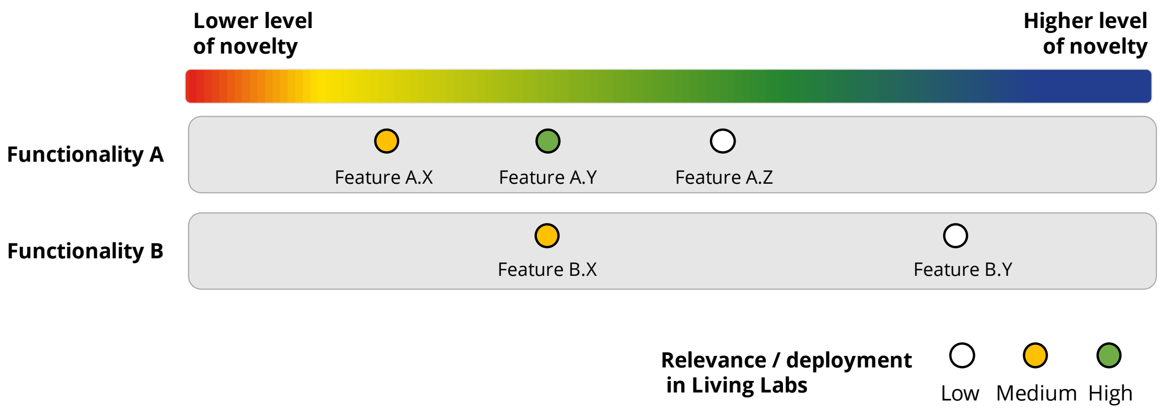


Figure 9. Example of classification of functionalities from lower to higher degree of novelty (from left to right) and relevance/deployment (low -white-, medium -yellow-, and high -green-) in African Living Labs.

Hence, Chapter 3 aims to be a reference document for technical and functional requirements of the selected energy technologies ('energy innovations'), that provides useful guidelines for decision-makers and other stakeholders to technology deployment purposes. Moreover, by mapping the degree of novelty of key innovation's requirements and functionalities, it is aimed to provide a perspective on technological evolution and be a proposal for advanced functionalities.

2.2 Deliverable usage and functionalities tracking

How to use a guideline of functional requirements to track and evaluate which functionalities and features are being considered, and what is the degree of innovation they will reach?

The diagram depicted in Figure 10 summarized the main stages of the usage of the information which contain this document (mapping of potential end-user groups and use cases for each energy innovation, description of technical and functional requirements and checklist of Annex 1) along the design and deployment of energy solutions of Living Labs in the SESA project:

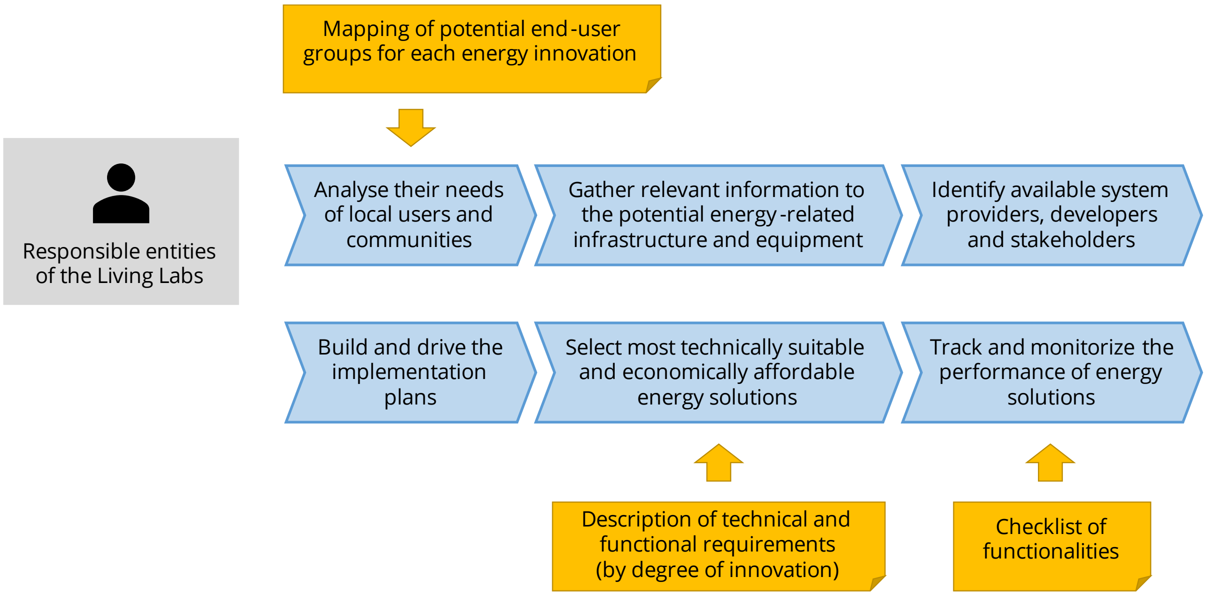


Figure 10. Main stages for the usage of the information and material covered in the Deliverable D3.2.

The targeted audience of this Deliverable D3.2, behind the SESA project, are the responsible entities of the Living Labs and project development partners, who will drive the implementation plans, and are responsible to select the appropriate technologies, systems, or solutions; and at the end, successfully deploy the demonstration actions in the Living Labs.

Out of the scope of this Deliverable 3.2, the responsible entities of the Living Labs should clearly analyse their needs of local users and communities from a technical and energy point of view; gather relevant information to the potential energy-related infrastructure and equipment; identify available system providers, developers and stakeholders; build the implementation plan; and select the energy solutions and the corresponding features (functionalities) to be deployed in those Living Labs, according to the identified energy needs and use cases of the local end users of the Living Lab. In SESA all these activities (covered within the WP4) will be carried out with the support of other partners and experts of the technical, socioeconomic, and environmental domains.

Table 2 shows the potential end-user groups for each energy innovation (identified in subsection 2.1). Each end-user group represents a set of individuals (i.e., households, rural communities, drivers, or municipality) and different sector activities (i.e., small business, offices, agriculture, fishing sector, health sector, education sector or e-mobility companies). For further detailed description of potential end-user groups and main applications for each energy innovation, see 'Introduction' section of each energy innovation included in Chapter 3.

Table 2. Potential end-user groups for each energy innovation. Source: own preparation.

End-user group	PV	ESS / SLB	e-mobility	BioCooker	Biodigester	Microgrid
Households (residential)	✓	✓	✓	✓		
Rural communities	✓	✓	✓	✓		✓
Small businesses / tertiary sector	✓	✓	✓	✓	✓	✓
Municipalities / public services	✓	✓	✓			✓
Agricultural sector	✓	✓		✓	✓	
Fishing sector	✓	✓				
Educational institutions (schools)	✓	✓	✓	✓		✓
Healthcare facilities (hospitals)	✓	✓	✓	✓		✓
E-mobility companies / drivers	✓	✓	✓			✓

As can be observed, Table 2 can support the responsible entities of the Living Labs to identify the potential energy technologies that are usually demanded by each end-user group.

The detailed description of technical and functional requirement aims to provide useful information to responsible entities and stakeholders of the Living Labs and support in the **decision-making process** toward the identification of the most technically suitable (available technology which satisfies the user needs, with lower/higher degree of novelty) and economically affordable (within the cost margins and budget) energy solution to be deployed in the Living Labs.

As mentioned before, a questionnaire (**checklist**) is also included in the Annex I, that summarizes the functionalities of all presented energy technologies in a brief and concise manner, to be used for responsible entities of the Living Labs, after the release of this deliverable. Thus, this guideline and checklist can be used to track which energy solutions are needed by local users, which functionalities and features are considered, and what is the degree of innovation they reach. Then, final functionalities implemented in the Living Labs shall be tracked within the WP2.

To sum up, the information contained in the present document may be helpful to:

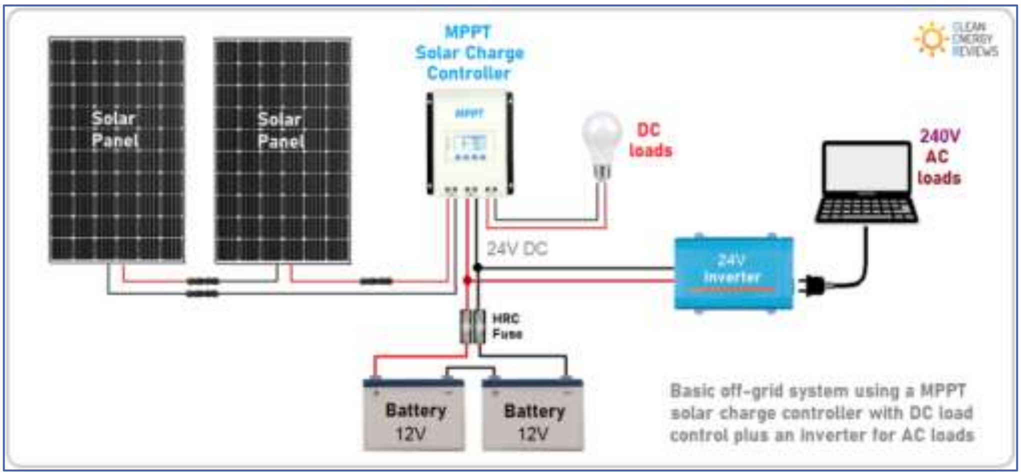
- Identify the potential energy technologies that are usually demanded by end-user groups.
- Identify which functionalities and features are considered in the energy solutions which will be deployed in Living Labs and track what is the degree of innovation they reach.
- Identify the most technically suitable (available technology which satisfies the user needs) and economically affordable (within the cost margins and budget) energy solutions.
- Replicability and scalability: for *equipment providers or project developers* to compare their products regarding a level of innovation and functionalities; or *local authorities* to be used as technical assistance in the preparation of bid specifications on a tender documentation.

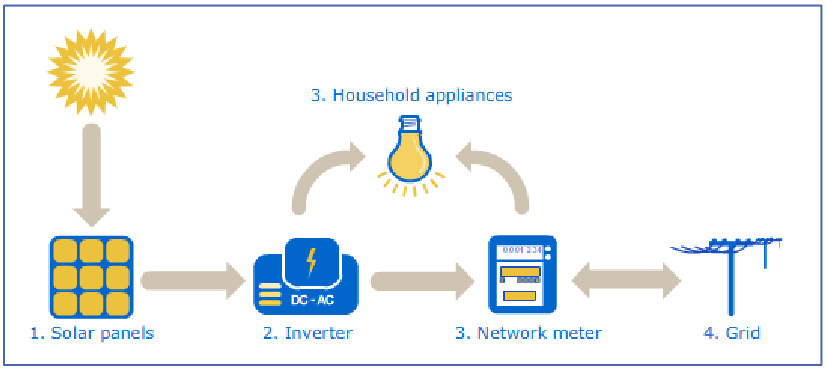
3 Description of technical and functional requirements

3.1 Solar photovoltaics

3.1.1 Introduction

A photovoltaic system, also PV system or solar power system, is the set of elements that provides electricity based on photovoltaic effect. It includes the PV panels to absorb and convert sunlight into electricity, a solar inverter to convert the PV panels output from direct to alternating current, as well as mounting, cabling, and other electrical accessories to set up a working system. It may also use a solar tracking system to improve the system's overall performance and include a battery for energy storage. The PV systems does not have moving parts and they produce electricity silently during the daylight hours. Most common PV modules are composed by crystalline silicon (c-Si) solar cells, which are recognized by its squared-shape and dark-blue colour within the PV module. The PV inverter is required to transform the direct current produced by the PV modules into alternating current normally required by the appliances. The batteries for energy storage are optional, and they are normally managed by a charge controller, although hybrid inverters can do it (see Figure 11). If there are no batteries, the electricity is directly consumed (for instance by household appliances) or injected to the grid, otherwise the electricity is lost. Depending on the country, some revenues could be obtained from the electricity injection.





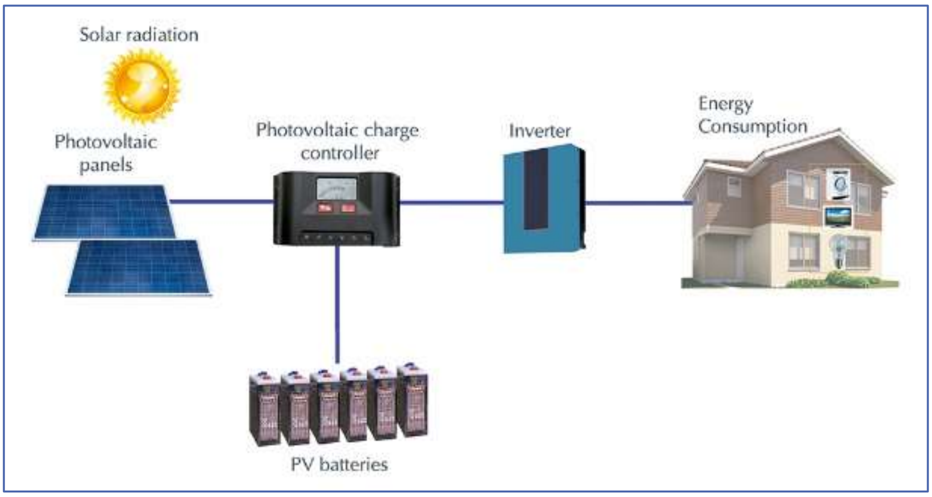


Figure 11. Different small-medium PV systems connection schemes. From top to bottom: Off grid system; Grid connected without batteries; Grid connected with battery charge controller and non-hybrid inverter.

PV systems should not be confused with other solar technologies, such as solar thermal normally used for heating water instead of produce electricity. The visible part of the PV system are the PV modules or panels, normally located on the building roofs or on the ground, while the other set of elements are often summarized as balance of system (BOS). To properly sizing and design the PV system, demand assessment is a crucial aspect as it determines the amount of energy that will be necessary to meet the energy needs of a building or facility. This assessment considers factors such as energy consumption, usage schedules, which are essential for determining the appropriate size of the photovoltaic system and its energy production capacity. An accurate and detailed demand assessment ensures that the photovoltaic installation is designed to efficiently meet the energy demand, avoiding excess or insufficient energy production, and therefore improving the system's profitability and sustainability.

PV systems range from small rooftop-mounted or building-integrated systems with capacities from a few to several tens of kilowatts, to large utility-scale power stations of hundreds of megawatts (see Figure 12). Generally, the PV systems are grid-connected in developed countries, while off-grid or stand-alone systems are used only where no grid is available.

Figure 12. Examples of PV systems. Top-left: small PV system on a house. Top-right: medium scale PV system on commercial building. Bottom: Big utility scale PV system on ground for massive electricity production.

PV systems are key to delivering reliable and affordable electricity and to enabling sustainable socio-economic development (IRENA, 2022). In particular, rural populations in Africa stand to benefit, as up to 80% of the population currently lack energy access. In rural and remote locations, minigrids (including solar systems) are a more viable solution to electricity access than grid expansion. In fact, 65% of new connections in communities located more than 20 km from the grid infrastructure will be minigrids and 25% are stand-alone systems (see Figure 13) (IEA, 2022).

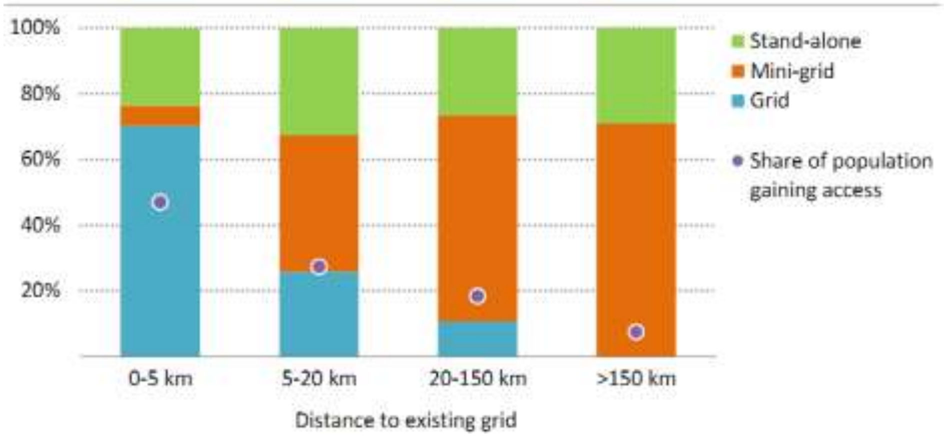


Figure 13. Share of electricity connections by technology and distance in the SAS, 2022-2030 (IEA, 2022).

Solar PV is a key enabler for energy access increase and economic transformation. All end-user groups would strongly benefit by installing PV due to higher efficiency and automatization levels in their processes.

Solar photovoltaics (PV) have the potential to benefit a wide range of end-users in Africa, as the continent has abundant sunlight and many areas with limited access to traditional energy sources. PV is a key enabler technology for fossil fuel deferral, energy access increase and economic transformation through electrification. Within the SESA project, several potential PV system end-user groups have been identified (see Table 2). Each of these groups have specific characteristics and economic activities that will define the T&F requirements to be met by PV technology:

- **Households (residential users) and rural communities** need electricity, among others, for lighting and small device/appliance powering, as well as for other basic needs and potentially even powering appliances, such as water pumping, e-micromobility uses.
- **Small businesses, manufacturing companies and tertiary sector (**mostly consisting of market trade, offices, small retail products, artisanal services, small scale construction and transport) rely on solar electricity to power their operations and business activities, enabling increased productivity and economic growth, i.e., to power electronic devices, lighting, and required appliances for their productive processes.
- **Municipalities and government facilities** may use electricity to provide reliable electricity for public services like lighting, information spot provision, public buildings, community facilities (i.e., gathering spaces), or public e-mobility fleet powering.
- The **fishing sector** requires electricity supply, for recharging electric boats and lanterns, for improving fish drying process efficiency and for fish cooling and storage purposes.
- Similarly, the **agricultural sector** would increase its efficiency on several processes thanks to electrification. For instance, by implementing water irrigation, water pumping and purification systems, as well as agricultural machinery powered by clean energy.
- The **educational institutions,** represented by public primary and secondary schools and universities, need electricity for daily educational purposes (i.e., power computers and lights), night-time learning activities and illuminating school to ensure security at night.
- The **healthcare facilities** represented by hospitals and small healthcare centers require reliable and uninterrupted electricity supply for the medical equipment, lighting in remote areas. Solar energy by itself can provide clean and stable electricity during sunny days.
- **Transport service companies,** like battery swapping stations or leasing companies, strongly rely on solar PV systems for vehicle battery recharge, powered by solar minigrids.

PV systems are key to delivering reliable, secure, clean, sustainable, and cost-efficient electricity to households, businesses, and critical infrastructure such as schools and hospitals in many African countries. Examples around the world demonstrate that the users need to be involved at all stages of project development in order to realize and maximize the benefits of solar installations to the users, and to ensure the long-term viability of the systems. Solar minigrids bring specific benefits to businesses (e.g., higher productivity, efficiency and working conditions), households (e.g., availability of light in the evening can improve educational outcomes), and communities (e.g., hospitals, etc.). Additionally, solar installations have recently also become important in the promotion of electrified mobility, by using solar PV to battery charge.

It's important to note that the specific end-users of solar PV in Africa can vary greatly depending on the region, local needs, regulatory environments, and economic factors. Different models of solar PV deployment, such as standalone systems, mini-grids, and grid-connected installations, can be tailored to meet the diverse energy requirements of these end-users.

3.1.2 Estimated technology costs

PV systems have developed from being niche market applications into a mature technology used for mainstream electricity generation. Due to the growth of photovoltaics, prices for PV systems have rapidly declined since their introduction. However, they vary by market and the size of the system. This is the case of some niche markets on the African context.

The current prices (Nov 2022) of PV modules at the European market for wholesales purchases are between 0.35-0.45 €/Wp, so a normal PV module of about 400 Wp would cost 140-180 €. However, this price could be higher for small quantity purchases. Also, this price does not include the price of other BOS elements like structure, inverter, and cables. The total cost of a medium-size or small-size PV system including all the elements might be in the range of 1-2 €/Wp depending on size, type of installation, profit margins, and taxes (Ramasamy et al., 2022).

Small solar DC systems (< 1kW) are not benefitted from economy scales and come along with batteries. Therefore, they experience high costs, and they are exposed to wide cost variations (USD 4.3-14.2/W compared to USD 1-3/W for PV panels only). AC systems are even more expensive, ranging from USD 14-23/W, mainly, due to the need of an inverter and more advanced battery systems. Bigger solar DC systems (> 1kW) range between USD 3.6-17/W and grid- connected rooftop systems (> 1kW) range between USD 2-3/W according to IRENA database (IRENA, 2016). This data is for 200 to 750W modules and are updated until 2015. The following figure shows the cost breakdown for small solar DC systems, which includes PV modules, the battery, the charge controller, and other system elements. The cost breakdown for the rest of African niche markets can be found in the referenced report.

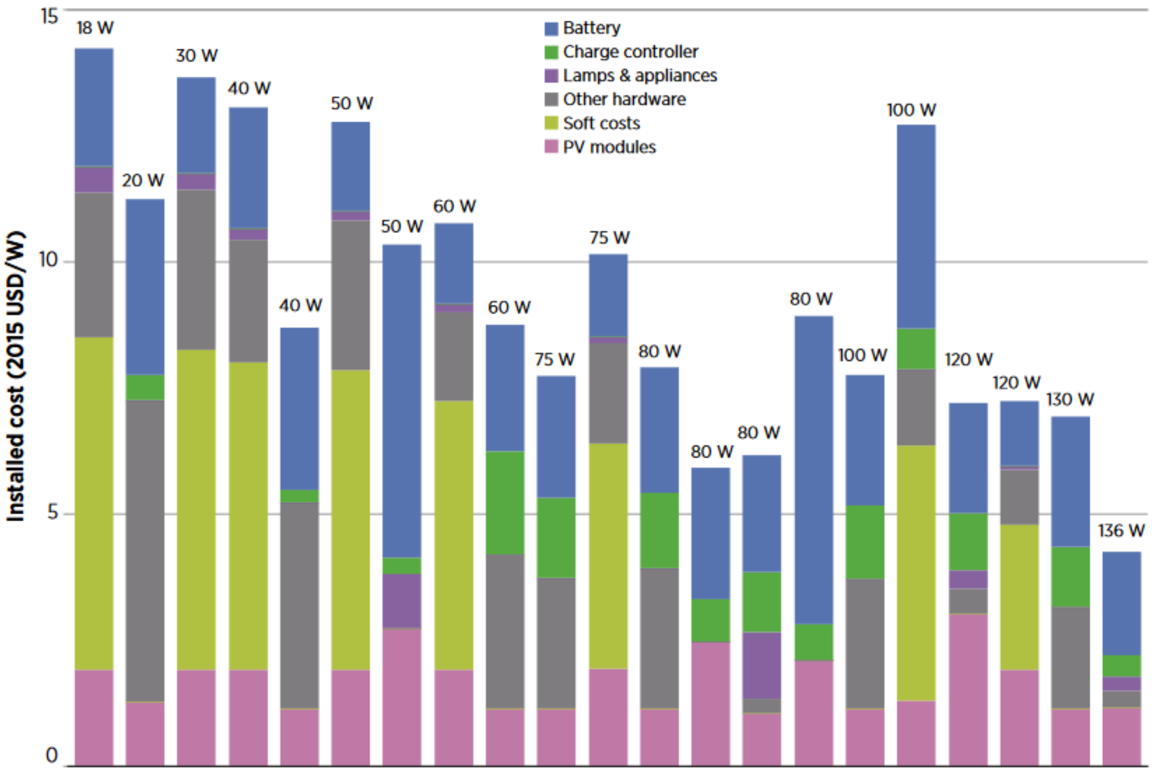


Figure 14. Small solar home system (<1 kW) cost breakdown by cost component. Source: ("Solar PV in Africa: Costs and Markets," 2016).

The Levelized Cost of Energy (LCOE) of PV systems represents the average revenue per unit of generated electricity required to recover the costs of building and operating a PV plant during an assumed financial life and duty cycle. According to (IEA, 2022), the LCOE for solar PV in 2020 ranged between 30-90 $/MWh, but with significant decline projections for 2030 that would make it the cheapest alternative with 20-50 $/MWh in Africa, under the Sustainable Africa Scenario.

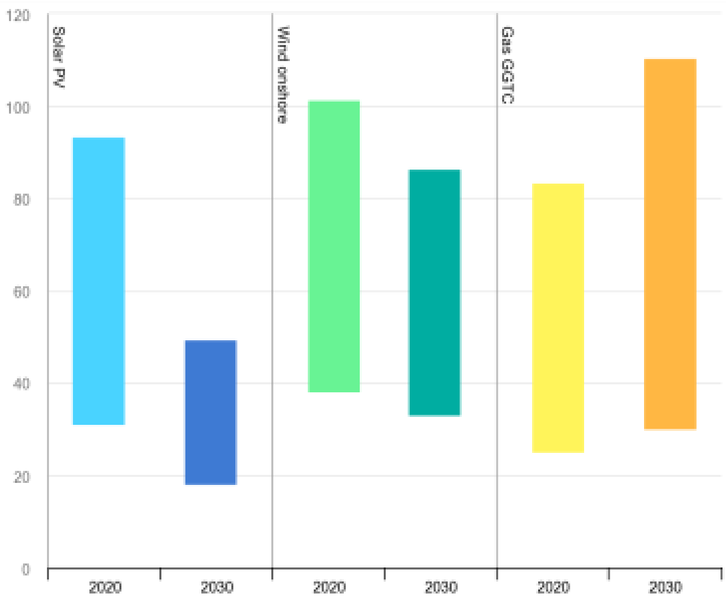


Figure 15. Levelized cost of electricity by technology in Africa in the Sustainable Africa Scenario, 2020-2030 . Source: (IEA, 2022).

3.1.3 Summary of PV systems functionalities

The functional requirements for big PV plants normally located on ground for massive electricity generation, where the most exhaustive control is required. For small installations, the technical and functional requirements can be significantly reduced. Considering the solar photovoltaics technology in general, the following functionalities could be considered ordered at certain extend according to their increasing innovation degree. In this sense, the following diagram aims to classify the main functionalities of PV plants per level of novelty and relevance in Living Labs.

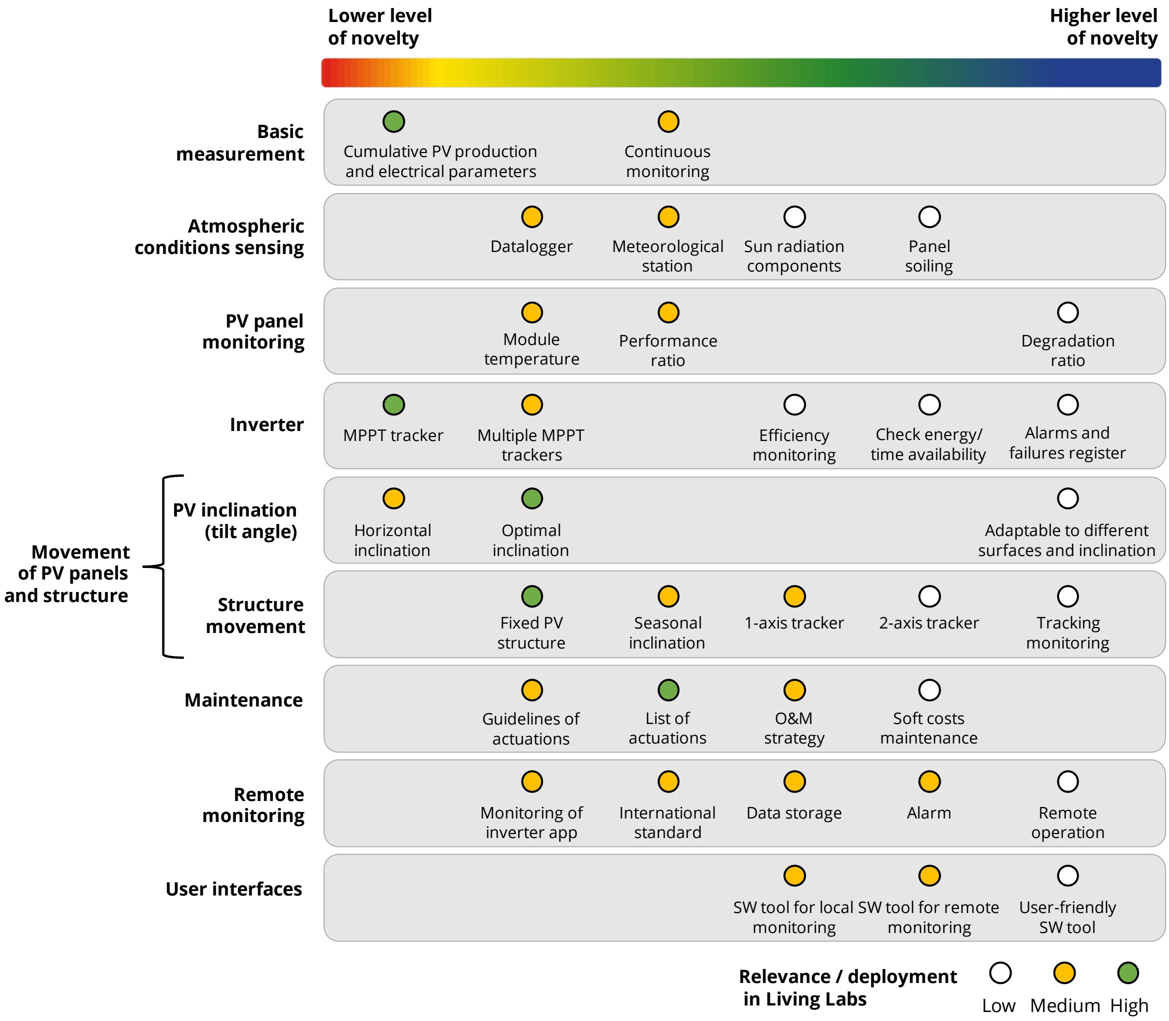


Figure 16. Classification of PV plants functionalities from lower to higher degree of novelty (from left to right) and relevance/deployment (low -white-, medium -yellow-, and high -green-) in African Living Labs.

3.1.4 Description of PV systems functionalities

Regarding international standards, (IEC 62548-2016, 2016) sets out design requirements for photovoltaic (PV) arrays including DC array wiring, PV system architectures, mechanical design, electrical equipment, electrical protection devices, switching and earthing provisions and safety issues. (IEC TS 62738-2018, 2018) sets out general guidelines and recommendations for the design and installation of ground-mounted photovoltaic (PV) power plants. A PV power plant is defined within this document as a grid-connected, ground-mounted system comprising multiple PV arrays and interconnected directly to a utility's medium voltage or high voltage grid.

3.1.4.1 Basic measurements of PV production

- Measurement of cumulative PV production and other electrical parameters made by the inverter. Normally the inverters include this function.
- Continuous monitoring of PV power thought the inverter. Many inverters, even small ones, have extra functionalities to provide the monitored AC production data during a period (not only the cumulative production).

3.1.4.2 Monitoring of the PV panels

- Datalogger: Advance monitoring will require a datalogger to collect data of the sensors.
- Sensing of atmospheric conditions: air temperature, humidity, wind velocity, wind direction, normally with a meteorological station; and solar radiation at the PV modules plane using a pyranometer. There might be basic meteorological stations that already integrates a monitoring system without the requirement of datalogger.
- Continuous monitoring of electrical parameters, including PV production in DC and AC (before and after inverter), through specific voltage-current sensors located on the cables, together with a datalogger.
- Performance Ratio of PV system, it can be calculated knowing the irradiance at the plane of the modules and the real measured PV production.
- Sensing of sun radiation components, this are global horizontal radiation (GHI), diffuse at horizontal plane (DHI) and direct/beam normal solar radiation (DNI/BNI). GHI is normally measured with a pyranometer. DHI and DNI require advance equipment that follow the sun movement. These parameters are normally required for the meteorological data required by the PV simulation software.
- Sensing of panels temperature, placing temperature sensor (thermocouples) at the back side of some of the panels.
- Sensing of soiling using specific sensors.
- Measurement of annual degradation ratio of PV panels. Common degradation of PV panels is 0.5%/year, so after 25 years they have lost about 12-13% of their initial capacity.

3.1.4.3 Monitoring of the inverter

- Inverter efficiency monitoring. This require monitoring of electrical parameters before and after the inverter, and it is calculated dividing Energy_DC / Energy_AC.
- Maximum Power Point Tracker (MPPT) efficiency. The inverter makes the system operates in the optimal point voltage-current, that provides the maximum power. This due to the MPPT algorithm implemented. In practice, this MPPT might have some deviations.
- Possibility of multiple MPPTs, in case of complex installations. This is useful when PV modules with different orientations are connected to the same inverter because each orientation has its own Maximum Power Point (MPP).
- Energy availability (in %), Time availability (in %) higher than given value.
- Ancillary services in place.
- Register of alarms and failures.

3.1.4.4 Movements of PV panels and structure

- Most basic and common configuration are fixed PV panels with optimized inclination according to location.

- Seasonal movement, normally two times per year (March-September) modifying manually the panels inclination. The structure should be prepared for this inclination modification.
- Use of 1 axis solar tracker may increase the PV production about 10-25%. They move the modules from east to west following the Sun during the day.
- Structural system (either fixed or tracker) should be adapted if bifacial PV panels are used, so there are no structural elements that block the radiation to the backside of the panels.
- In 1 axis trackers different module configurations are possible with modules in vertical or horizontal. 1-portrait (1P) and 2-portrait (2P) are the most commons, but 1-landscape or 2-landscape are also possible. Trackers normally include backtracking algorithm to avoid shadows from one tracker to another.
- The use of 2 axis trackers is more expensive and normally do not worth, but it may be useful if the available area is small, and the PV production must be maximized.
- In case of using trackers: Tracking accuracy and tracking error might be monitored.
- Structure adaptable to different surfaces and tilt angles.

3.1.4.5 Maintenance

- Book of interventions (preventive maintenance, cleaning of PV panels, visual inspection).
- List of failures and interventions: programmed and non-programmed.
- Replacements (mechanical parts, PV modules / inverters; other components).
- O&M strategy: responsible company, agreement based on key performance indicators.
- Other common soft costs: insurance, security, communications, and databases, etc.

3.1.4.6 Remote monitoring

- The international standard for monitorization of PV plants is IEC 61724-1.
- If monitoring, normally a datalogger is required, and maybe additional systems.
- The maximum timestep is 1 hour for data storage. A few minutes is recommended. See IEC 61724-1 for more information.
- The monitoring system might include alarms.
- Online / offline (both are valid)
- The remote operation might be available.

3.1.4.7 User interfaces

- User friendly SW tool for local monitoring.
- SW tool for remote monitoring, normally offered as an extra functionality.
- User-friendly remote-control interface

3.1.5 Solar PV for residential or public services

The following points describe the additional **functional requirements for residential or small-medium PV installations in public services**. This PV installations will be normally placed on the building roof, but they can also be located on the building's façades or on the ground nearby the building. From less to more innovative within the different topics, the PV installation functions are:

- **Monitoring of the PV panels:** Specific monitoring of the PV panels is not normally performed in residential or public services except for R&D purposes. If this is the case, the previous "Monitoring of the PV panels" points can be applied depending on the interest.

- **Monitoring of the inverter:** Specific monitoring of the PV inverter parameters normally is not required in residential or public services except for R&D purposes and is sufficient with the electrical data provided by the inverter. If a deeper analysis is required, the previous "Monitoring of the inverter" points can be applied.

- **Movements of PV panels and structure**

  - Their structure and position in residential or public services are normally fixed.
  - Most basic structure is coplanar to the building surface, for instance, coplanar to the roof, so the roof and the modules have the same inclination. Also, the orientation of the PV panels is determined by the orientation of the building surface, being desired the South orientation in the north hemisphere and vice versa.
  - Alternatively, especially on flat roof or terraces, the structure might have a different inclination for optimizing the production. Normally in these cases the PV modules can be optimally oriented to South (or North in the south hemisphere). In this case, the structure might be prepared for different seasonal inclinations.
  - The PV installation must comply with design criteria related to strong winds, normally higher than 100-150 km/h. Thus, the structure should be attached to a fixed part of the building or to the ground. If this is not possible, heavy weights (i.e., concrete blocks) can be attached to the structure.
  - For improving the aesthetics, especially in BIPV installations (Building Integrated Photovoltaic) the cables could be hidden in the structural profiles.

- **Maintenance**: The maintenance of residential, commercial, or public services PV installations normally includes a book of actuations where the preventive maintenance, cleaning of PV panels and visual inspection is tracked. It is important to order additional number of modules or other parts to be used as replacement for future breakages, especially in those elements that can be difficult to be found/purchase in the future. Depending on the size, it might be interesting to subcontract operation and maintenance (O&M) activities.

- **Remote monitoring**: For small-scale PV, like residential and public services PV installations normally do not require remote monitoring. If it is desired, some inverter manufacturers can provide remote monitoring tools that can be accessed from mobile app or computers.

- **Building integration strategies:** The PV products can be specifically designed to be integrated in the building, replacing sometimes conventional building materials. This is known as Building Integrated Photovoltaics (BIPV). In this sense the module or system may have different functionalities:

  - Backside of module in black (instead of white) to have similar colour than the solar cells and be more aesthetical.
  - Busbars and ribbons (metallic parts within the module) might be black covered to improve aesthetics.
  - The PV cells are integrated in a laminated glass like the one used for architecture. This PV glass can be used in curtain walls, skylights, or other parts where the common glazing can be used. In this case, the structural system could be used to hide the cables.
  - These modules fulfil the construction requirements (fire safety, wind loads, etc)
  - Module front glazing might include a surface treatment or coating that provide a colour appearance and hide the solar cells.

3.1.6 Solar PV for water-energy nexus technologies

On the water domain, the solar-powered water pumps are predominant combined to PV systems. The functionalities of the PV system depend on its size and its location/ integration, but it does not normally depend on the use of the energy. In this sense, a PV plant producing electricity for water pumping might have the same functionalities (in terms of measurements, monitoring and structural systems) than a common PV plant of its size. However, there are some specifications regarding the water pumping system. Below, the main functionalities are described:

- **Movements of PV panels and structure**: The PV panels could be adapted to irrigation hours and seasons. Thus, if irrigation is more interesting during dry seasons, the inclination of the PV modules could be adapted to the sun position during those months. If irrigation is interesting during the morning or evening, the PV modules could be oriented to east or west respectively.

- **User interfaces**: Mobile phone application that allows total control of the system: start-stop of pumps, opening-closing of valves, start-stop and pivot movement and the ability to visualise in real time all its variables (photovoltaic power, pumping and irrigation flow rates and tank filling level).

- **Pumping system**

  - An intermediate water tank is recommended to regulate the possible variations in the radiation obtained by the panels, in which it is stored a quantity of water, similar to what would be a few minutes of the maximum flow of the extraction pump.
  - Water tank should include a filling sensor to stop the pump if necessary.
  - A programmable automaton will be in charge of controlling the pump motors, depending on the information available (solar radiation and water contained in the tank) it will establish which of the pumps should start either separately or jointly.
  - The system can include a second pump for providing the pressure required by the irrigation system used (sprinkler, pivot or any other). It will be also feed by the PV system.
  - It can be included a database where all irrigation and rainfall records are automatically stored, which can be consulted from a computer or mobile phone.

3.1.7 Solar PV for e-mobility

The functionalities of PV installations used for charging electrical vehicles is presented. The functionalities of the PV system depend on its size and its location/ integration, but it does not normally depend on the use of the energy. In this sense, a PV plant producing electricity charging e-vehicles might have the same functionalities (in terms of measurements, monitoring, and structural systems) than a common PV plant of its size. Below, the main one is described:

- **Movements of PV panels and structure**: The structure could be designed to cover partially the vehicles and protect them from rain or other weather events. In other words, the structural system can be a carport or similar.

3.2 Second-life energy storage systems

3.2.1 Introduction

Batteries are energy storage devices that can convert chemical energy and store it as electricity by means of internal electrochemical reactions. Batteries are built out of small battery cells, where electrochemical reactions occur, connected in series and/or parallel to reach desired voltage and power levels. Cells conform battery modules, which are at the same time connected in series and/or parallel creating battery racks for stationary applications. A key aspect for batteries is monitoring for safety and efficiency aspects. For that, the Battery Management System (BMS) is used for cell, module and/or rack level variable (voltage, temperature and current) monitoring and control. This data is sent to a central server and stored online. Some additional elements need to connect to the battery system for grid and/or generation system interaction: first, the Power Conversion System (PCS) in charge of accommodating electrical power; second, the Energy Management System (EMS) in charge of system power flow control, management and distribution and, third, a Thermal Management System (TMS) dedicated to maintaining temperature levels of the system (see Figure 17 and Figure 18).

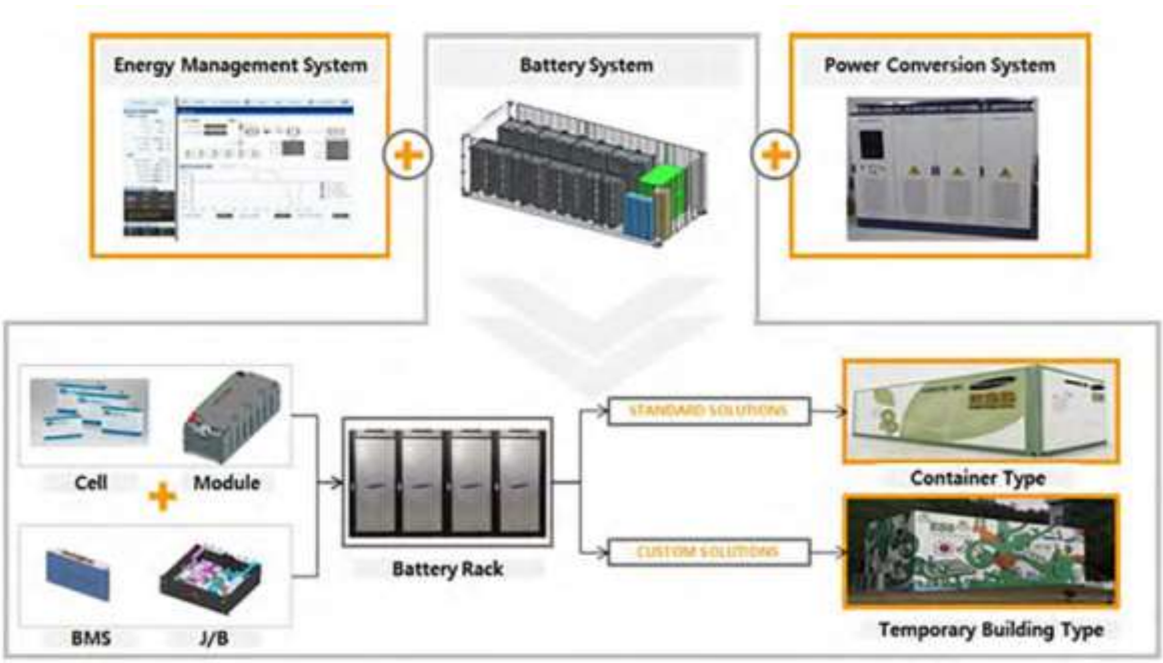


Figure 17. Schematic of a battery energy storage system (Asian Development Bank, 2018).

As to grid connection and PCS topologies, different alternatives do exist for batteries. Common variants of the PCS side are dedicated connections where each battery rack or string has its own PCS or parallel connections where the PCS is shared among different battery racks or strings. Additionally, it is common to install a transformer in order to adapt output battery and grid voltage levels (see Figure 19). Dedicated connection's main advantage is that it permits separate power flow management among racks, hence being a more reliable and flexible alternative. On the other hand, parallel connections might lead to reduced costs since less equipment would be needed.

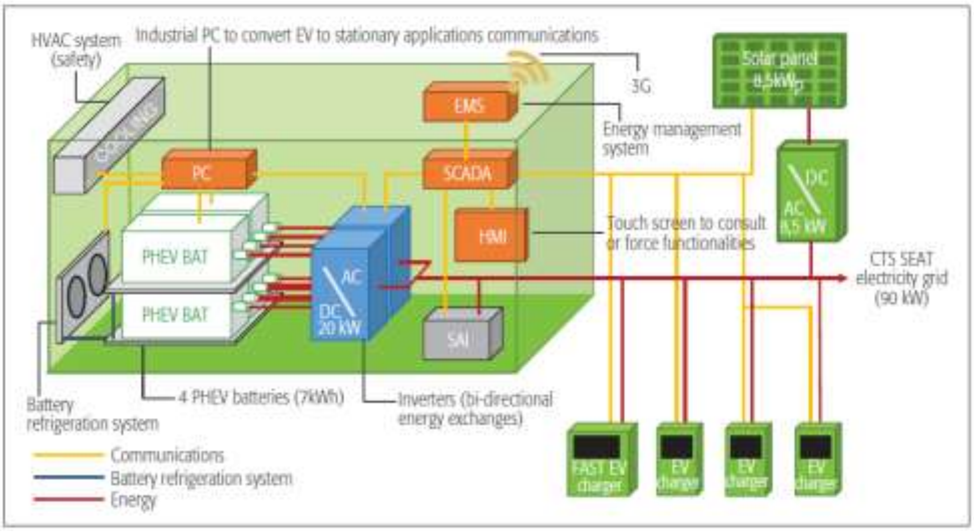


Figure 18. Schematic of a SLB storage containerized system from Sunbatt project (Casals and Garca, 2016).

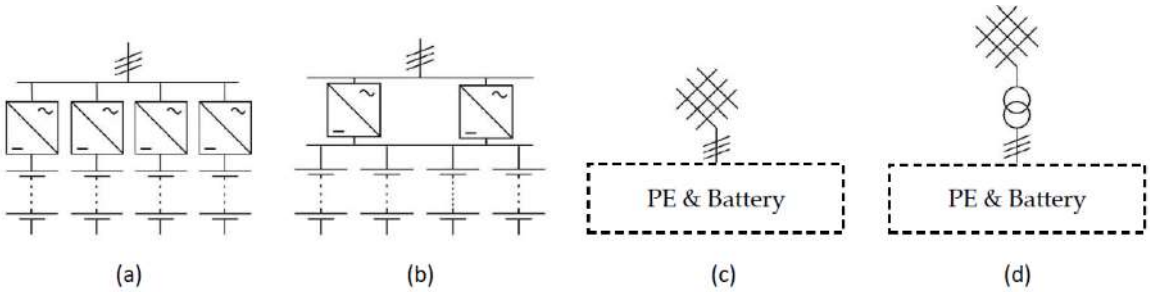


Figure 19. Variants of PCS topologies: (a) dedicated and (b) parallel connection. Direct grid connection (c) and connection via transformer link (d) (Hesse et al., 2017).

When pairing solar PV systems and batteries, three main configurations stand out (see Figure 20): a) AC coupling where PV and batteries have their own PCS (DC-DC converter and inverter), b) DC coupling where PV and batteries have their own DC-DC converter but share a common inverter and c) the MPPT coupling where DC-DC converters are connected in series.

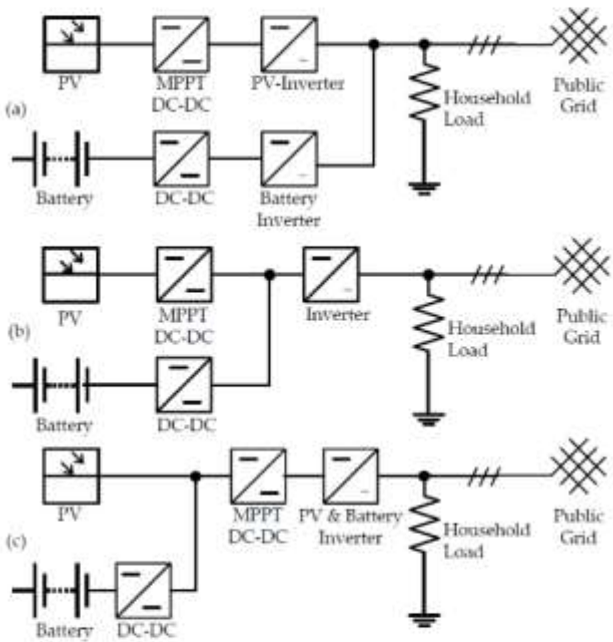


Figure 20. System coupling variants for PV plus battery systems (Hesse et al., 2017).

Many different types of batteries coexist nowadays, (for instance, lithium-ion, lead acid or redox flow batteries) all of which with remarkable differences on energy density, efficiency, cycle lifetime or time of response. Nonetheless, for second-life applications lithium-ion batteries are mainly used due to their extensive utilization on their first life electromobility applications. In this regard, retired Electric Vehicle (EV) batteries are still usable for several stationary applications since they retain about 70-80% of their original capacity. Some common SLB stationary applications could be renewable energy support or EV charging infrastructure backup (Casals and Garca, 2016). Moreover, SLB can reduce the amount of waste while avoiding the depletion of critical raw minerals such as cobalt, lithium, and nickel. Therefore, SLB are valuable assets for both economic and environmental concerns.

Batteries allow more efficient electricity usage of existing activities, ensuring a continuous and reliable power supply, for a wide range of applications, by shifting excess solar power during the day to night-time or high-demand periods. Batteries can also harness transport electrification and enable new business opportunities.

Energy storage solutions can be beneficial for a wide range of end-users by providing reliable and continuous power supply, improving energy access, and supporting various applications. In particular, energy storage is crucial for maximizing the benefits of PV in Africa as batteries allow a wider and more efficient electricity usage by storing excess solar power during the day for night-time periods, as well as an increased efficiency of energy usage in many processes. Additionally, batteries can help on transport electrification, enabling new business opportunities like battery swapping. Within the SESA project, several potential battery end-user groups have been identified (see Table 2). Each of these groups have specific characteristics and economic activities:

- **Households (residential users) and rural communities** need electricity, among others, for lighting and small appliance powering, as well as for other basic needs. Energy storage systems can provide households with backup power during grid outages, enabling uninterrupted lighting, charging of electronic devices, and running essential appliances. In rural communities, off-grid or underserved communities can use energy storage to store excess energy generated by solar PV systems during the day for use at night. This improves the energy access and quality of life of grid-isolated communities.
- **Small businesses, manufacturing companies and tertiary sector** mostly consisting of market trade, offices, small retail products, artisanal services, small scale construction and transport would complement solar with batteries. Businesses and industries can benefit from energy storage by reducing energy costs through peak shaving (using stored energy during high-demand periods) and load shifting (storing energy when prices are low and using it when prices are high), enhancing power quality and reliability for their operations.
- **Municipalities and government facilities** may use batteries to provide reliable and continuous supply for their public services, like lighting, information spot provision, public buildings, community facilities (i.e., gathering spaces), or public e-mobility fleet powering.
- In the **fishing sector**, apart from supporting solar on activities like rechargeable lanterns, fish drying, cooling, and storing processes, there exists a big opportunity for clean electric fishing boats, driven by electric motors, batteries, and even with solar energy.
- The **agricultural sector** would improve water irrigation, water pumping and purification systems, as well as agricultural machinery powered by clean energy. Additionally, battery-powered agricultural machinery and water pumps are an opportunity for a more modern agricultural activity, allowing them to operate efficiently and improve productivity.
- The **educational institutions** may be supported by batteries during power outages, night-time learning activities and lighting to ensure security at night.

- The **healthcare facilities** have some critical loads that need uninterrupted power supply. It can be ensured by storage devices like batteries. Energy storage can provide backup power to healthcare centers, ensuring uninterrupted operation of critical medical equipment, lighting, and refrigeration for vaccines and medicines.
- **Transport service companies,** like battery swapping stations or leasing companies, can install stationary batteries to manage their business when no solar power is available. That is, EV charging stations can utilize energy storage to manage demand spikes and ensure efficient charging of EVs or batteries, promoting the clean transportation.

3.2.2 Estimated technology costs

The increasing demand of stationary and mobile battery systems is driving technology costs down. Additionally, while first-life battery deployment happens, a pool of SLB mainly coming from e-mobility sector is being created. In fact, re-utilization of batteries is nowadays the least costly and manufacturer-preferred solution for SLB (Casals and Garca, 2016). Battery repurposing costs differ depending on the desired second-life application, being residential setups considerably cheaper than industrial applications. SLB costs are in the range of 20-80% of the cost of new batteries, but entail uncertainty respect to remaining lifetime and available capacity. (Dong et al., 2023) showed several SLB cost estimations reported in the literature which are summarized as follows.

Table 3. SLB costs estimation. Source: adapted from (Dong et al., 2023).

Reference	Retired battery cost (USD/kWh)	Repurposing cost (USD/kWh)	Total cost (USD/kWh)	Comments
(Neubauer et al., 2015)	19-131	25-49	44-180	Retired battery collection, testing and packaging considered.
(Jian, 2017)	-	-	72	SLB total cost reported (2017).
(Li, 2023)	-	-	41,4	SLB total cost reported (2023).

(Kebir et al., 2023) showed the economic benefits of accessing energy by means of SLB utilization in Kenyan primary schools. Concluding that SLB can decrease the LCOE by 5.6–35.3% in comparison to installing equivalent (same size, chemistry, and technical functionalities) new battery systems, while the payback period could be decreased by 8.2–42.9%. Moreover, SLB can decrease the LCOE by 41.9–64.5% respect to obtaining the electricity from the utility grid.

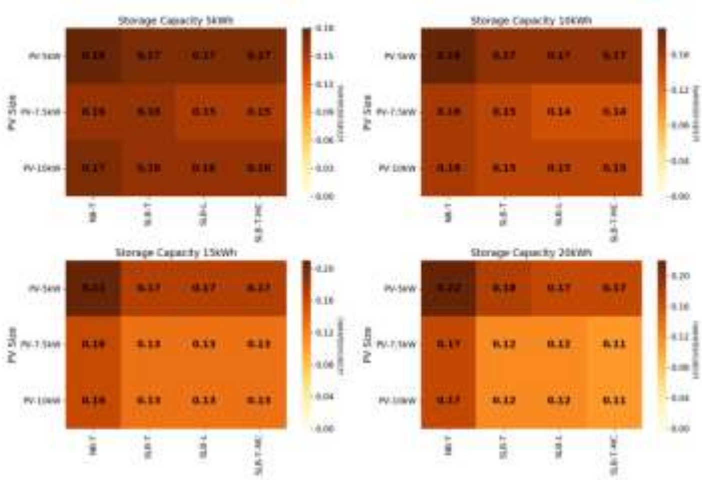


Figure 21. LCOE of different SLB plus PV systems in the Kenyan context (Kebir et al., 2023).

3.2.3 Summary of second-life batteries functionalities

The following diagram aims to classify the main functionalities of second-life batteries per level of novelty and relevance in African Living Labs. Each functionality will be described henceforth.

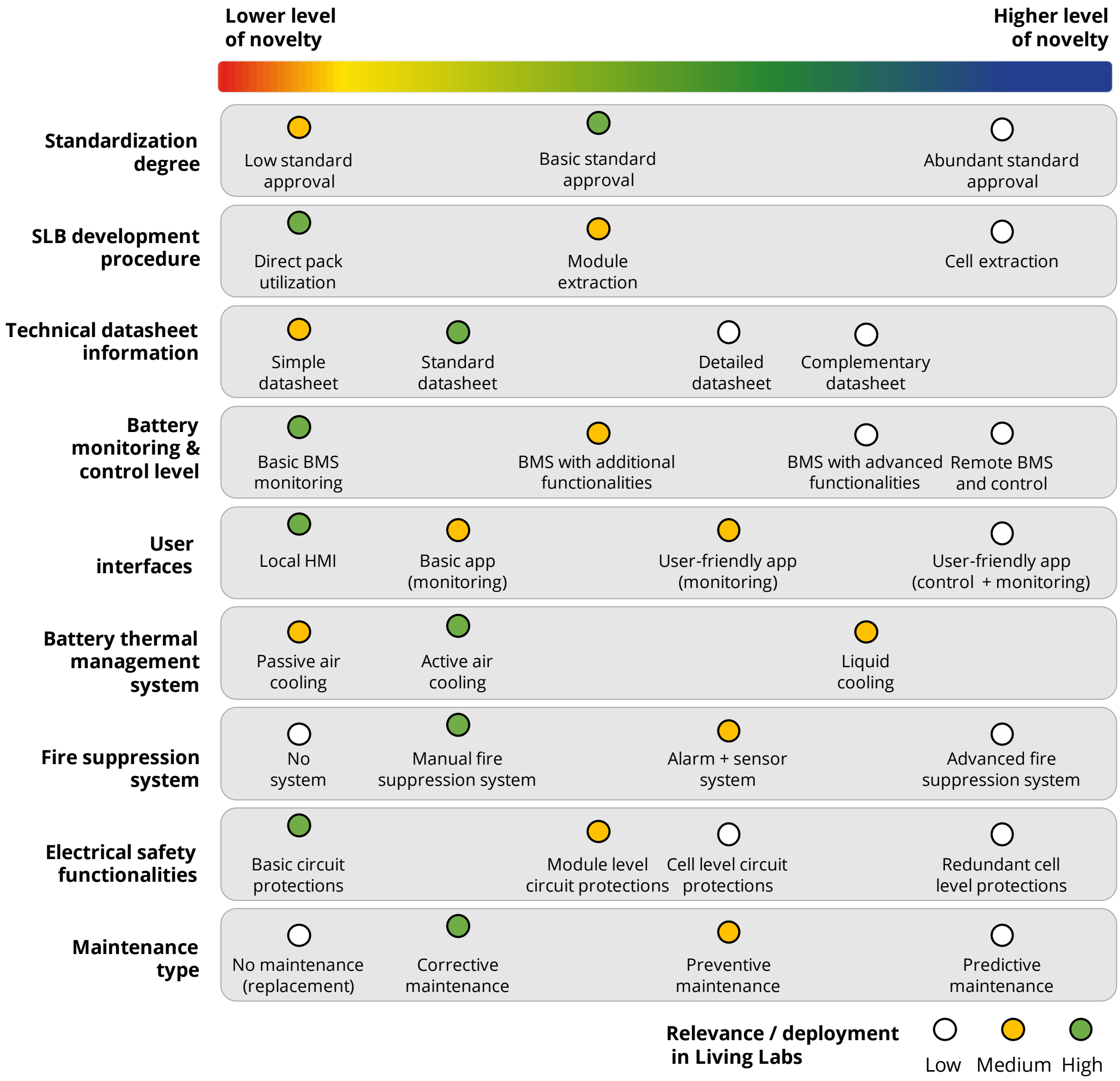


Figure 22. Classification of SLB functionalities from lower to higher degree of novelty (from left to right) and relevance/deployment (low -white-, medium -yellow-, and high -green-) in African Living Labs.

3.2.4 Description of second-life batteries functionalities

3.2.4.1 SLB standardization specifications

Currently, SLBs do not have any governing standards. This is partially due to the fact that there are many different cell chemistries and types adopted by manufacturers, since there is no cell standard for first life applications. Nevertheless, as part of the EU Green Deal, the European Commission proposed a new Battery Regulation that aims to ensure that EU-marketed batteries are safe and sustainable during their whole life cycle ("Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) No 2019/1020," 2020). Specifically, regarding SLBs, the following points were highlighted:

- Independent operators should have access to BMS information needed. This aspect is critical since EV manufacturers are hesitant to provide their CAN matrixes, which is critical to decode and communicate information through the battery.
- EV batteries will no longer be waste if the holder proves 1) battery State-of-Health (SOH) checks (still usable), 2) a 2nd life will be provided by means of a contract and/or 3) that the battery will be safely transported.
- The 'battery repurposer' would be the new manufacturer, therefore he will have to comply with all applicable standards and requirements.

One standard for battery reuse that is currently being developed is the SAE J2997, which defines key aspects related to battery SOH, labelling and transportation aspect as criteria for determining the safety of reuse. Additionally, Underwriters Laboratories (UL) is working on a first edition of the Standard for Evaluation for Repurposing Batteries (ANSI/CAN/UL 1974), which covers a sorting and grading process of battery pack, module, cell and electrochemical capacitors (by SOH determination) that were designed and used for other applications (European Commission. Joint Research Centre., 2018). Nonetheless, some available automotive lithium-ion battery standards, such as ISO 12405-2:2012 and IEC 62660-2, could be effective to construct the new standards for second-life batteries. Nonetheless, safety is meant to be the major concern in SLB standards.

First life batteries are manufactured complying with several standards related to key aspects like transportation, safety, and electromagnetic compatibility. The following battery standards could be listed since they are commonly reported in commercial lithium-ion battery products:

- **UN38.3. Standard requirements for lithium battery production.** It consists of tests and requirements for the safe packaging and shipment of lithium-ion batteries. It must be requested at cell and system level.
- **UL 1973. UL Standard for Safety Batteries for Use in Stationary and Motive Auxiliary Power Applications.** It is an equivalent standard to the previous.
- **UL 1642. UL Standard for Safety Lithium Batteries.** It must be requested at cell level.
- **IEC 62619. Safety requirements for secondary lithium cells and batteries, for use in industrial applications.** It is the standard for lithium-ion batteries for industrial applications by ensuring several failure scenario tests. It should be requested at module or system level.
- **IEC 61508. Functional Safety of Electrical/Electronic/Programmable Electronic Safety-related Systems.** It is the standard for functional safety of BMS. A highly valuable additional standard for batteries to be provided at system level.
- **IEC 61000. Electromagnetic compatibility (EMC).** Specifically, IEC 61000-6 which is related to residential, commercial, and light-industrial environments and IEC 61000-2 related to low voltage grid applicated devices. It should be requested at PCS and/or system level.

All in all, as stated, there is no SLB standard for product development yet. Nonetheless, some commonly provided first life standards have been indicated which, along with a rigorous module SOH check and assembling, have been proved to be enough for second-life applications.

3.2.4.2SLB product development methodologies

Another key aspect on safe SLB development is battery disassembling and SOH estimation methods. Two main processes can be applied for that nowadays: first, is based on direct use of the battery pack (without opening and module selection) and second, is based on pack opening and most suitable module selection (based on SOH). As can be guessed the first is a simple way that allows visual inspection and SOH measurement according to European Directive 2006/66/EC on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC, but it could require additional software and electronics. The second option allows a better second-life products by best module selection but on expense of a higher cost and complexity (Tolós, 2020) ("tuvsud-a-second-life-for-lithium-ion-batteriy-modules.pdf," 2019).

Additionally, there is a third option which is the most sophisticated possibility for battery disassembling and SLB product development which is selecting most suitable cells out of the previously selected modules. This solution is disregarded by industry and research due to the excessive complexity and effort required. Figure 23 shows the steps of the disassembly process.

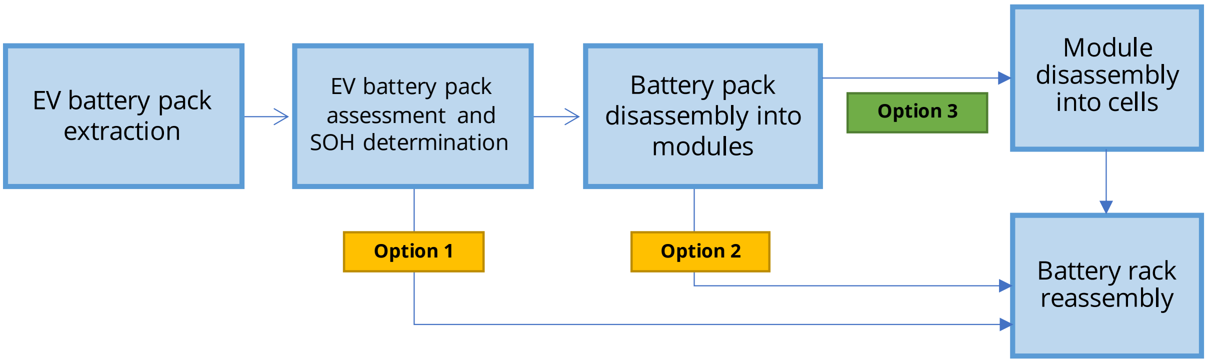


Figure 23. EV battery disassembling process.

3.2.4.3Technical SLB specifications

SLBs, in a similar way to first life batteries, do need to meet some technical characteristics and the manufacturer does have to provide some warranties to the end-user. This warranty aspect becomes even more critical on SLBs, first, due to the immaturity of these products and, second, due to the previous use that it has experimented. Table 4 shows some key specifications of SLBs that could be provided by manufacturers.

Many times, only part of the information shown in table below is publicly available or facilitated by battery manufacturers, which could be considered as a detailed datasheet. Nevertheless, many battery manufacturers provide some performance test results in table and graph formats that show further details on key aspects like degradation, TMS performance, efficiency and/or communications architecture. Nevertheless, this information generally entails an extra cost and must be requested.

3.2.4.4 SLB monitoring and control system specifications

Lithium-ion battery monitoring is done at different levels but with the overall goal of always maintaining system efficiency and safety. On the lowest level, the monitoring and control device in charge is the BMS. At the same time, different BMS monitoring levels are implemented in battery systems. As mentioned, batteries are made of cells, modules, and racks, respectively.

Table 4. Exemplary SLB technical specifications (detailed datasheet).

Item	Specification
Second-life battery origin	Example: Electric vehicle
Battery chemistry	Example: NMC, LFP...
System scalability	Example: N battery modules/ racks in series and/or parallel
Nominal energy	Example: 40 kWh
Nominal power	Example: 20 kW
Nominal capacity	Example: 200 Ah
Nominal voltage	Example: 200 V
Operating DC voltage range	Example: 160-240 V
Maximum current	Example: 300 A
Roundtrip efficiency	Example: 96 %
Response time	Example: 0.5-1.2 s
Maximum depth of discharge (DoD)	Example: 80 %
Cycle life (80% DoD, 25ºC)	Example: 2.500 cycles
Calendar life (50% SOC, 25ºC)	Example: 5 years
Dimensions	Example: 1.900×760×420 mm
Weight	Example: 540 kg
Operating temperature range	Example: 10-45 ºC
Maximum relative humidity	Example: 95 %
IP protection degree	Example: IP 54
Fire detection	Example: Smoke and heat sensor and sprinkled water fire suppression system
Protections	Example: Overcurrent, isolation monitoring, overvoltage, overtemperature
Cooling system type	Example: Forced air cooling
Control & monitoring	Example: HMI with local and remote access,
Communications	Example: TCP/IP, Modbus, CAN bus, RS-485
System warranty	Example: 2.000 cycles or 10% SOH by 3 years
Standards and regulations	Example: EMC: IEC 61000-2, IEC 61000-6 Safety: UN 38.3, IEC 62619 CE marking

Therefore, the BMS architecture follows a similar disposition. The following list shows the minimum parameters that should be monitored by the BMS at each level:

- **Cell level:** voltage and temperature. In any case, single cell voltage and temperature measurement is not always available (but recommended). These measures are collected with a very high resolution (some mV and < 1ºC) and sampling time for enhanced accuracy (few seconds).

- **Module level:** voltage, current, minimum, and maximum cell voltage in the module and temperature. Additionally, battery State of Charge (SOC) and State of Health (SOH) are estimated at a module level.
- **Rack level:** voltage and current.

Internally, these data are communicated by using different protocols like Modbus TCP, CAN or RS-485, mainly. Moreover, external communications with PCS, the grid and other elements are also carried out using protocols like Modbus TCP, MQTT or IEC 61850. Communications alternatives are shared lines (existing power or telephone lines), specific lines and wireless systems (WiFi, ZigBee, or Bluetooth).

Apart from monitoring, the BMS needs to implement other relevant functionalities like cell balancing to distribute evenly the energy among cells and modules which are key for SLBs since they are expected to be slightly imbalanced even after 1st life testing and classification. Moreover, very high data resolution and sampling rates lead to advanced BMS functionalities, development of data-driven models and prognosis capabilities which are key to optimize battery use and lifetime by sending and processing them in cloud-based systems.

Regarding interactions, the BMS interacts with many other systems like the EMS, the TMS, the power electronics and, in some cases, with the fire suppression system, as shown in Figure 24. From Figure 24, system control and monitoring is in charge of the highest-level system monitoring, which combines the overall supervisory control and data acquisition (SCADA) system and the EMS but may also include fire protection or alarm units. The EMS is the first layer of system level monitoring and control responsible for system power flow control, management, and distribution based on user pre-defined criteria and existing grid/market codes. It is a higher-level monitoring and control layer that interfaces the battery BMS and the grid or plant monitoring elements. Besides, in big battery systems, a system level thermal management is usually included to control all functions related to the heating, ventilation, and air-conditioning of the containment system.

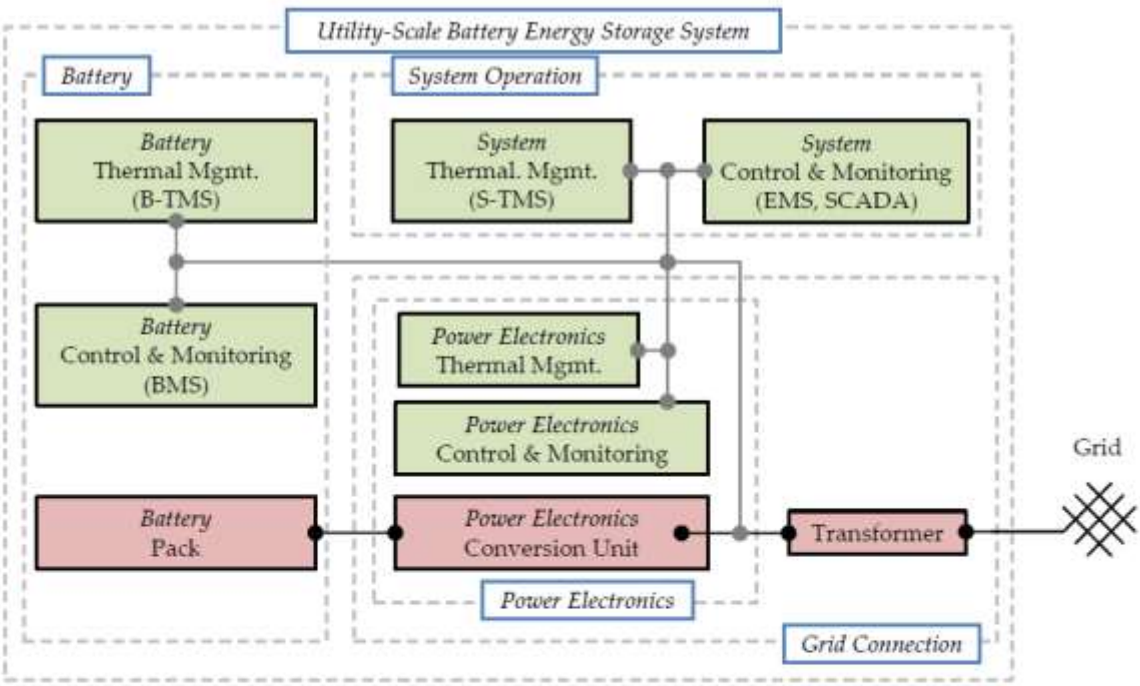


Figure 24. Functional monitoring and control systems and interaction with ESS elements (Hesse et al., 2017).

In lower scale systems two main alternatives for system monitoring and control do exist. On the one hand, Human Machine Interfaces (HMI) and, on the other hand, user applications. Nonetheless, in bigger scale systems remote control functionalities are envisaged to optimize and control system performance. These functionalities are further described above:

- User-friendly HMIs are very useful to teach end-users in a simple manner system performance ratio and logic in situ. Nevertheless, it is more interesting to have applications that allow consulting such information but in a remote manner.
- The two options mentioned simply receive and show system information in real-time, but do not allow interacting with it and send/receive commands to modify operation. For that, remote access and control systems should be implemented.

3.2.4.5SLB safety functionalities

SLB safety is usually referred to three main danger sources: thermal aspect, electrical aspects and chemical aspects. These are further detailed next:

- **Thermal aspects:** two main layers of safety measures are commonly implemented in batteries. The first is a preventive action related to system status monitoring and efficient management which is carried out through the interaction of BMS and TMS. The second is the fire suppression system which corresponds to a corrective action. These systems do also communicate with the BMS.

  Layer 1: The goal of thermal management is to avoid fire hazards that lead to system destruction and, potentially, to human damage like thermal runaway. TMSs are generally installed along with batteries to control system temperature. These systems are optimized and programmed to dissipate heat using different fluids and a set of logics that manipulate temperature setpoints and/or fluid flow rates. Figure 25 shows most common battery TMS configurations depending on the coolant fluid:
    - Air cooling: it is an established method, inexpensive to install and maintain, reliable and its uniform heat dissipation prevents temperature differentials. Passive cooling method is based on natural air convection and active cooling methods are based on conventional HVAC and fan systems.
    - Liquid cooling: these are based on water and/or refrigerants like glycol, have better cooling performance, but are often more expensive, complex, and susceptible to malfunction. For the moment, passive liquid cooling is being implemented in big-scale stationary applications.

  Layer 2: The goal of the fire suppression system is extinguishing a fire event to minimize its damage. This system is usually composed of different sensors that detect heat and or fog, alarm devices and fire extinguishing systems based on water or other chemical products, as shown in Figure 26. These elements are connected at the same time with the BMS which is in charge of taking the first steps on potential fire hazardous events.

- **Electrical aspects:** in batteries main electrical protection needs are overcurrent, ground faults, arc flash, and transient overvoltage issues. For that, different protections need to be installed at different levels of the battery. The following devices are usually installed (see Figure 27): current interrupt devices (CIDs), positive temperature coefficient (PTC) thermistors, current-limiting fuses, disconnection switches diodes and isolation measurement devices. Many times, these protections are centralized in the so-called Battery Protection Unit (BPU).

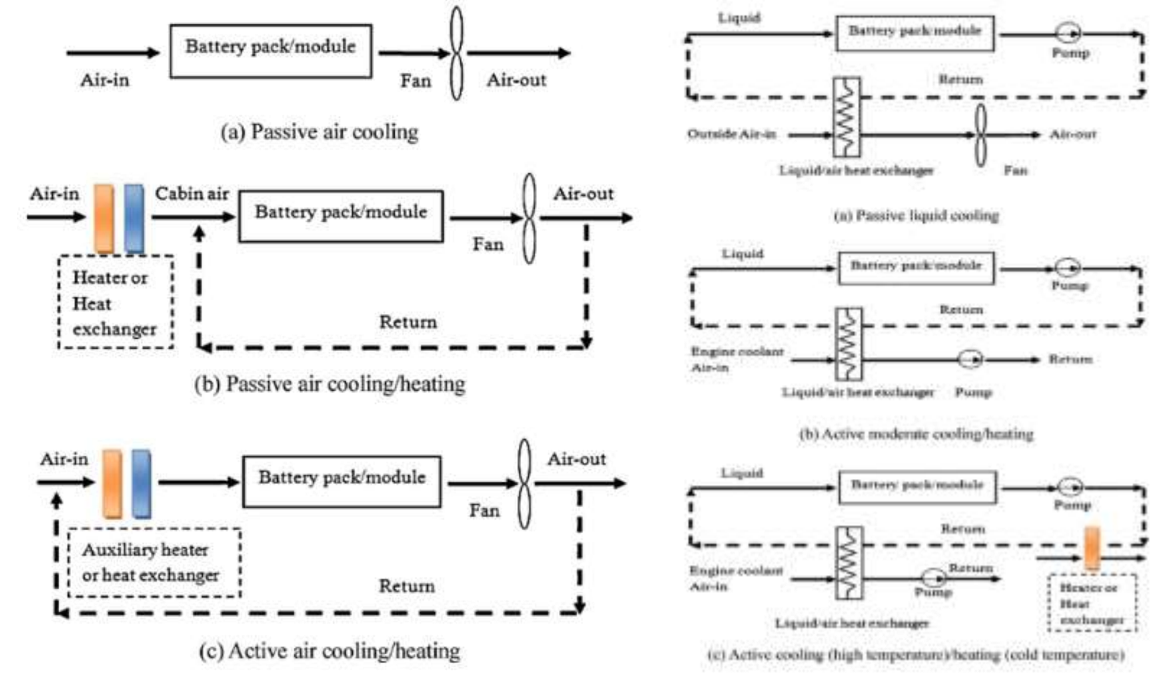


Figure 25. Stationary battery TMS configurations (Henke and Hailu, 2020).

Figure 26. Exemplary fire protection system for a lithium-ion battery (Mellon, 2022).

3.2.4.6SLB maintenance functionalities

Battery maintenance is a key performance in order to preserve a minimal loss of energy yield while avoiding premature degradation or damage. Two types of maintenance are commonly executed, i.e., preventive and corrective. These concepts are further detailed next (Arrinda et al., 2022):

- For corrective maintenance, periodical system element repairs are done when significant damage is caused to the battery. All these activities should be properly verified and documented by technical workforce. In any case, corrective maintenance should always be avoided by anticipated diagnosis using battery measurements and SOH indicators.
- Preventive maintenance consists of diagnosing the actual state of the battery and acting once some damage thresholds are overcome (but not critical). It is the most common maintenance type nowadays on lithium-ion batteries.
- Predictive maintenance is an increasingly interesting concept on batteries (currently, mostly in EV applications), and it consists of predicting failure before any real damage is inflicted. This is done by using recorded data that are recurrently analyzed using aging models and prognosis algorithms.

Some other maintenance aspects are listed below:

- Easy maintenance by means of module accessibility in case of single element failure is highly recommended. Specially in SLBs which usually require higher maintenance efforts.
- High battery monitoring functionalities lead to reduced maintenance needs due to constant status updating and (advanced) predictive maintenance realization.
- Environmental aspects like vegetation, dust and waste abatement should be considered.
- Avoid humid and/or corrosive environments.
- The battery systems should be located in an adequate place with limited accessibility (only authorized personnel) to avoid criminal acts like theft or vandalism. Besides, keep the battery away from children.
- Avoid high temperatures and solar exposure.
- Avoid exposing the battery to excessive shock or vibration.

3.2.4.7 SLB usability specifications

Some key features for SLB usability could be:

- High system modularity is key, especially in cases when system upgrades are projected.
- High environmental protection degree, particularly regarding tightness against dust and humidity.
- Adequate placement of the SLB to avoid overheating due to solar exposure. In this regard, thermal management systems are strongly recommended.
- If possible, try to avoid deep and fast cycling of the system, in order to extend battery lifetime.
- Easy installation and usage is a key feature for non-technical end-users. In this regard, plug & play solutions that include all abovementioned elements are a great option.
- Main inverter manufacturer compatibility required (most inverter manufacturers implement CAN bus protocols). In any case, incorporated inverter is an interesting option to avoid compatibility issues.

CIRCUIT PROTECTION PRODUCTS FOR BATTERY ENERGY STORAGE SYSTEMS

High-Speed Square Body Fuses

Energy storage customers require higher dc voltage rating, higher dc current rating, and higher interrupting rating fuses to protect batteries and dc circuits. The PSX and PSR square-body fuses deliver high-speed protection at an increased voltage and interrupting rating to help prevent costly catastrophic failures due to overcurrents. In addition, the small case size facilitates the design of more compact high-energy density systems. These semiconductor fuses will protect applications in energy storage and power conversion operations.

The PSX Series has a voltage rating of 1500 V dc and an interrupting rating of 250 kA dc.

The PSR Series has a voltage rating of 1000 V dc and an interrupting rating of 150 kA dc.

Arc-Flash Protection

Arc-flash relays quickly detect a developing arc flash by sending a trip signal to the circuit breaker, which reduces the total clearing time and any subsequent damage. They do this by providing an output that directly activates an electrical system circuit breaker, which cuts off the current flow to the arcing fault. The installation of an arc-flash relay reduces the total clearing time and the amount of energy that is released through an arcing fault which in turn helps limit damage to equipment and injuries to nearby personnel.

CNN 48 V Dc Fuses

CNN fuses are specifically designed for heavy loads associated with dc battery-powered equipment such as battery systems. Its compact size saves space and provides design flexibility. A window displays fuse status for added convenience.

Dc Disconnect Switches

The energy-efficient and compact dc disconnect switches quickly break or resume the flow of current safely to prevent shock hazards when trying to isolate circuits or repair systems. Available in various voltage and ampere ratings, they are applicable for energy storage systems, photovoltaic and uninterruptible power supplies (UPS).

ESR Battery Protection Fuses

The Energy Storage Rack (ESR) series of fuses is designed specifically to protect battery racks in energy storage systems, inverters, and many other dc applications. This 1500 V dc high-speed square body Class aBat partial range fuse is extremely fast-acting. It has superior short circuit protection and low minimum breaking capabilities (MBC) to cover a range of overcurrents that traditional high-speed partial range fuses do not protect against.

Ground-Fault Protection

A variety of factors can contribute to the development of ground faults. Even low-current ground faults can often go unrecognized and cause serious damage. BESSs are typically ungrounded systems and may remain in operation after the first ground fault, resulting in higher voltage on the unfaulted bus with reference to ground but with no current flow. However, subsequent ground faults on the opposite bus can have catastrophic consequences from both an equipment-protection and worker-safety perspective. Ungrounded, and even grounded BESSs, require ground-fault detection and protection to keep systems operating.

Surface Mount Fuses

The 501A series AECQ-compliant fuses and halogen-free fuse series are specifically designed to provide protection to cell monitoring within battery energy storage systems.

Surface Mount TVS Diodes

The TPSMC series of TVS Diodes is designed specifically to protect sensitive electronic equipment from voltage transients induced by lightning and other transient voltage events. Its small size and surface-mount form factor are ideally suited to protect battery sense lines from these events.

Surge Protective Devices

Surge protective devices (SPDs) provide battery energy storage system protection from transient overvoltage events lasting micro-seconds. By limiting the overvoltage to the equipment during these events, costly damage and downtime can be mitigated.

Temperature Sensors

Littelfuse offers a broad selection of Negative Temperature Coefficient (NTC) thermistors, Resistance Temperature Detectors (RTDs), as well as probes and assemblies, to meet the unique temperature sensing needs of your battery energy storage system at the cell and module levels.

TLS Compact Current-Limiting Fuses

The TLS series fuses are engineered to operate up to 170 V dc to provide current-limiting short-circuit protection for cables and components found in the dc power distribution circuits like modules found in battery energy storage systems. The compact design and multiple mounting configurations of the TLS series allow it to be used in a variety of applications.

UL Class T Fast-Acting Fuses

Space-saving Class T fuses are the most compact fuses available in ratings above 30 amperes. In fact, they are less than one-third the size of comparable Class R fuses. When rated in accordance with the NEC, Class T fuses provide fast-acting overload and short circuit protection for non-inductive circuits and equipment.

Figure 27. Main circuit protection elements for battery systems ("Littelfuse," 2023)

3.2.5 Usable EV batteries for solar self-consumption

In this application, SLB is paired with solar PV energy systems oriented to residential and productive uses. As already mentioned, required functionalities depend on system size (few kW or MW scale), its location mainly regarding environmental factors (will define IP grade), grid topology to be connected (AC or DC, 50 or 60 Hz, etc.) but also in the expected use of the energy. This last is the fact that will define the EMS that will need to be developed and/or integrated in the system. The following specific requirements are indicated:

- Battery system needs to be compatible with the specific inverter (single- or three-phase, output frequency, voltage ranges, communication protocols, etc.).
- Before installation, it must be checked whether if the battery can be wall mounted or directly placed on the floor, since many devices do not have mechanical connectors.
- On residential or commercial applications, remote applications for energy flow and battery status monitoring are key.
- In general, EMS strategies are based on solar PV maximization and battery systems include their own algorithms compatible for this application. In residential applications, local grid tariffs must be considered for system calibration and, in grid-scale applications, country grid and market codes.
- Nevertheless, smart batteries do require constant internet connection for remote monitoring, maintenance, firmware updating and app utilization.
- Ground connection must be independent to PV ground connection.
- The battery should have its own bidirectional meter to differ PV and battery power flows.
- Specific country grid code compliant technology is preferred in systems paired with PV and connected to the grid.
- Class A PV panels must be connected to the batteries. Grounded panels would derive in electrical isolation failure of the inverter.

3.2.6 Stationary batteries in electric charging infrastructure

In this application, SLB is paired with a charging infrastructure being a buffer system connected in parallel to the existing grid, i.e., the battery provides part, or all the power required for vehicle charging. Similarly, to solar paired system, required functionalities depend on system size, location, grid topology to be connected (AC or DC, 50 or 60 Hz, etc.) but also in the expected use of the energy. This last is the fact that will define the EMS that will need to be developed and/or integrated in the system. The following specific requirements are indicated:

- Battery system needs to be compatible with the specific inverter (single- or three-phase, output frequency, voltage ranges, communication protocols, etc.). In this case, special attention needs to be paid to charging infrastructure and EV on-board charger communication protocols in order to properly interoperate the system.
- In general, EMS strategies are based peak shaving (providing the extra charging power that the grid cannot provide) and battery systems include their own algorithms compatible for this application. For this, local grid codes and access capacity (peak grid power) need to be specified.
- Higher environmental degree is required for this application because the battery will likely be installed outside.
- The battery should have its own bidirectional meter to measure the power consumed from the grid (for its own re-charge) and the part provided for charging.

3.3 e-Mobility

3.3.1 Introduction

Electric mobility, also known as electro-mobility or e-mobility, refers to the use of electric vehicles and charging infrastructure. In Africa, electric mobility can have a positive impact on reducing greenhouse gas emissions, improving air quality, and promoting sustainable transportation.

The current section focuses on e-mobility opportunities and key requirements, especially for two- and three-wheeled electromobility, as the fastest electrification segments in Africa ("Power to move: Accelerating the electric transport transition in sub-Saharan Africa | McKinsey," 2021). Two- and three-wheelers are essentially electrified scooters and small vehicles.

Micromobility is also deployed, defined as small and lightweight (less than 500 kg) modes of transport with speeds less than 25 km/h, most of which are used individually, such as the use of bicycles, and with standing position, such as the use of scooters (Şengül and Mostofi, 2021).

These two alternatives present significant advantages in comparison to heavier vehicle options:

- Commercial use results in a higher average distance traveled per vehicle, which improves the Total Cost of Ownership (TCO) of the electric two-wheeler versus the ICE two-wheeler.
- Because electric two-wheelers have a small battery, they can be charged via a microgrid, making them suitable for use in locations with low access to grid.
- The "battery-swap model", which could be of high interest for the commercial fleets or e-moto drivers, in case of weak grid connections, see further detail in subsection 3.3.5.1.

Another e-mobility segment to be developed in Africa is the passenger cars segment for personal use. Its usage ranges from 20 to 40 km/day demand, most likely provided by overnight charge in household Mode 1 or 2 chargers ("Power to move: Accelerating the electric transport transition in sub-Saharan Africa | McKinsey," 2021). EV drivers will be in the center of a multi-agent ecosystem which will allow them many options regarding received or provided services (when smart or bidirectional charging), billing and pricing mechanisms and charging infrastructure access, all of which will be further detailed in the following sections.

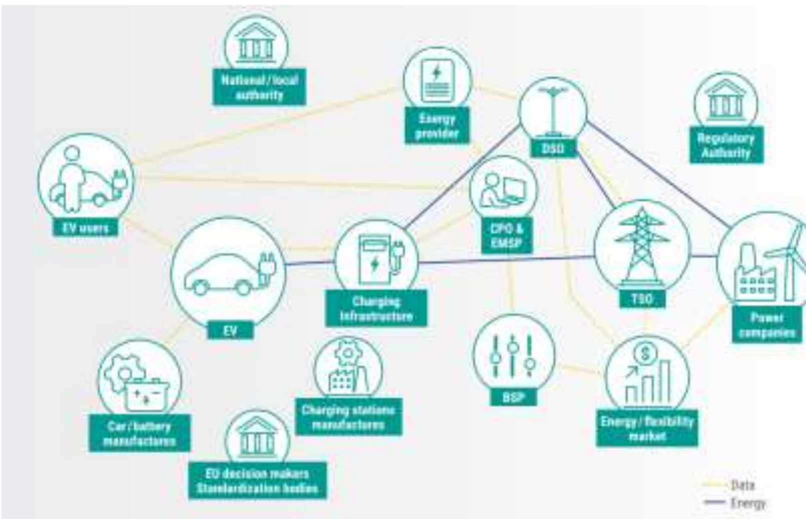


Figure 28. Data and energy interactions among e-mobility ecosystem actors ("ENTSO-E Position Paper on Electric Vehicle Integration into Power Grids," 2021).

E-mobility represents a powerful transformation tool for many of the targeted end-user groups, specially 2- and 3-wheelers Apart from enabling private transportation by acquiring e-mobility passenger service or owning electric vehicles, it can offer job opportunities for individuals and small companies.

E-mobility represents a powerful transformation tool for many of the targeted end-user groups, specially 2- and 3-wheelers in the short term. Apart from enabling individual transportation by means of acquiring e-mobility services or owning electric vehicles, it can offer job opportunities for individuals and small companies. Within the SESA project, several potential e-mobility end-user groups have been identified (see Table 2). Each of these groups have specific characteristics and economic activities that will define the T&F requirements to be met:

- **Households (residential users) and rural communities** may take advantage of urban electric mobility, which provide a clean and cost-effective mode of transportation for people commuting within near towns and/or workplaces. Electric mobility can help reduce air pollution and traffic congestion, particularly in densely populated urban areas, as well as be an alternative to traditional modes of transportation in rural areas.
- **Small businesses, manufacturing companies and tertiary sector** operate commercial delivery vans, and other small vehicles for goods transportation, personnel transportation and for itself business activity. It can benefit from electric mobility to lower operating costs, reduce emissions, and contribute to corporate sustainability goals.
- **Municipalities and government facilities** may improve the quality of public transit services and foster electric minibuses, to be used for public transportation systems, offering a quieter, emissions-free alternative to traditional fossil fuel-powered vehicles.
- The **education sector** can introduce e-vehicles as part of their transportation fleets, promoting sustainable practices and educating students about clean transportation.
- The **health sector** can introduce e-vehicles for urgency activities.
- The **transport service companies** are the main targeted group of e-mobility. Companies for vehicle rental and car-sharing services can offer electric vehicles to customers, providing a sustainable and convenient option for short-term transportation needs. E-mobility drivers (i.e., motorcycle taxi drivers) can lease or be owners of an electric vehicle for their own activity. And finally, charging infrastructure providers or operators can provide charging services can cater to the needs of EV owners, in public or private spaces.

3.3.2 Estimated technology costs

Nowadays, there are no EV producing units in Africa and almost all vehicles are imported from Europe, America, or Asia. In fact, according to (G.K. Ayetor et al., 2023), the cost parity of owning an EV for five years compared to an internal combustion engine vehicle is only achieved in 4/18 African countries that have been analysed (Seychelles, Morocco, Mauritius and Egypt), which means that the cost per driven mile in the rest of the countries is yet more expensive for electric cars. A different scenario is reported when comparing plug-in hybrid EVs, where 13/18 reached the cost parity.

Regarding 2- and 3-wheelers, reduced fuel costs of electromobility devices give them an advantage respect to combustion-based wheelers despite of the higher upfront costs ($1700-1800 vs $1300 in Kenya) ("Power to move: Accelerating the electric transport transition in sub-Saharan Africa |

McKinsey," 2022). (Godwin Kafui Ayetor et al., 2023) reported the difference in annual operational costs for six African countries (Ghana, Mauritius, Rwanda, Kenya, South Africa, and Egypt).

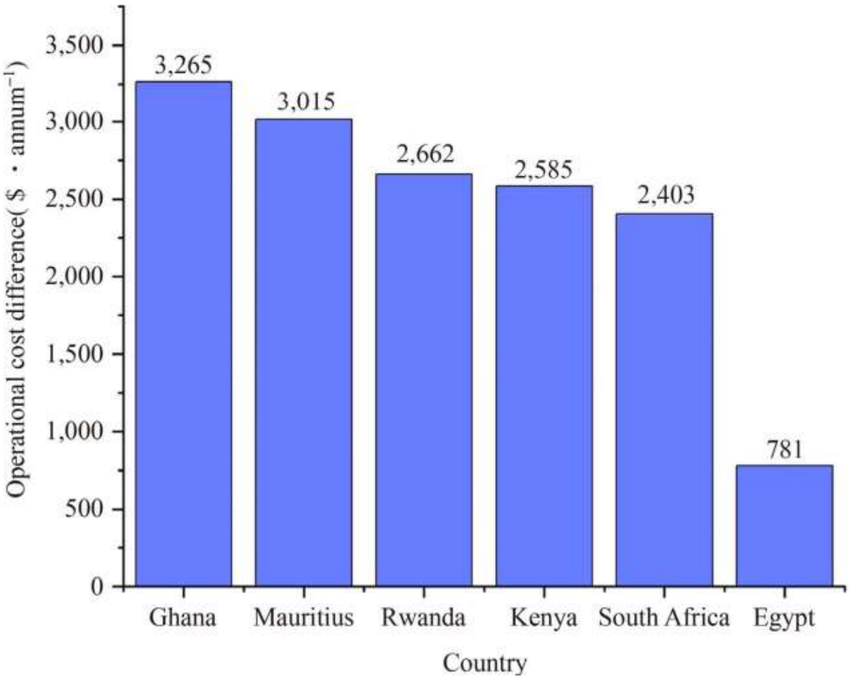


Figure 29. Operational cost differences of electric and combustion scooters in Africa (Godwin Kafui Ayetor et al., 2023).

3.3.2.1 E-mobility standardization requirements

Manufacturers of battery-powered products like micromobility devices need to ensure that they integrate certified batteries safely into their products while also taking deliberate steps to ensure that their end products meet known safety standard requirements. Currently, there exist some North American standards developed by UL Solutions that provide a comprehensive suite of testing and certification services for micromobility devices ("UL Solutions, 2022."):

- **UL 2849, the Standard for Electrical Systems for eBikes.** The standard covers electric bicycles, both pedal assisted, and non-pedal assisted.
- **UL 2272, the Standard for Electrical Systems for Personal E-Mobility Devices.** The standard covers consumer mobility devices intended for a single rider with a rechargeable electric drive train that balances and propels the rider, and which may be provided with a handle for grasping while riding (hoverboards, e-skateboards and e-scooters).

Such standards consider a range of topics that require specific tests to develop a safe solution: safety, EMC wireless, radio performance, battery safety, global market access, functional safety, and energy efficiency. Some of these are international but the specific aspects have not been internationally adapted yet. For instance, EMS, safety, and battery safety regulations applied to e-bikes and e-scooters have their equivalents in an IEC standard but specific standards for product development and efficiency are not in place yet. Nonetheless, existing European or North American standards can be useful guidelines for African standard development. Figure 31 and Figure 30 show the specific requirements for the European Union and North America, respectively.

European Union requirements

	E-Bikes	E-Scooters and other micromobility devices
Safety	EN 15194 for e-bikes is the only specific standard that has been published. At this time EN 15194 does not cover the necessary safety of electrical systems utilizing battery packs in the same manner of how UL 2849 covers this subject.	EN 60335-1 is a generic standard commonly used for hoverboards. This standard does not cover the necessary safety of electrical systems utilizing battery packs in the same manner as UL 2272 covers this subject. Hoverboards, e-Skateboards, e-Uniwheels and other forms for personal e-mobility are covered by this standard.
Battery safety	EN15194:2017 standard for eBikes specifically refers to IEC/EN62133 and EN 50604-1 standards for battery safety. IEC/EN62133:2017 covers saftey for secondary Cells and Batteries Containing Alkaline or Other Non-Acid Electrolytes – Safety Requirements for Portable Sealed Secondary Cells, and for Batteries Made from them, for Use in Portable Applications EN 50604-1- this standard covers secondary lithium batteries for light electric vehicle (LEV) applications	
EMC	EN 15194 - ANNEX C Contains the EMC emission and immunity requirements for EPAC and ESA devices	EMC Directive (2014/30/EU) Most common applicable standards: • EN 55014-1 or EN61000-6-3 • EN 55014-2 or EN61000-6-1 • EN 61000-3-3 • EN 61000-3-2
Wireless	RE-Directive 2014/53/EU (RED) Depending on the wireless technology, different standards can be used: • For WIFI EN 301 489-1/17 + EN 300 328 • For BLUETOOTH EN 301 489-1/17 + EN 300 328 • For SRD EN 301 489-1/3 + EN 300 220-2	
Global Market Access	Requirements for micromobility devices vary depending on target country. Please contact UL team for more information.	
Energy Efficiency	ErP Directive manadatory requirements, covering battery charging systems (eBike+battery+charger) and chargers. Example standard EN 50563.	ErP Directive manadatory requirements, covering battery charging systems (micromobility end-product+battery+charger) and chargers. Example standard EN 50563.

Figure 30. European Union requirements for e-bikes, e-scooters and other micromobility devices ("Guide to micromobility, UL Solutions, 2020.").

North America requirements

	E-Bikes	E-Scooters and other micromobility devices
Safety	**UL 2849 Electrical Systems for eBikes** The standard covers electric bicycles, both pedal assisted and non-pedal assisted. An eBike is defined as a two or three wheeled electrical/mechanical device provided with functional pedals that includes one or more electric motors to either assist the rider when pedaling (EPAC versions) or provide motive power to the wheels when the rider is not pedaling. • UL 2849 is bi-national accredited consensus Standard for USA and Canada. • As a minimum, the electrical system consists of the drive unit [electric motor], battery, battery management system (BMS), interconnecting wiring, and power inlet. Any additional components or systems required to demonstrate compliance are included based on the overall system application and risk.	**UL 2272 Electrical Systems of Personal E-Mobility Devices** The Standard covers consumer mobility devices intended for a single rider with a rechargeable electric drive train that balances and propels the rider, and which may be provided with a handle for grasping while riding. This device may or may not be self-balancing. This Standard covers micromobility devices not intended for use on roadways, such as hoverboards, e-skateboards, e-scooters. • UL 2272 is bi-national accredited consensus Standard for USAand Canada. • From 1 January, 2021 only UL 2272 certified electric scooters will be allowed in Singapore. Hoverboards, e-Skateboards, e-Uniwheels and other forms for personal e-mobility are covered by this standard.
Battery safety	**UL 2271 Batteries for Use in Light Electric Vehicle (LEV) Applications** This standard covers requirements for electrical energy storage assemblies (EESAs) such as battery packs and combination battery pack-electrochemical capacitor assemblies and the subassembly/modules that make up these assemblies for use in light electric-powered vehicles (LEVs) as defined in this standard. UL 2271 is bi-national accredited consensus Standard for USA and Canada.	
EMC	• US EMC requirements set by FCC. Typically FCC Part 15B unintentional radiators requirements • CANADA EMC requirements set by ISED Canada. Typically ICES-003 unintentional radiators requirements	
Wireless	US wireless requirements set by FCC. Typically FCC Part 15C, intentional radiators requirements. • For 2.4GHz WIFI FCC part 15.247 • For Bluetooth FCC part 15.247 • For SRD typically FCC part 15.231/15.247 CANADA wireless requirements set by ISED Canada. Typically RSS intentional radiators requirements • For 2.4GHZ WIFI RSS-247 • For Bluetooth RSS-247 • For SRD typically RSS-210	
Global Market Access	Requirements for micromobility devices vary depending on target country. Please contact UL team for more information.	
Energy Efficiency	DoE and CEC (Department of Energy and California Energy Commision) US and NRCan Canada manadatory requirements covering battery charging systems (micromobility end-product+battery+charger) and chargers. Tetsing at accredited lab required and additionally, for NRCan only , certification required. Energy efficiency testing includes a range of specific tests and assessments intended to evaluate various design features and use considerations of a given product. Energy efficiency testing typically includes: 1. Charge mode and battery maintenance mode test 2. Battery discharge energy test 3. Standby mode energy consumption test 4. Off mode energy consumption test	

Figure 31. North American requirements for e-bikes, e-scooters and other micromobility devices ("Guide to micromobility, UL Solutions, 2020.").

3.3.3 Summary of e-mobility functionalities

The following diagram aims to classify the main functionalities of e-mobility per level of novelty and relevance in African living labs. Each functionality will be described henceforth.

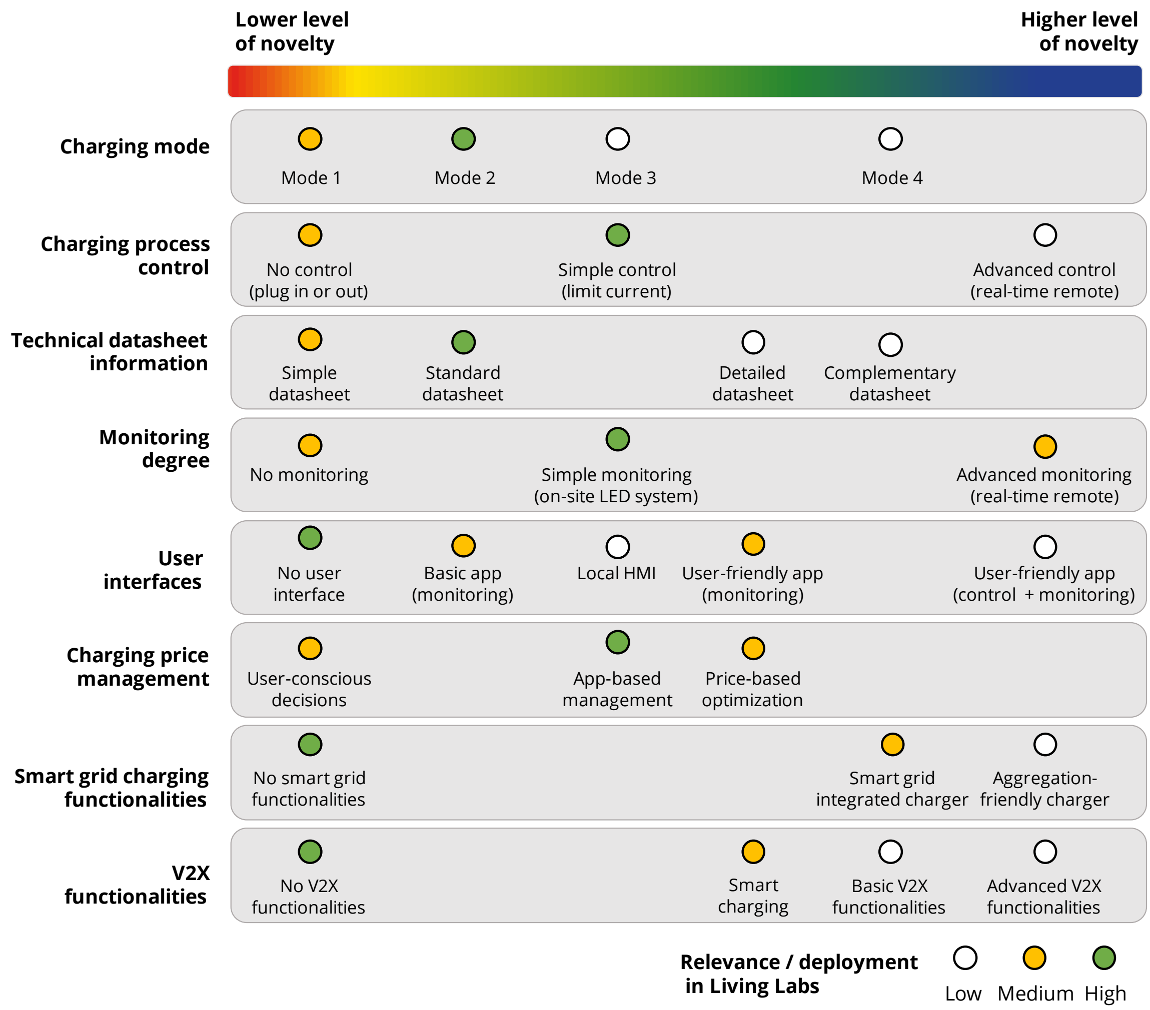


Figure 32. Classification of e-mobility functionalities from lower to higher degree of novelty (from left to right) and relevance/deployment (low -white-, medium -yellow-, and high -green-) in African Living Labs.

3.3.4 Description of e-mobility functionalities

3.3.4.1 E-mobility battery requirements

As to electrical scooters, the following battery requirements are highlighted (ERRA, 2021):

- Only a single traction battery pack may be installed in a motorcycle (generally of the same electrochemical battery type). This battery pack must be made from commercially available cells or modules must be used.
- The maximum power output and energy storage capacity are unlimited by some regulations.

- On standard motorcycles, the battery pack, motor, motor controller and the interconnections themselves cannot be modified to increase power or to allow the battery pack to operate at unsafe temperatures.
- For prototype motorcycles, the maximum voltage present anywhere on the vehicle must not exceed 1500 Vdc or 1000 Vac.
- The battery pack must be appropriately fused to prevent overcurrent in the event of a short circuit.
- Any prototype motorcycle with an HV battery pack must be capable of being isolated from the rest of the tractive system by at least two independent systems, for example by using contactors.
- The battery pack must be installed within, or integral to, the main structure of the motorcycle. IP44 must be met by the battery pack enclosure.
- Enclosures must be designed to retain all cells and modules in the event of a reasonably foreseeable crash.
- The enclosure containing the cells must also contain the BMS voltage and temperature sensing elements associated with the cells, manual service disconnection, fuses and contactors or similar safety and control equipment.
- A battery pack may use any cooling strategy including air, liquid, oil or dielectric fluid cooling provided appropriate engineering practices.

3.3.4.2E-mobility motor requirements

As to electrical scooters, the following motor requirements are highlighted:

- Any number of motors and motor controllers is allowed in any configuration for any purpose.
- Motorcycles may be driven by any wheel or combination of wheels.
- Only motors and motor controllers built to a recognized safety standard are permitted. Custom-built or modified motors and inverters may be allowed but documentation of good engineering practice must be provided.
- If the motor or motor controller is liquid cooled, its coolant must be specified.
- All motor and motor controller connections that use bolted HV terminals must be fitted with terminal covers that are sealed to satisfy the requirements of IP44 or higher.
- Under normal conditions, the motorcycle must be able to freewheel in forward and reverse directions when turned off and de-energized.

3.3.4.3E-mobility safety requirements

As to electrical scooters, the following safety requirements are highlighted:

- All motorcycles must be equipped with at least 1 emergency stop switch. In addition, all motorcycles must be equipped with a lanyard switch, located on the handlebars.
- Any auxiliary low voltage (12 V) battery and auxiliary loads must be appropriately fused and isolated.
- All motorcycles must be fitted with a Vehicle Status Indicator Light (VSIL).

3.3.4.4E-mobility charging requirements

As to electrical scooters, the following motor requirements are highlighted:

- Standard motorcycles must use the unmodified on-board charger, charge port and charging cables supplied with the vehicle or approved for use by the vehicle manufacturer.
- Prototype motorcycles must use a charging system compliant with a recognized charging standard.
- Off-board chargers must be commercially available and meet all local electrical safety requirements.
- Charging of the battery pack must be done with the battery pack in-situ. In exceptional circumstance discretionary exceptions may be made for vehicles designed with easily removable battery pack systems where you can demonstrate and prove the safety of their system.
- It is prohibited for any work to be carried out on the motorcycle whilst any traction battery is charging or charging equipment is connected to the vehicle.
- The use of fossil-fuel generators to provide the energy to charge motorcycles is strongly discouraged.

3.3.5 Description of charging infrastructure functionalities

3.3.5.1 Battery swapping station functionalities

Battery swapping is a technology based on replacing the used or completely drained battery with a fully charged battery (Hemavathi and Shinisha, 2022). Several advantages can be attached to this technology, for instance, promoting large-scale EV adoption, reducing charging-related wait-times or providing the possibility of acting as energy reservoir during grid emergency events (Arora et al., 2021). Nonetheless, several challenges need to be faced for battery swapping deployment. Mainly regarding interoperability since battery packs and its components are not standardized and regulation (to the date only Kenya is working on battery-swapping regulation in Africa).

At an international level, two main standards dictate battery swapping technology development of up to 1000 Vac or 1500 Vdc:

- IEC 62480-1 (2016), Electric vehicle battery swap system Part 1: General and Guidance.
- IEC 62480-2 (2016), Electric vehicle battery swap system Part 2: Safety Requirements.
- IEC 62480-3 (2021), Electric vehicle battery swap system Part 3: Particular safety and interoperability requirements for battery swap systems operating with removable RESS/ battery systems.

Battery swapping can be classified according to two aspects: first, according to the position of the battery and, second, according to the swapping method. Depending on the position of the battery, swapping can be side, top, bottom or rear swapping which will vary according to the vehicle. Depending on the swapping methodology, manual and automated battery swapping can be distinguished. In manual swapping the driver is in charge of the swapping process. On the contrary, in automated swapping batteries are swapped out using a robotic arm (Mwangi, 2018).

Kenyan battery swapping regulation introduces some key functionalities regarding both, battery and swapping station safety and technical specifications. The following ones are summarized (Mwangi, 2018):

- Only advanced chemistry cells are supported.
- Compatibility between batteries and other components for swapping must be provided by battery providers.

- BMS-enabled batteries are only supported for efficient battery monitoring, data analysis, and safety.
- Additional features regarding battery pack dimensions, charging connectors and other relevant components would be developed to enhance interoperability. Countries like Thailand already do have specific standards regarding these design aspects.
- Batteries must be tested and certified according to AIS 156 (2020) and AIS 038 Rev 2 (2020) standards. Additionally, some coupling and decoupling tests need to be performed to verify adequate swapping capabilities of the connections and packs.
- Electrical interface is a key matter in battery swapping to avoid electrical shocking during manual extractions. For that, rigorous dielectric breakdown, arc phenomenon and temperature rise tests must be performed.

Battery swapping stations are the facilities where battery coupling, and decoupling occur. Moreover, this is where empty batteries need to be re-charged. Therefore, energy transfer between grid, batteries and swapping station is given. This can facilitate extended battery lifetimes since battery swapping station has the possibility to charge batteries with lower voltage compared to rapid charging stations. A simplified representation of the battery swapping ecosystem is shown in Figure 33.

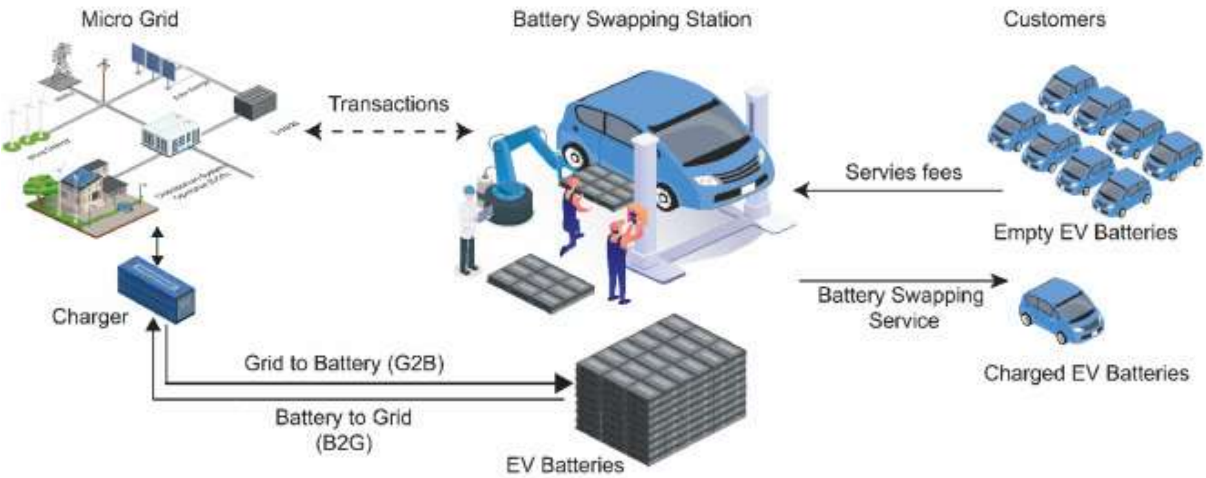


Figure 33. Battery swapping ecosystem representation (Lebrouhi et al., 2021).

The following key functionalities of battery swapping stations are highlighted:

- Data management and cloud storage capabilities.
- Adapted communication interfaces and constant communication flow between batteries, information systems and the station.
- Users should be aware of swapping station location, availability, and real-time pricing, ideally, using a mobile app.
- And, on the contrary, the swapping station should be able to access vehicle speed, location, availability, and payment service for good service provision.
- At all swap stations, the battery charger is plugged direct to the standard AC mains outlet (50Hz, 220-240Vac).
- Tailored battery handling systems to safely transfer equipment within the facility.
- Well-designed battery storing systems to safely store batteries.
- When automated systems, supervisory and control systems are required.
- When EV or heavy-duty battery swapping stations, lane systems are needed to collocate vehicles for the extraction process.

- The charging stations should provide interoperable alternatives for payment, for instance, using RFID cards.
- Swapping stations would have to be connected to off-grid systems like solar PV generators.

3.3.5.2 Charging infrastructure standardization requirements

Charging infrastructure is a multi-agent ecosystem where different communication standards coexist. Actors like EV drivers, charging point operators, e-mobility service providers and DSOs interact between them following the standard protocols depicted in Figure 34:

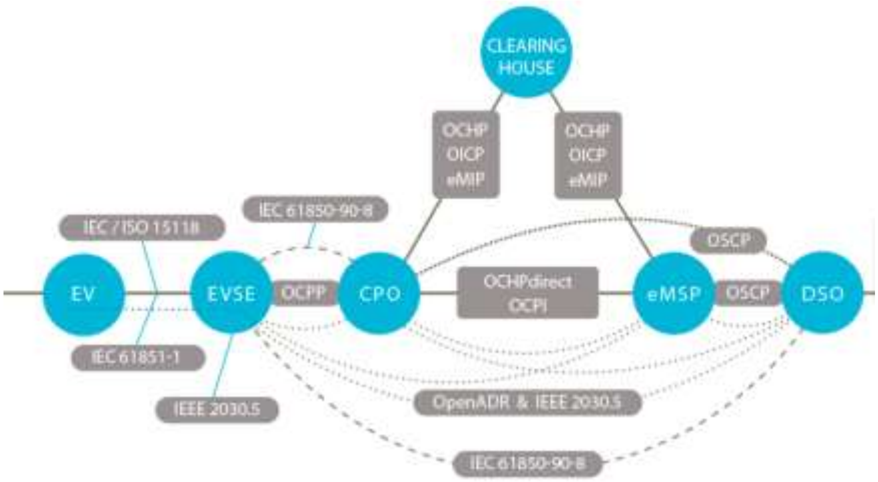


Figure 34. Global view of the main actors and communication protocols considered in mobility (Elaadnl, 2017)

Moreover, each of the individual components that are part of the ecosystem are ruled by their own IEC and/or ISO standards. In this regard, EV batteries, charging points and household and/or distribution grid elements' standards must be considered (see Figure 35).

Figure 35. IEC standards for EV charging stations (Rajendran et al., 2021).

3.3.5.3Support and configuration of different charging modes

According to the IEC 61851-1 Committee on “Electric vehicle conductive charging systems”, four main modes of EV charging coexist in Europe. These modes are categorized according to the required charging power ranging from conventional household AC plugs (Mode 1) to ultrafast dedicated DC chargers (Mode 4). Figure 36 shows these modes and describes their main features:

- **Mode 1** is an EV charger fed from a conventional 230 Vac household plug. These has no protection circuit interfacing between plug and vehicle; hence it is considered as a potentially unsafe option. This is mode is typically the one used for micromobility and is implemented in all e-motorbikes, but not anymore for electric cars.
- **Mode 2** is also a charger fed from a conventional household plug, but it has a control and protection device implemented in the charging cable (IC- CPD – In-Cable Control and Protection Device) which makes this mode much safer than the previous one. Nevertheless, it is usually limited to the maximum rating current of the household plug, and it could be possible not to reach the 3.7 kW and the 7.4 kW for industrial applications. This mode ranges between the named normal charge (6-10h for a 21 kWh battery) and the semi-fast charge (3-4h for a 21 kWh battery) (“A decarbonized transport model for Spain in 2050, Deloitte,” 2017). This option is available for all cars but for few e-motorbikes.
- **Mode 3** is a dedicated charging point that usually ranges between 3.8 and 22 kW. Like the previous one, it includes its own protections and control, and it is usually a wall-mounted device that looks like a small PV inverter. As to charging power, the fast-charging option should be mentioned, which is around 45 kW and is implemented in public chargers connected to the distribution grid.
- **Mode 4** is a high-power DC charging system where the EV on-board charger is by-passed, and the charger directly feeds the battery. In this mode, super-fast (100-150 kW, 20 min) and ultra-fast (150-350 kW, 5-10 min) charging is included. Nonetheless, this last is mostly experimental to the moment (“A decarbonized transport model for Spain in 2050, Deloitte,” 2017).

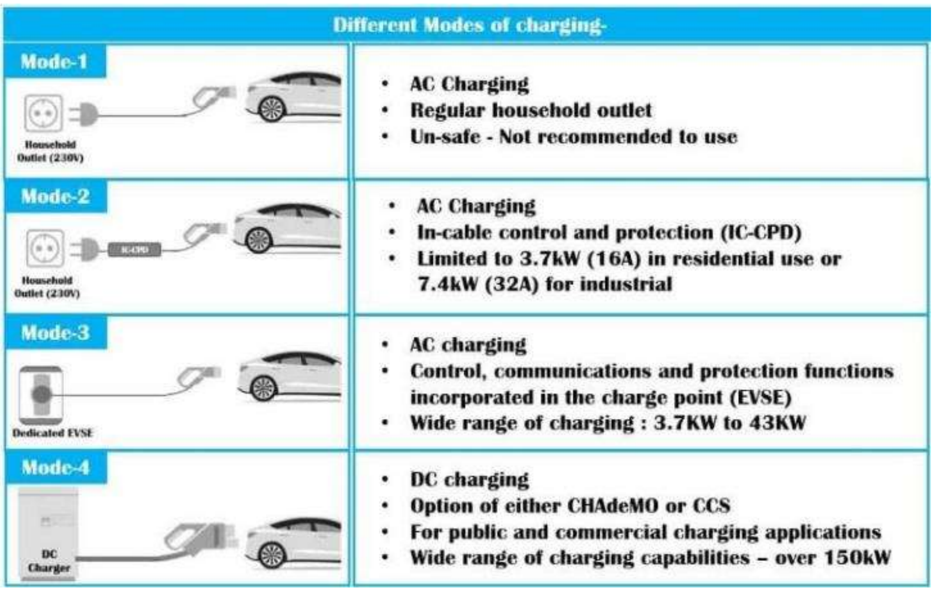


Figure 36. Main modes for EV charging (“Connector types for EV charging around the world,” 2022).

As to connector types, different standardized solutions exist nowadays. These are mainly categorized either on AC or DC connectors and, among these, different options exist depending on the country and its grid infrastructure. The main alternatives are presented in the following bullet points:

- **Type 1 – J1772** is the standard AC connector in Asia and North America. It is a single-phase connector, and it is based on the SAE J1772/2009 communications protocol.
- **Type 2 or Mennekes** is the standard AC connector in Europe. It can be either single- or three-phase and it is also based on the J1772.
- **CHAdeMO** is the standard DC connector in Japan. This follows IEC 61851-23 standard and is valid for ultra-fast charging systems.
- **CCS – Type 1 is** the standard DC connector in America. This is valid for ultra-fast charging systems up to 350 Kw because it is an extension of the IEC 62196 Type 1 connector, with two additional direct current (DC) contacts to allow high-power DC fast charging.
- **CCS – Type 2 is** the standard DC connector in Europe. This is a combination between CCS and Type 2 connector and is also valid for ultra-fast charging systems up to 350 kW.

The mentioned charging ports and connectors are summarized in Figure 37:

Figure 37. Charging ports and connectors (Das et al., 2020a).

All in all, as to charging modes, in Table 5 the main technical aspects should be considered for adequate charging infrastructure selection are depicted:

Table 5. Example of EV charging system specifications.

Item	Specification
Charging mode	Example: Mode 1
Nominal charging power	Example: 2.3 kW
Minimum charging power	Example: 1.2 kW
Maximum charging power	Example: 3.7 kW
Type of grid	AC or DC, 1- or 3-phase
Grid frequency	50 or 60 Hz
Maximum rated plug current	Example: 16 A
Nominal plug/grid voltage	Example: 230 V
Connector type	Example: Type 2 – Mennekes
Charger efficiency	Example: 95 %
Communications protocol	Example: SAE J1772
Weight	Example: 2 kg
Dimensions	Example: 260x192x113 mm
IP protection degree	Example: IP 54
Protections	Example: Overcurrent, isolation monitoring, overvoltage, overtemperature
User interface	Example: user app
Connectivity	Example: WiFi, Ethernet…
Standards and regulations	Example: IEC 61851-1, IEC 61851-22, IEC 62196-2, CE marking

3.3.5.4Control of the charging process

Charging process control aims to adapt available electrical power, user needs and/or vehicle capabilities to get the best charging process. Depending on the charging mode, control functionalities range widely, as described below:

- **Mode 1** charge has no control functionalities other than plugging in or out the vehicle.
- **Mode 2** incorporates a simplified charging control based on limiting the charging current which is set to a specific value. When such rated current is exceeded, the charging process is stopped automatically.
- **Modes 3 and 4** include real-time remote-control capabilities of key features like charging power-current, charging start and end time and/or desired electricity price.

Additionally, this control varies depending on the dimensions of the charging station. For instance, for fleet charging, specific control functionalities like power sharing among vehicles can also be implemented. This power share can be a simple even distribution among vehicles, which would not require constant real-time measurement. But also, dynamic power sharing capabilities could be implemented which would adjust charging power of each vehicle according to their real-time status.

3.3.5.5 Monitoring of the status of the charging process

Monitoring status varies widely depending on the charging mode and charger type implemented. The higher the charging power and mode, the more sophisticated that will be monitoring functionalities associated to the charger. Mode 1 charging infrastructure incorporates no monitoring functions of the charging process. Therefore, variables like the current or the SOC of the battery would have to be checked directly from the plugged vehicle.

Mode 2 plugs do show the charging status of the vehicle with some LED lighting implemented in the cable which, generally, use the traffic lights logic. Commonly shown parameters are charging power, ON/OFF status, and temperature and fault alarms.

Many modes 3 and 4 chargers include real-time monitoring of the charging infrastructure. In this case, not a simple status monitoring is carried out, but detailed electrical variables are supervised. Additionally, in many cases real-time statistics are created with monitored data. Main monitored variables are:

- **Electrical variables** like Charging current (A), voltage (V) and power (W) values. These parameters can be manually or automatically adjusted depending on local grid or household restrictions. For automatic parameter adjustment, a specific EMS is necessary.
- **Status notifications** like end of charging, pre-defined beginning of charge, software updates and others.

3.3.5.6 Processing of monitoring data

Monitoring data processing varies depending on the charging control architecture implemented. Two main charging control architectures are applied nowadays: centralized control and decentralized or distributed control (Das et al., 2020a).

Centralized charging systems acquire information from EVs, process them centrally and provide a global optimal solution considering all grid and user constraints. Therefore, the central processor acts as a master and sends all commands to each EV or slave.

In decentralized or distributed control architectures each user defines its EV's charging parameters, and all monitored data and charging preferences are processed and set locally. In this case, the user selects charge and pricing values.

3.3.5.7 Integration to remote management systems

In general, two key actors arise in the EV charging scenario: 1) the Charge Point Operator (CPO), a company operating a pool of charging points and 2) the e-Mobility Service Provider (eMSP), a company trat provides access to its customers (EV drivers basically) by providing access to several charging points around a specific geographic area.

These two roles can be separated or concentrated in a single agent. Their main responsibilities are the following ("Current state of electric vehicle charging in Spain, FUTURED," 2022):

- **eMSP:** its main duty is to engage EV drivers as customers by providing them with access to different services in charging points:
  - Offers a charging service to EV drivers.

- Provides EV drivers with a variety of charging points around a geographic area.
- With this service, drivers can identify available charging stations and different paying methods are offered. Typically, eMSPs only serve registered customers, but they can also provide services to non-registered users.
- In conjunction with the service provided by a CPO, an eMSP focuses on giving access to the charging stations that belong to their company.
- Additionally, eMSPs may be interested in providing access to third-party charging points through roaming. In this case, the companies that offer these freight services usually have an existing and extensive customer base.

- **CPO:** They manage their own or third-party charging infrastructure.
  - A CPO operates a set of charging points and ensures that the charging network runs smoothly.
  - The CPO adds value by connecting smart charging devices to an eMSP.
  - The CPO oversees the diagnosis, maintenance and charging price for each charging station.
  - As a separate service, CPOs rely on other eMSPs to provide EV drivers with access to their charging stations. This is enabled through roaming networks. Even if the CPO's company also offers the services of an eMSP, they may want to enable other customers of other eMSPs to access their charging points.

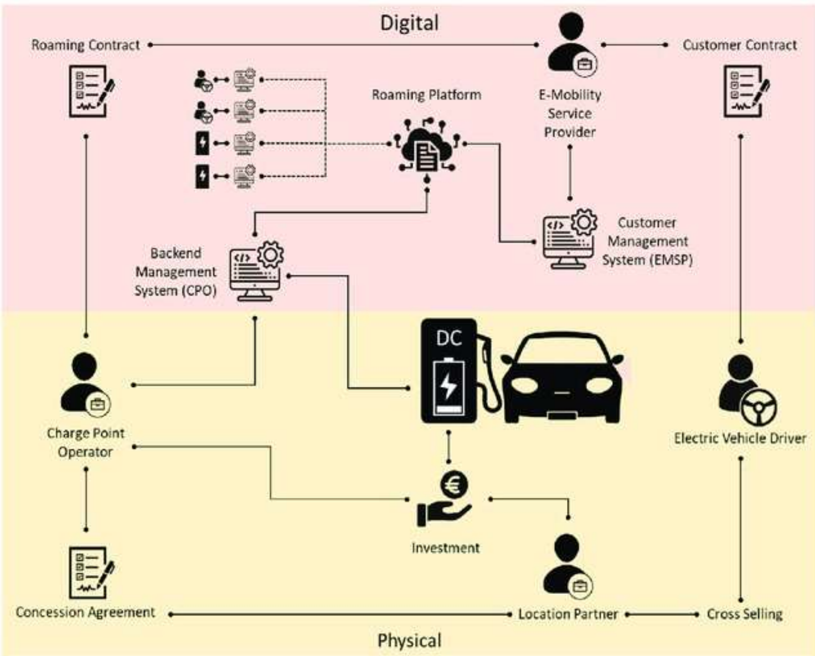


Figure 38. Actors involved in electric vehicle (EV) charging processes (Röckle and Schulz, 2021).

3.3.5.8Charging prices management

Like monitoring and control functionalities, charging price management options vary depending on the charging mode, but also on the exploitation method of the charging point. For private chargers, Modes 1 and 2 basically rely on user-conscious decisions, meaning that it must be the own user the one who plugs in and/or out the vehicle in order to manage the charging pricing. Modes 3 and 4 include more sophisticated price management options which are functionalities provided by their app or web portals. These are usually fixed user-defined charging times based on price estimations provided by the own app or web portal. A more advanced option which should be carried out by a higher-level EMS is an adaptative charging process that adapts charging time frames dynamically to minimize the charging costs considering also user requirements or restrictions.

Public chargers usually are based on fixed price tariffs related to the company in charge of operating such charging point. Nonetheless, a more innovative option is available where different eMSPs offer their prices/tariffs for the same charging point. In this case, the user is the one in charge of deciding the tariff and charging timeframe. These solutions are closely related to pay-as-you-go pricing mechanisms. These basically allow users pay based on their consumption by using easy-to-use online-based payment methods and selecting different tariffs. On the contrary, subscription-based payment alternatives can be utilized in public charging. These are based on a monthly subscription fee over a fixed term that allow easy charging for users and upfront cost reductions for CPOs.

Another business case that is widely extended is the e-mobility leasing which is based on paying for the real use of the vehicle on a monthly rental basis. It consists of a monthly fee plus a utilization fee that sets a price per kilometer and a monthly kilometer limitation.

Once selected the pricing management mechanism and executed the charging process, the billing needs to be carried out. This can be done in several formats, for instance, in domestic charge a very common option is linking it directly to the electricity bill. Another option is to link the billing to the contract established with the EV manufacturer as an additional service. Nowadays, the most extended billing method is credit card payment along with other digital payment options provided by eMSP (Röckle and Schulz, 2021).

3.3.5.9 Charging roaming

eMSP can provide access to third-party charging stations by using roaming networks (like telephone roaming). It is a cloud-based platform that matches CPOs, eMSPs and EV drivers (see Figure 38). It acts as a marketplace where different charging services can be offered within the same physical infrastructure. EV drivers of a single eMSP can access to many other points of different CPOs, while these can enlarge their business without having to upgrade their charging point network.

3.3.5.10 Interaction with the customers applications

Customer-side interaction functionalities depend widely on the charging mode and charger type implemented. Mode 1 chargers usually don’t include customer applications that monitor and set charging parameters; therefore, the EV would act as a conventional load. Similarly, Mode 2 chargers do not include user applications, but a higher degree of monitoring compared to Mode 1 is provided. For higher power charging modes, it is very common to have chargers with tailor-made customer applications that enable charging control and monitoring.

For instance, wall-mounted devices (Mode 3 chargers) do include user applications that allow instantaneous communication and monitoring via Wi-Fi. Besides the application it is common to have a web portal where you can also configure, monitor, and manage remotely the charge. These two should have the following functionalities:

- Real time data availability of key variables like charging power and time, electricity costs and a set of alarms to notify inappropriate operation situations.
- Real time charging parameter configuration to modify charging status, power or current.

- Charging time and period definition according to user preferences like low electricity prices or pre-defined fixed charging period.
- Additionally, charging process reports could be generated and downloaded.
- These must be user-friendly tools, easily accessible by the user in any place and moment by using any electronic device.

3.3.5.11 Integrated line protection system (LPS) features

The initial objective of line protection solutions is to protect the general power supply line against possible surges produced by the set of charging infrastructures included in an installation ("Current state of electric vehicle charging in Spain, FUTURED," 2022). In this way, the LPS solutions will allow and execute a fixed or dynamic regulation of power on the charging points, so, affecting to the charging process.

To be considered as a LPS solution, the charging infrastructure must communicate in real time via Ethernet, Wi-Fi or other wireless technologies (ZigBee, Z-wave or Lora). This communication makes possible the real time identification of the power consumed by each charging point as well as, compulsorily, the excess available power on the grid connection point which has previously been dimensioned so that the LPS regulates the independent charging points circuit charges. By this, enhanced safety of the dimensioned grid connection point is guaranteed.

The main features of a LP or DLM (Dynamic Load Management) systems would be the following:

- Protect the sizing of the building's general power supply line. Avoid power cuts by avoiding exceeding the contracted power in the installation.
- Energy measurement to read the consumption of the general power supply line in real time, an essential element to control power availability in real time and adjust the consumption of electric vehicles.
- Automatic detection of a fully charged vehicle to optimize the available power in real time to what the vehicles may need.
- Detection of single-phase, two-phase or three-phase vehicles to adjust each need and optimize the electrical consumption of EVs.
- Special functionalities focused on vehicle fleets.
- Prioritization of charging by plug/connector. Each priority plug will be charged using the maximum possible supply with the possibility of establishing time slots for priority and non-priority plugs.

LPSs are defined in the UNE 0048 standard and, in turn, are referenced in the different collective trunk schemes detailed in each country's low voltage regulations (for instance, in Spain in the ITC BT 52).

3.3.5.12 Smart grid charging features

Smart charging implies the charging process to be managed in a coordinated way accordingly to the conditions of the available energy sources (main grid with the DSO, local energy sources or both), the charging services providers (CPO and eMSP) and user requirements.

That EV charging smart management allows the provision of several services like ("ENTSO-E Position Paper on Electric Vehicle Integration into Power Grids," 2021):

- **Reshaping the Power Load Curve in the charging system connection to the grid:** The EV charging process can be shifted from peak (e.g., evening hours) to off-peak hours to avoid the need for additional (marginal and therefore more expensive) power capacity during the peaks.
- **Ancillary Services for Transmission and Distribution Grid Operation:** EVs could modulate their charging profile (or even the generated power in the V2G scheme) and participate in reserve markets (where in place), providing frequency-response reserve and replacement reserves.
- **Management of Grid Congestions:** EVs can be used as distributed resource to reduce the risk of transmission grid congestions, so to minimize sub-optimal "re-dispatching".

So, the effect of smart charging and V2G on the EV load curve is quite relevant, as shown in the next Figure 39, allowing to modulate it according to the need of the different actors involved (EV users/customers, DSO, TSO, retailers, aggregators…). The figure shows the case of Belgium and clearly depicts these effects, highlighting the impressive regulation capacity which can be offered by EVs. In a scenario with a great amount of EVs, this effect is clearly multiplicative and considerable.

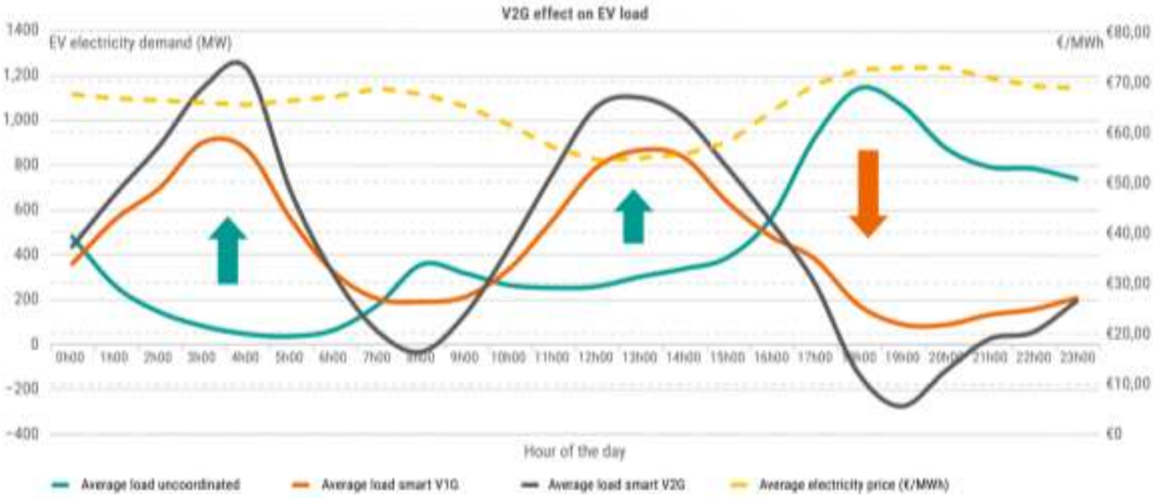


Figure 39. Uncoordinated EV load, load smart and V2G smart charging, i.e., in Belgium 2030 EV penetration scenario ("ENTSO-E Position Paper on Electric Vehicle Integration into Power Grids," 2021).

3.3.5.13 Integration with other local energy resources

In order to avoid over-generation and curtailment of green energy, coordinating optimally EV charging infrastructure demand could be a feasible solution. EVs can schedule their charging process to match and hence maximize renewable generation exploitation. For instance, to align wind generation (commonly in excess during nighttime) and night charging, no special measures are required. On the contrary, to align excess PV production and EV charging user habits should be modified by means of economic incentives.

In order to adapt EV charging with local energy production, the following basic functionalities are required:

- Battery parameters would have to be adjustable as close as possible to real-time while respecting driver requirements. For this, monitoring and control devices need to be adapted to modify their status according to renewables variability.

- A high-level EMS is needed for coordinating local energy production with EV consumption.

3.3.5.14 Vehicle to everything (V2X) features

V2G a technology domain in the e-mobility framework that enables the energy stored in a battery of an EV to be pushed back to the power grid. Therefore, the battery can be charged and discharged based on different signals allowing the EV to behave, both, as an energy generator or as a manageable load.

V2G could be considered an emerging technology with already available hardware providers compatible with V2G for charging power around 10kW in DC. However, at present the V2G domain is still a business at project stage hoping to be a feasible and profitable option in the medium-term. As to standardization, the new European ISO 15118-20 standard (Road vehicles — Vehicle to grid communication interface), released in 2021 aims to accelerate this V2G commercial adoption enabling bidirectional power transfer for multiple cars.

The bidirectionality of the energy flow is gearing the electric vehicle to other application where the vehicle is being used as an electricity source, specially:

- Vehicle to Load (V2L), where vehicle is designed with socket to feed other electric loads.
- Vehicle to Home (V2H), where the vehicle is used to power some home loads during a blackout or just some specific home appliances.
- Vehicle to Building (V2B]), like the previous V2H but feeding loads corresponding to the building level.
- Vehicle to Grid (V2G), in which the EV can discharge electricity directly to the grid. This option could allow, for instance, to sell renewable energy previously charged in the VE to the power grid or even supply electricity to your neighbors through the microgrid in case of a power disruption.
- Vehicle to Vehicle (V2V), where the two-way charging is designed to recharge other EVs.

3.3.5.15 Vehicle to Vehicle (V2V) features

As a general description, V2V charging is the capability to transfer power from an electric vehicle to charge another one. This power transfer requires the corresponding power electronics in both vehicles jointly an interconnection between them for the proper exchange of power.

That interconnection between vehicles is basically wired. Wireless energy exchange is already technologically possible but the majority of the wireless V2V charging are at research and demonstration levels and very far away from commercial applications. Besides, direct wired connections for charging between vehicles is more feasible but the required technology is nor widely available and basically at demonstration stage.

The present lack of standardization is also hampering the technical development and adoption of the V2V charging option. However, the traditional V2G charging infrastructure could be adapted to allow the transfer of energy between vehicles. That is the case of dynamic fleet charging configuration in which a charging hub of several charging points are interconnected to allow the exchange of energy between vehicles connected to charging point of the hub without getting energy for the main energy source that the charging hub could be connected to.

3.4 Improved biomass cookstoves: BioCookers

3.4.1 Introduction

The traditional use of biomass in household is associated with significant negative environmental and health effects because of indoor air pollution. To avoid these environmental and health effects, the burning of biomass must be made cleaner. Many parts of Africa do not have reliable electricity or infrastructure to deliver gas for LPG (Liquid Propane Gas) stoves. As biomass is expected to remain the dominant source of cooking heat in developing countries, a short and medium-term solution is to change to efficient utilization of biomass through improved and efficient cooking technologies. Improved biomass stoves, which burn more cleanly than traditional cookstoves, should be a suitable option.

An BioCooker, also known as a clean cookstove or improved biomass cookstove, is a cooking device designed to burn biomass fuels more efficiently and cleanly than traditional open fires or rudimentary stoves. The BioCooker utilizes traditional wood-based fuel (a variety of feedstock such as manure, crop residue, small sticks, crops, pellets, grass, firewood, etc.) to provide heat for cooking and produces biochar as a by-product.

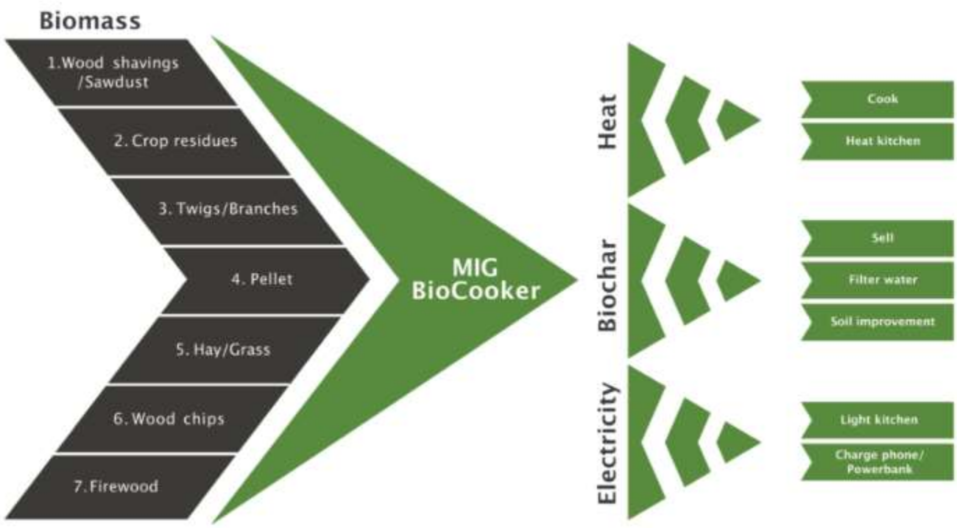


Figure 40. BioCooker feedstock and products. Source: *MiG|BioCooker* [1]

As products, the BioCooker produces heat to cook, and in a collateral way, it heats the ambient. BioCooker is a cooking method which reduces risks related to cooking smoke, dirty water. Additionally, it produces biochar, a valuable by-product, that can be sold, be used to filter water or soil fertilizer. Biochar is generated as a solid residue during the pyrolysis process, which occurs when no more gas is produced from the fuel, and the combustion phase, indicated by the yellow flames, disappears. The biochar thus obtained, is used as an affordable water purification system and enriching soil for agriculture. It provides an alternative and sustainable agriculture through

[1] MiG BioCooker - Make It Green in https://makeitgreen.net/biocooker/ [last access: 20/03/2023]

the use of biochar. The use of biochar for agriculture has been seen as an efficient means of carbon sequestration. Finally, BioCookers can also produce electricity for lighting or small devices.

BioCooker is a cooking method which reduces risks related to cooking smoke, dirty water. Biochar cookstoves are cost-effective and less time-consuming, while produce a low carbon footprint. From an environmental perspective, the BioCooker mitigates air-born soot, sequesters carbon, reduces deforestation in forest, and improve the soil structure and drought resistance.

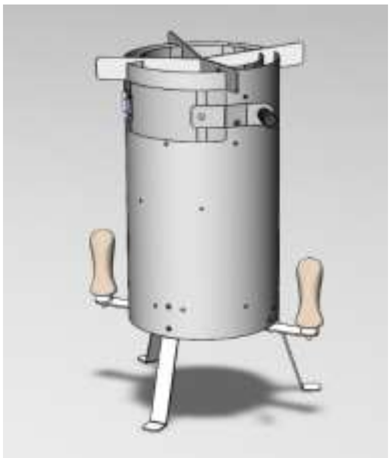


Figure 41. MIG BioCooker.

BioCookers are designed to be affordable especially in regions where clean cooking solutions are needed the most. Households and rural communities are the primary end-users of BioCookers in Africa, mainly women who are in charge of cooking.

BioCooker can provide clean cooking method, not limited to households, but also to public facilities, small business, and other specific economic activities. Generally, BioCookers are designed to be affordable for the target communities and users, especially in regions where clean cooking solutions are needed the most. Within the SESA project, several potential BioCooker end-user groups have been identified (see Table 2). Each of these groups have specific characteristics and economic activities that will define the T&F requirements to be met by BioCooker technology:

- **Households (residential users) and rural communities** are the primary end-users of BioCookers in Africa, especially those in rural areas and low-income communities. BioCookers can help reduce indoor air pollution, lower fuel consumption, and improve cooking efficiency, leading to better health outcomes, reduced deforestation, time savings for families, and reduce the exposure to harmful smoke, especially for women. The predominant cooking practices are cooking on three-stone open fires and/or cooking mostly on a traditional stove.
- **Small businesses, manufacturing companies and tertiary sector,** especially those who are specialized on food vendors, urban food stalls, and restaurants.
- The **agricultural sector** would be benefit from the greater use of BioCookers, those farmers whose by-products (biomass, crops residues) can be used as feedstock. They can sell these by-products, previously worthless, and obtain additional incomes. For example, a small-scale sunflower oil pressing plant can be interested. The sunflower production comes mainly from smallholders. This is due to the fact that sunflowers are an easily manageable crop that smallholders use to cycle and back up other crops such as maize.

From the sunflower production there will be biomass residues that can be briquetted and used as a potential fuel for the cooking stoves. The seeds are harvested by hand from April to May and. Usually, the stalks are left in the field and collected later to be used as fuel, but they can be collected during the harvest. The sunflower stalks can be briquetted and used as a fuel in the cooking stoves. It is preferable that briquettes be produced locally by the farmers to be sold and make an income.

- The **educational institutions** can utilize BioCooker in schools to provide nutritious meals to students, promoting better attendance and health among children.
- The **healthcare facilities** can also rely on BioCookers, to ensure a cleaner cooking environment and reducing health risks to patients.

3.4.2 Estimated technology costs

The cost of purchasing a new stove will remain a barrier for many households. A cooking stove can cost anything between US$2 to over US$100 per stove, depending on the technology used and thermal efficiency characteristics of the stove. According to Project Drawdown the average cost of an improved clean cookstove is US$45 (drawdown, 2021). A first estimation of material costs for the MIG BioCooker from Make It Green is around US$50. The investments for setting up the production are estimated to be of 904 €. The material cost is based on European prices and can decrease if it is locally produced. Efforts to find local solutions to decrease costs are ongoing.

Many cookstove initiatives in Africa have largely failed to reach scale. Among other issues, access to affordable finance is still an immense barrier. To overcome this difficulty, one potential business model is based on the BioCooker being sold on loan. For example, the household must pay a quarter of the stove price when taking the stove and sales agent will collect the remaining balance monthly. Still, this option will require households with greater purchasing power than those existing today or households with consistent cash flows and internal discussion are ongoing to better define the most suitable target group for the potential commercialization of the SESA cookstove.

Studies have shown that there are varying interests for taking on loans for cooking solutions. Those that purchase cookstoves, typically use cash. The most vulnerable households are unable to afford any type of cooking solution and will require subsidies. According to (Johnstone, 2020), "Public finance must boost demand for improved and 'cleaner' cookstoves by addressing the affordability gap in the poorest households (through price subsidies, concessional end-user financing, and other means. And it must increase supply to expand distribution channels), e.g., through grants, concessional finance, guarantee instruments, and patient capital to enterprises".

3.4.3 Summary of BioCooker functionalities

The below Figure 42 aims to classify the main functionalities of BioCookers per level of novelty and relevance in African Living Labs. Each functionality will be described henceforth.

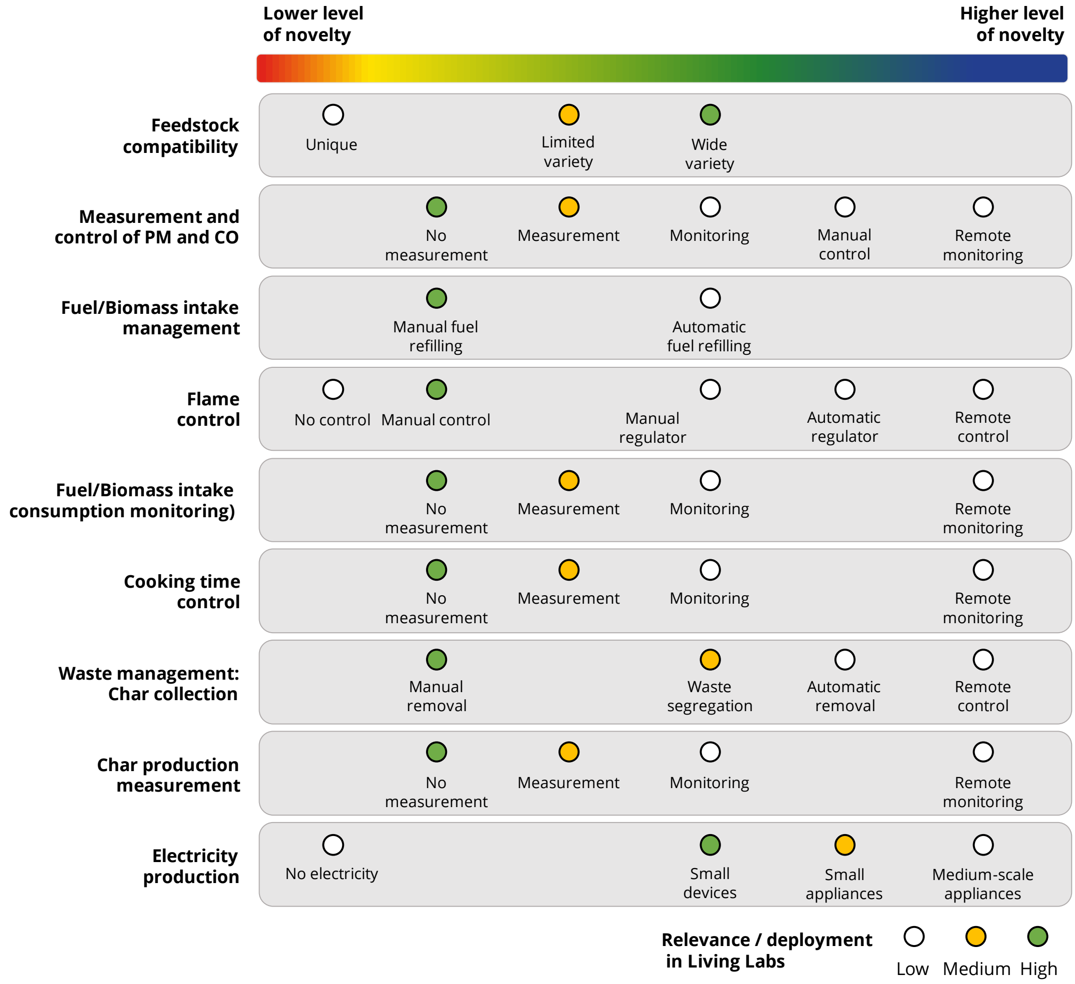


Figure 42. Classification of BioCooker functionalities from lower to higher degree of novelty (from left to right) and relevance/deployment (low -white-, medium -yellow-, and high -green-) in African Living Labs

3.4.4 Description of BioCooker functionalities

(ISO - ISO 19869-2019 - Clean Cookstoves and Clean Cooking Solutions — Field Testing Methods for Cookstoves, 2019)(ISO - ISO 19869-2019 - Clean Cookstoves and Clean Cooking Solutions — Field Testing Methods for Cookstoves, 2019) provides field testing methods to evaluate cooking system performance in real-world conditions. This document is intended to provide quantitative and qualitative measurements of cooking system performance. Requirements and guidance are provided for evaluation of **usage, usability, fuel consumption, energy consumption, power, emissions, safety, and durability**. These measurements include uncontrolled and controlled cooking tests. It provides guidance for measurements of household air pollution to PM2,5 and CO.

Table 6 presents testing bounds for cookstove to qualify as clean cooking technology, for 5 tiers (categories), from the most efficient and safer technology to the lowest. The cookers inside tier 5 are classified as clean cooking stoves. The lowest tier is based on the worst tested metrics.

Table 6. Testing bounds for cookstove to qualify as clean cooking technology. Source: ISO 19869:2019

Voluntary Performance Targets – Default Values					
ISO VPT Tier	Thermal efficiency (%)	COE missions (g/MJ)	$PM_{2.5}$ emissions (mg/MJ)	Safety (score)	Durability (score)
5	≥50	≤3.0	≤5	≥95	<10
4	≥40	≤4.4	≤62	≥86	<15
3	≥30	≤7.2	≤218	≥77	<20
2	≥20	≤11.5	≤481	≥68	<25
1	≥10	≤18.3	≤1031	≥60	<35
0	<10	>18.3	>1031	<60	>35

3.4.4.1 Feedstock compatibility

Several feedstocks from biomass can be used in the BioCooker, including wood shaving, sawdust, crop residues, twigs, branches, pellets, hay, grass, wood chips and firewood. Depending on the type of biomass used, the cooking process will be more efficient (i.e., firewood), more biochar will be produced, more heat will be produced to cook and electricity.

From lower to higher level of innovation or advance, this indicator can be classified as follows:

- Unique feedstock
- Limited variety of feedstock
- Wide variety of feedstock

3.4.4.2 Measurement and control of PM and CO

When burning any fuel unwanted emissions gets released into the surrounding air. These emissions apart from CO2 increase when incomplete combustion occur. These emissions have many side effects that affect both the human health and the environment. That is, stove design, fuel type, and operator usage impact on the BioCooker emissions.

Particulate matter (PM) is found in the air and is a mixture of solid particles and liquid droplets of a sufficiently small size to be suspended in air. Some particles are visible, this includes smoke, dust, dirt, and soot. Some can only be detected using an electron microscope. *Carbon monoxide* (CO) is formed when incomplete combustion of fuels occurs. It is a color and odorless gas.

From lower to higher level of innovation, this indicator can be classified as follows:

- No measurement: the emissions are not measured
- Measurement: the emissions are measured by sensors
- Monitoring: continuous measurement and data collection over the cooking processes
- Manual control: control, reduce or mitigate the emissions somehow.
- Remote measurement and/or monitoring: monitor emissions by using remote devices

In a field test (Ranung & Ruud, 2019), the BioCooker had the lowest concentrations of CO of all cooking methods. The tested BioCooker obtains a reduction of CO by 48.6% compared to three stone open fire. The CO concentration was 37±26 ppm for three stone open fire and 19±23 ppm for the tested BioCooker, when traditional dishes were prepared (Ugali and Sukuma Wiki) with firewood. The PM2.5 concentration was 17 780 ± 23 470 µg/m3 (equal to 15.5 ± 20 ppm) for three stone open fire and 2 490 ± 4 100 µg/m3 (equal to 2.2 ± 3.5 ppm) for the tested BioCooker. It obtains a reduction of PM2.5 by 86% compared to three stone open fire.

Precision refers to how close measurements of the same item are to each other. As can be observed, the measurement precision is extremely low, because despite the same dishes were prepared, the tests are replicate in several locations with multiple variable human and environmental conditions which influence the measurements.

3.4.4.3 Fuel/Biomass intake management

The higher opening of the stove is used for adding fuel and controlling the flame. The stove is designed for continuous feeding of fuel (in this context biomass) enabling it to cook meals for a long period of time. In contrast, the BioCooker enable to have a continuous refill of feedstock (i.e., firewood, corps, etc.) or another kind of biomass.

From lower to higher level of innovation, this indicator can be classified as follows:

- Manual fuel refilling: the fuel intake is done manually as continuous refill is required.
- Automatic fuel refilling: the fuel intake is done by an automated method somehow (i.e., feedstock storage or tank connected to the feed opening).

When considering the cooking process, the parameter of how much time the cook needs to spend keeping an eye on the fire needs to be considered. For the tested BioCooker, it was harder to leave it for more than five minutes or so because the stove needed refilling and the wooden pieces should be moved that the flame would not die.

3.4.4.4 Flame and combustion control

The higher opening of the stove is used for adding fuel and controlling the flame. It seems to be easy to regulate the flame and heat. As presented previously, the stove needed refilling and the wooden pieces should be moved that the flame would not die. Ignition of the stove takes place directly in the combustion space and from above, which allows for an almost smoke-free start to the fire when proper control measures are employed.

From lower to higher level of innovation, this indicator can be classified as follows:

- No control: the strength of the flame cannot be controlled
- Manual control: the strength of the flame can be controlled manually (i.e., stirring biomass)
- Manual flame regulator: the strength of the flame is regulated manually (i.e., gauge with a circular scale to regulate the strength of the flame)
- Automatic flame control: the flame can be regulated via a digital gauge or a fan. The fan should be used early in the process to ensure smoke-free combustion during the cooking.
- Remote flame control: the flame can be regulated remotely (i.e., digital device)

Regarding automatic flame control, the BioCooker may have a built-in fan for enhanced combustion. The fan can be powered by a solar-charged power bank, ensuring a sustainable energy source. The main function of the fan is to supply sufficient air to achieve cleaner combustion, especially when dealing with agriculture crop residues such as sunflower stalks, readily available close to the households in the local area. Electronic parts such as the fan should be easily replaceable once they reach the end of their lifespan.

3.4.4.5 Fuel/Biomass intake consumption monitoring

Gross fuel consumption is amount of fuel used during the whole cooking process. This indicator is calculated using a large pile of firewood or other kind of feedstock that was measured before the start of cooking. At the end of cooking the remaining firewood in the pile and the withdrawn fuel from the stove was weighed and subtracted from the weight of the large pile.

Net fuel consumption assumes that the char will be used as fuel and that the char has close to the same heating capacity as the firewood. When calculating net fuel consumption, the difference between gross fuel consumption and char produced is calculated.

From lower to higher level of innovation, this indicator can be classified as follows:

- No measurement: the fuel/biomass intake consumption is not measured
- Measurement: the fuel/biomass intake consumption is measured by sensors (i.e., weight)
- Monitoring: continuous measurement and data collection over the cooking processes
- Remote measurement and/or monitoring: monitor consumption by using remote devices

In a field test (Ranung & Ruud, 2019), the tested BioCooker has a fuel consumption of 1.07 ± 0.25 kg of firewood, when traditional dishes were prepared (Ugali and Sukuma Wiki).

3.4.4.6 Cooking time control

When the cooking time is measured two parameters are usually taken into account. *Time to light* was calculated from the moment the cook set fire to some of the lighting materials to the moment when the fire was considered well lit. *Time to cook* was the time between when the first pot was put on the stove and when the last pot was removed from the stove.

From lower to higher level of innovation, this indicator can be classified as follows:

- No measurement: the cooking time is not measured
- Measured: the cooking time is measured for a given cooking
- Monitoring: continuous measurement and data collection over the cooking processes
- Remote monitoring: monitor and data analytics (i.e., for different dishes, location, environmental data, etc.) of cooking time by using remote devices

The mean time was 03:02±00:37 for three stone open fire and 03:26±00:25 for the tested BioCooker, when traditional dishes were prepared (Ugali and Sukuma Wiki). The three stone open fire took significantly less time to cook both meals, because it produces more uncontrolled stronger flames. Nevertheless, improved BioCookers within SESA project aim to achieve by 55% reduction in cooking time compared to open fires. Water boiling tests indicate that 1 liter of water could be boiled in approximately 7,5 minutes.

3.4.4.7 Waste management: Char collection

The lower opening of the stove is for collecting char. The char is easy to remove. If the chamber becomes full of char the lower hatch can be opened to remove it while in use.

From lower to higher level of innovation, this indicator can be classified as follows:

- Manual removal: the removal of char is done manually when the chamber becomes full
- Waste segregation: any method to separate different kind of waste (i.e., ash and char)
- Automatic removal: the removal of char is done by means of any automated method
- Remote control: the removal of the char should be ordered remotely

In a field test (Ranung & Ruud, 2019), a suggestion raised for waste management. During the lighting process, since they often put in a lot of lighting material like small twigs, paper and leaves the tested BioCooker becomes full of ash before you put in the main firewood. To prevent the ash to affect the burning of the wood and to separate it from the char they suggested a mesh in the bottom of the stove where the ash could fall through.

3.4.4.8 Char production measurement

The net char production is the amount of solid material that remains after light gases (e.g., coal gas) and other volatiles have been released from a carbonaceous material during the combustion. *Char production* [%] is calculated by dividing the amount of net char produced by the amount of gross fuel consumption.

From lower to higher level of innovation, this indicator can be classified as follows:

- No measurement: the char production is not measured
- Measurement: the char production is measured by sensors (i.e., weight)
- Monitoring: continuous measurement and data collection over the cooking processes
- Remote measurement and/or monitoring: monitor char production by remote devices

In a field test (Ranung & Ruud, 2019), the tested BioCooker has a char produced of around 200 g of firewood, when traditional dishes were prepared (Ugali and Sukuma Wiki). Char production was the highest in the BioCooker compared to other cooking methods.

The percentage (by weight) of char produced from firewood is around 18 ± 5 % for the different tests made in field, when traditional dishes were prepared (Ugali and Sukuma Wiki) with the tested BioCooker. For the same scenario, the percentage (by weight) of char produced from firewood is around 12 ± 2 % with the three stone open fire. The BioCooker had a significantly higher char percentage than the three stone open fire according to the paired sample sign test.

3.4.4.9 Electricity production

A solar-biomass hybrid cooking device can be designed to combust biomass fuels more efficiently and cleaner, acting the fan, than traditional open fires or rudimentary stoves. The BioCooker itself can also produce electricity for small devices (i.e., lighting the room, charge a phone, etc.), through the combustion process. It can be provided in kWh per gross fuel consumption.

The electricity is generated using thermoelectric coolers which operate based on the Peltier effect (see Deliverable 4.2). This effect creates a temperature difference by transferring heat between two electrical junctions. When the current flows through these junctions, one junction expels heat while the other cools, generating electric power.

Additionally, a power bank can also be installed and used later for lighting or recharging a mobile phone, though a USB connector. With the existence of a power bank (a small energy storage system), it is also possible to extract electricity from the battery even when the stove is turned off.A solar-biomass hybrid cooking device can be designed to combust biomass fuels more efficiently and cleaner, acting the fan, than traditional open fires or rudimentary stoves. The power bank as well as the solar panel can be mounted permanently on the cooking stove for easier handling.

3.4.4.10 Durability/maintenance

The durability is the ability of a cookstove to continue to be operated for an extended period safely and with minimal loss of performance under conditions typical of those found in the target community. The maintenance procedure can be classified as corrective, preventive and predictive.

3.5 Biodigesters

3.5.1 Introduction

A biodigester consists of an airtight, high-density polyethylene container within which organic waste materials are diluted in water flow and are fermented by microorganisms. The biodigester is an anaerobic digestion system (it takes place without oxygen) that uses microorganisms to break down organic waste materials such as plant or animal waste, food scraps, and other organic matter to produce biogas (a mixture of methane and carbon dioxide) and organic fertilizer.

In addition to the biogas, rich fertilizer is produced, which contains macro and micronutrients. The biogas can be used as a renewable energy source for cooking, heating, or generating electricity, while the fertilizer can be used to improve soil health and crop yields. Biodigesters are considered a sustainable solution to waste management and renewable energy production.

At small scale, a home biodigester is a standalone system that transforms the organic waste (food scraps) into gas that can be used for cooking or also creating a liquid soil fertilizer. However, this kind of solution is out of the scope of this report. This subsection is focused on an anaerobic digester, addressing their functional requirements and showing the potential innovative uses.

Anaerobic digestion (AD) is the degradation and stabilization process of organic compounds by microorganisms in the absence of molecular oxygen leading to production of biogas. Moreover, anaerobic digestion generates a digestate that can be used as an organic amendment for agricultural purposes. At the same time, this technology permits the management of organic waste that would otherwise go to landfill.

A cheap digester design option is a tubular biogas plant, which consists of a longitudinal shaped heat-sealed, weather resistant plastic or rubber bag. The gas is stored in the upper part of the balloon, being the inlet and outlet attached directly to the skin of the balloon. The main inconvenient is the fragility of the plastic balloon which is susceptible to mechanical damage and has a relatively short life span of 2-5 years.

The anaerobic decomposition of organic matter occurs in a four-step process as presented in Figure 43 and described in the following sections:

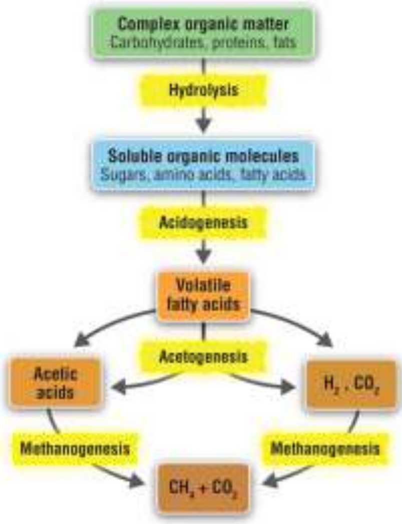


Figure 43. Schematic biodegradation steps of complex organic matter[2]

Hydrolysis is the first step and is usually the slowest of the four degradation steps. The bacteria transform complex organic materials (proteins, carbohydrates and lipids) into liquefied monomers and polymers (amino acids, monosaccharides and fatty acids).

Acidogenesis is the second stage, where acidogenic bacteria convert the soluble organic monomers of sugars and amino acids to ethanol and volatile fatty acids and H2 and CO2.

In the third stage acetogenesis, both long chain fatty acids and volatile fatty acids and alcohols are transformed into hydrogen, carbon dioxide and acetic acid.

Methanogenesis is the final stage, methanogenic bacteria convert hydrogen and acetic acid to methane gas and carbon dioxide. Methanogenesis is affected by conditions in the reactor such as temperature, feed composition and organic loading rate. Moreover, high concentrations of ammonia can inhibit the methane production.

The anaerobic digester can be coupled to a bioelectrochemical system (AD-BES). It is a technology that employs microorganisms to convert chemical energy into electrical energy or vice versa. These systems typically consist of an anode (where an oxidation occurs) and a cathode (where a reduction occurs).

The anode is inoculated with microorganisms that oxidize organic matter and release electrons, which then pass through an external circuit to the cathode. At the cathode, oxygen or another electron acceptor is reduced through a reaction that consumes electrons and generates a current.

The bioelectrochemical system (BES) might cover microbial fuel cell (MFC), microbial electrolysis cell (MEC), microbial desalination cell (MDC), microbial electrosynthesis (MES). The integrated AD-BES system shows potential for versatile applications (Wang et al., 2022), including AD effluent polishing, biogas upgrading, biosensor, and nutrient recovery, as depicted below.

[2] https://www.biocycle.net/managing-digester-feedstocks/ last access: 22/03/2023

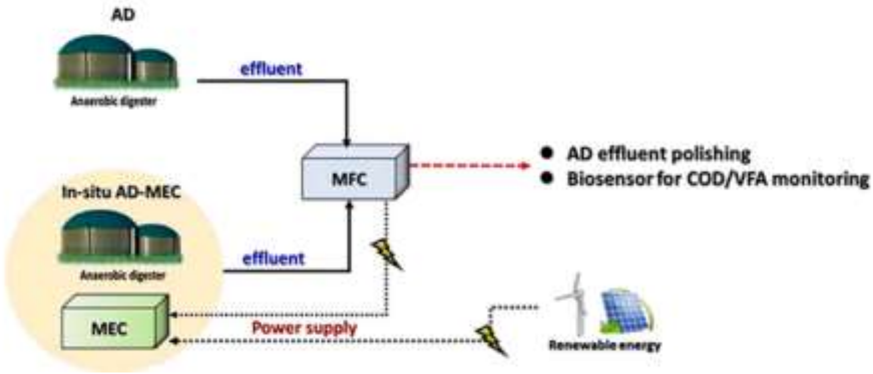


Figure 44. Potential applications for AD-MFC: anaerobic digester coupled to a microbial fuel cell

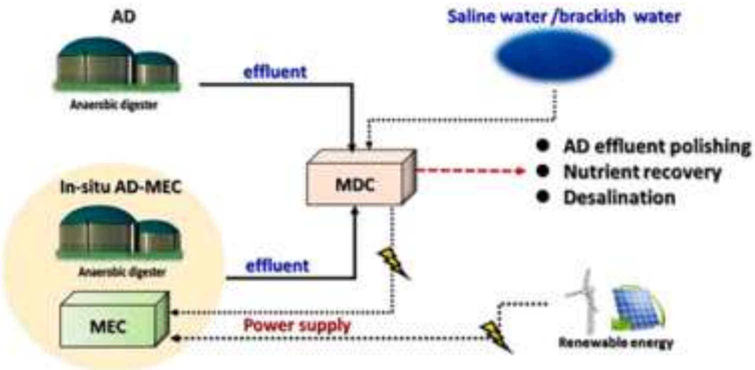


Figure 45. Potential applications for AD-MDC: anaerobic digester coupled to a microbial desalination cell

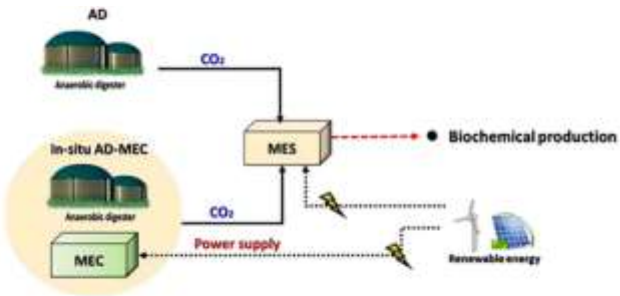


Figure 46. Potential applications for AD-MES: anaerobic digester coupled to a microbial electrosynthesis

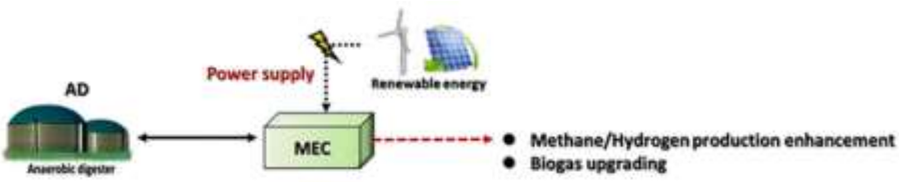


Figure 47. Potential applications for AD-MEC: anaerobic digester coupled to a microbial electrolysis cell

Biodigesters are devices that convert organic waste (i.e., crop residues and food waste) into biogas and organic fertilizer. Therefore, the targeted end-users are some specific manufacturing companies and the agriculture sector.

Biodigesters are devices that convert organic waste, such as animal manure, crop residues, and food waste, into biogas and organic fertilizer through a natural anaerobic fermentation process. Therefore, the targeted end-users are small business oriented to this energy technology and the agriculture sector. Within the SESA project, several potential biodigester end-user groups have been identified (see Table 2). Each of these groups have specific characteristics and economic activities that will define the T&F requirements to be met by biodigester technology:

- **Small businesses, manufacturing companies and tertiary sector** are the main targeted end-users of this energy technology, at different ways, for example:
    - Agro-industrial company (i.e., oil palm cultivation, crude palm oil extraction, and palm kernel oil extraction). Biodigesters can be used by small agro-processing businesses to manage organic waste generated during food processing and obtain biogas for heating or powering machinery.
    - Food processing companies (i.e., fruit processing company which fee biogas to process dry fruit), breweries, and other industries to manage organic waste and generate biogas for energy needs thanks to large-scale biodigesters.
    - Tertiary sectors, as hotels, which can own a biogas facility to reduce the use of natural gas for cooking, as well as make use of organic fertilizers.
    - Biogas can be used for industrial heating applications, such as drying processes, space heating, and steam generation, as well as for cooling application.
    - Waste management companies can use biodigesters to process organic waste and generate biogas, offering a sustainable waste treatment solution.
- The **agricultural sector**, such as small farmers, can use biodigesters by converting animal manure and agricultural waste into biogas for cooking and lighting, reducing the need for traditional fuels and improving soil fertility, using organic fertilizers.

3.5.2 Estimated technology costs

The cost of the implementation of biodigesters in Africa is difficult to estimate since the physical characteristics and the technological requirements of the technology vary greatly depending on where and for what are needed. The width rage of utilities of this technology ranges from the supply of small domestic units for the self-consumption of biogas or the production of fertilizer, to the large-scale application for the treatment of waste from markets or large communities. Biodigesters are designed to fit the requirements of a specific consumer, community, or facility, thus the cost will vary accordingly.

The use of biodigesters to produce biogas and bio slurry (digestate produced as waste that can be used as fertilizer) has been assessed in Africa for several years thanks to different local organizations and international projects, although they are not yet in general use. (Mulinda et al., 2013) presents several case studies in Uganda, Kenya, Rwanda, Tanzania, Ethiopia, South Africa etc. The studies show that the obstacles to the implementation of this technology are the high initial investment cost, inadequate subsidy, the long payback period and low rates of return, high-risk perception by financial institutions (Mulinda et al., 2013) and low rate of functional installed biogas systems/short lifespans, among others. Most studies conducted in various countries agree that the main obstacle is the initial investment. The Kenya Biogas Program estimates that installing a biodigester for biogas production in a household cost between KES 50,000 to 100,000 (EUR 318 to 637), a price well above what rural Kenyans households can afford. This situation is similar in most countries. The Africa Biogas Partnership Program (ABPP) estimated that the initial investment for the installation of a biodigester in East Africa would be around USD 700, in addition to an annual maintenance cost of USD 30 (Clemens et al., 2018) Figure 43).

Country	Bulk Construction	Plumbing	Appliances	Labor	Other	Total in US$/4m³ digester
Rwanda	521.94	112.51	70.33	226.21	48.09	979.08
Cameroun	410.64	73.08	9.00	205.10	-	697.82
Kenya	359.10	63.54	68.00	174.73	-	665.37
Tanzania	364.39	71.84	50.00	163.16	5.26	654.65
Burkina Faso	300.86	48.09	45.73	144.82	60.98	600.48
Senegal	251.33	51.72	73.17	186.05	22.10	584.38
Uganda	283.99	49.33	37.33	90.00	94.32	554.97

Figure 48. Cost of 4 m^3 digesters in different countries. Source: (Mulinda et al., 2013).

The time it would take to recover said investment varies enormously and it is where it can be found the greatest disparity in estimates. It is also difficult to measure, as many times the participants do not adhere to the program long enough. The ABPP estimates that said recovery can be obtained in 2.3 years for small digesters (Clemens et al., 2018), but other studies extend the range between 11.5 and 6 years, depending on whether they have the help of subsidies (Bedi et al., 2015). The use of digestate as fertilizer, in addition to the gas produced by the biodigester, also affects the benefit obtained from the installation of the biodigester, thus domestic units with crops or with the possibility of trading the digestate residue will take less time to recover the investment than those that use only the biogas produced.

The most limiting cost of the initial investment is the purchase and installation of the biodigester, since the maintenance or waste management expenses are small in comparison. The key point to reduce this initial cost is in the design of the digester, so that it adapts to the needs of the user while is economically accessible. Although different types of biodigesters are marketed in Africa, they can be divided into two large groups depending on the material from which they are manufactured. The first of these is the fixed dome, which consists of a cement chamber buried in the ground and another cement chamber for gas storage. This general design can vary, as digesters can be made with only one chamber where digestion occurs and gas accumulates, but most have two separate chambers in addition to a substrate inlet. They are more durable and resistant while, being buried underground, the temperature remains stable (key factor for methanogenesis), but it also requires a greater investment (Kabyanga et al., 2018).

As the cost is high, in recent years the designs have been adapted and the installation of other cheaper designs has been promoted. Among them the prefabricated plastic biodigesters are found, mostly used in South Africa, or the balloon biodigester plant, widely used in South America. They are cheaper designs due to their materials, which also makes them have a shorter lifespan. In addition, they are not usually installed underground, so they are more sensitive to changes in temperature, environmental phenomena, and the action of external agents such as animals. However, the cost is around 470-620 EUR, still high considering the income of rural populations (Kabyanga et al., 2018; Mukeshimana et al., 2021).

In Ghana, where SESA is looking into the implementation of this technology, the vast majority of biodigesters installed are fixed dome and previous research had shown that it is the best solution due its durability and easy handling (Figure. 45). Most of the business that commercialized biodigesters in the country have specialized in this kind of design and the prices range Gh¢ 333.3 – 633.3 (USD 235 – 446) per cubic meter (Bensah et al., 2011).

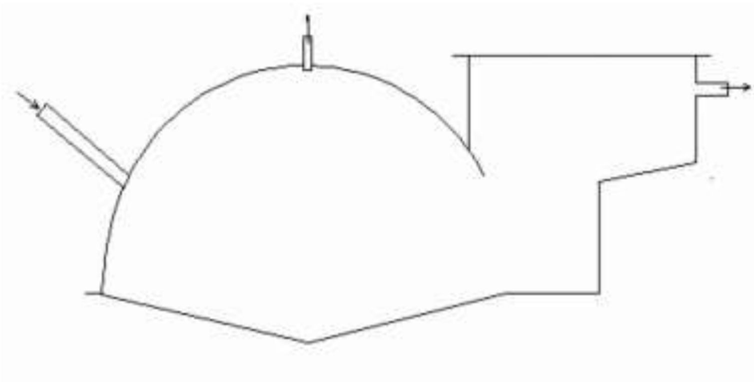


Figure 49. Proposed fixed-dome model for large scale promotion in Ghana. Source: (Bensah et al., 2011)

Regarding the implementation of electrochemical systems, we do not have much there is a lack of available information for the African context. The cost of this kind of rectors depends mainly on the materials used. Actually, the capital costs of BES are several orders of magnitude higher than conventional technologies. However, the development of new and cheaper materials is moving fast.

Roughly speaking, the current cost to establish this technology is estimated to be 8€ per kg of COD, while the AD or the use of activated sludge for wastewater treatment is between 0.1€ and 0.01€ per kg of COD (Rozendal et al., 2008).

3.5.3 Summary of biodigester functionalities

The following diagram aims to classify the main functionalities of biodigester per level of novelty and relevance in African Living Labs. Each functionality will be described henceforth.

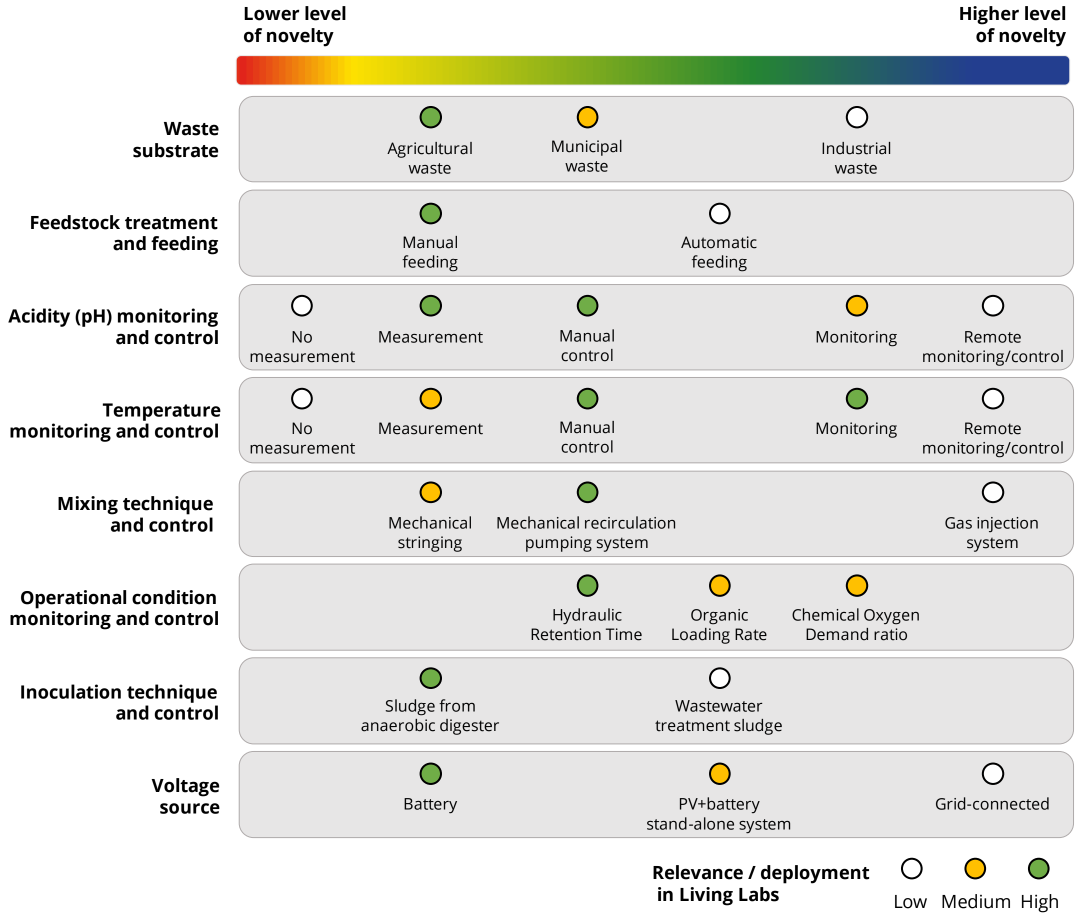


Figure 50. Classification of biodigester functionalities from lower to higher degree of novelty (from left to right) and relevance/deployment (low -white-, medium -yellow-, and high -green-) in African Living Labs.

3.5.3.1 Feedstock treatment and feeding

Pre-treatment of the feedstock, in this case, organic wastes from a local market.

- Agricultural waste: Agricultural waste is a commonly available substrate for use as a primary source to produce biogas. Therefore, effective use of agricultural waste has a positive impact on countries' economy and waste disposal problem. These substrates include animal manures and slurries, crop waste and agricultural by-products.
- Municipal waste: It refer to organic household waste, and food residues.
- Industrial waste: By processing different raw materials, various industries pro-duce enormous amounts of by-products, residues, and waste that can be used for AD.

Food waste needs to be shredded to avoid the clogging of pipes and to increase the area that can be degraded by microorganisms, a grinder can be used (either manual or automatic) , as follows:

- Manual feeding: the suitable amount of organic waste is added manually.
- Automatic feeding: the suitable amount of organic waste is added manually by an automatic method somehow (i.e., feedstock storage or tank connected to the AD).

AD-BES needs to be fed 2-3 times per week with the suitable amount of organic waste.

3.5.3.2Acidity (pH) monitoring and control

One of the most crucial parameters during the AD process is pH, affecting reactor performance.

pH has impacts on the growth rate of methanogenic bacteria and the breakdown of ammonia, sulphide, and organic acids (Atelge et al., 2020). The acidity (pH) of the biodigester process should be measured, monitored, and controlled. pH controller and pH probe to maintain a constant pH in the AD-BES should be required. The optimum pH is in the range of 6.5 - 7.5.

From lower to higher level of innovation, this indicator can be classified as follows:

- No measurement: the acidity is not measured
- Measurement: the acidity is measured by sensors
- Monitoring: continuous measurement and data collection over the digestion processes
- Manual control: control, reduce or increase the acidity somehow
- Remote monitoring/control: monitor and/or control acidity by using remote devices

3.5.3.3Temperature monitoring and control

Temperature is another key operational parameter for AD processes. Temperature is a factor of reaction velocity, chemical dissociation, and physical diffusion (Atelge et al., 2020). At low temperatures (<15ºC) the digestion process does not work satisfactorily, and heating systems and insulation may render the biogas system economically unviable. Therefore, digesters built underground help to minimize the temperature variations between day and night by using the temperature buffer capacity of the soil.

AD-BES might be built underground to minimise the temperature changes and to avoid the installation of a heating system. A temperature above 15ºC is needed to assure a satisfactorily digestion process and methane (biogas) production. There ideal temperature range for the performance of anaerobic bacteria is between 30-40ºC. Additionally, temperature can be measured 2-3 times per week to check and monitor this parameter.

From lower to higher level of innovation, this indicator can be classified as follows:

- No measurement: the temperature is not measured
- Measurement: the temperature is measured by sensors
- Monitoring: continuous measurement and data collection over the digestion processes
- Manual control: control, reduce or increase the temperature somehow
- Remote monitoring/control: monitor and/or control temperature by using remote devices

3.5.3.4Mixing technique and control

Mixing helps to balance pH and temperature and to prevent stratification and deposition of solids and scum in the reactor. It creates a uniform physical, chemical and biological environment. Mixing helps to blend the fresh material with the sludge inside the reactor. That is, mixing has the purpose of blending the substrate with digestate and also avoiding temperature gradients within the digester. In systems with no stirring, recirculation of digestate can help to mix the fresh feedstock with bacteria-rich digestate. Mixing can be divided: mechanical stringing, mechanical pumping, and a gas injection system (Atelge et al., 2020).

- Mechanical stringing is the most common type of mixing. It consists of a propeller, a rod mixer, and a paddle agitator. The main drawback of this system is the wear of its components and consumption of more time and money required for repair.
- A mechanical recirculation pumping system takes substrate in a digester and sends it back with pressure. This creates a flow inside of the reactor. The disadvantage of the system includes a clog caused by substrates.
- A gas injection system injects procured biogas to lower the level of the reactor with pressure. The gas bubbles move upward in the reactor and create mixing.

3.5.3.5 Operational conditions control and monitoring

Chemical Oxygen Demand ratio on biological nitrogen removal ((COD):N) and microbial distributions is of high importance in anaerobic digestion. With COD measurement, the maximum chemical energy in substrates is determined. It helps to calculate recovery energy from a substrate since bacteria convert chemical energy to the energy form of methane (Atelge et al., 2020). In AD-BES, the optimal value for this ratio is between 16 and 25, up to 40.

The hydraulic retention time quantifies the time the liquid fraction remains in the reactor. Recommended hydraulic retention time for wastes treated in a mesophilic digester range from 10 to 40 days. *Hydraulic Retention Time* (HRT) is the time duration that substrate stays in the reactor. Hydraulic retention time range from 10 to 40 days.

The *Organic Loading Rate* (OLR) is a measure of the biological conversion capacity of the anaerobic digestion system and is an important control parameter in continuous systems, as overloading leads to a significant rise in volatile fatty acids which can result in acidification and system failure. It describes the maximum organic material that can be digested in the reactor per volume and time. The ideal organic loading rate for stirred reactors is in the range of 4 – 8 kg volatile solids/m3 of reactor and day. However, for non-stirred anaerobic digestion systems values below 2 kg volatile solids/m3 of reactor and day is recommended.

3.5.3.6Inoculation technique and control

Anaerobically treated sewage sludge or animal manure can be used as inoculum for a standard Biochemical Methane Potential (BMP) test. Adaptation of bacteria to a new substrate is essential for reliable BMP results. Therefore, inoculum can be acclimatized to a new substrate in a separate digester by introducing the new substrate gradually (Atelge et al., 2020).

- Sludge from anaerobic digester: AD-BES is typically inoculated with sludge coming from an operating anaerobic digester. As an inoculum source, sludge from operating biogas plants should not be used because of potential inhibitor accumulation in the reactor.
- Wastewater treatment sludge: If this is not possible, wastewater treatment sludge or animal manure can be used as inoculum.

The ratio of substrate to inoculum should be considered. The minimum amount of sludge required for a good inoculation is between 10 – 30% of the total active reactor volume.

3.5.3.7Voltage source

The AD-BES performance implies to apply a voltage; however, it would be enough with a battery, or the energy generated by the solar PV systems. Electrodes are connected to a power source which allows controlling the applied potential and measure current. Typical voltage is in the range of 0.5-2V. This parameter is selected according to the specific conditions of each installation.

3.6 Smart Microgrids

3.6.1 Introduction

Smart microgrids are advanced, interconnected systems that manage various energy sources and loads, while stand-alone PV installations focus on generating solar energy for specific applications, often without the advanced control features of microgrids. In fact, the stand-alone PV systems oriented to residential rooftops, small businesses, remote locations, and off-grid applications or use cases for agriculture are presented in subsection 3.1.

In this subsection 3.6 smart microgrids are covered, conceived as modern electricity distribution systems that use digital technology to monitor, control, and manage the flow of electricity. They enable more efficient and reliable energy distribution, integration of renewable energy sources, and improved demand response. Microgrid (MG) is defined as a group of interconnected loads, storage devices and distributed energy resources (preferably renewable technologies), which acts as a single controllable entity with respect to the external grid (Hirsch et al., 2018).

Compared to a stand-Alone PV installation, a smart microgrid is a more complex and integrated energy system that typically includes multiple sources of energy generation, energy storage, and loads (consumers). Microgrids use advanced control and automation systems to monitor and manage energy flows in real time. They can intelligently switch between different energy sources and manage energy storage to ensure efficient operation and grid stability. Thus, smart microgrids can manage the internal loads to optimize energy usage and minimize costs.

Another key feature of a microgrid is its ability to operate in islanded mode. **Microgrids can operate in both grid-connected** (i.e., in rural and peri-urban areas) **and off-grid** (during main grid outages, as well as in rural or remote areas without access to the main external grid).

Smart microgrids enable more reliable, secure, clean, sustainable, and cost-efficient electricity to rural and urban communities, small businesses, municipality, educational and healthcare facilities, and e-mobility companies, among others. Energy sector companies, such as grid operators, renewable providers, energy services providers, can be essential stakeholders to deploy cost-efficient microgrids.

The main objective of the deployment of microgrids in SESA project is to **enable the access and use of a more reliable, secure, clean, sustainable, and cost-efficient electricity** to the users (including residential and educational buildings, productive sector, and critical facilities such as hospitals) through an adequate energy management regarding the energy exchange between the main grid, the local renewable resources, energy storage assets and the manageable demand.

Within the SESA project, several potential end-user groups have been identified (see Table 2). Each of these groups have specific characteristics and economic activities that will define the T&F requirements to be met by smart microgrid. Hereafter, these potential end-users are presented:

- **Households (residential users) and rural/urban communities** need reliable electricity, for lighting and small device/appliance powering, and potentially even powering larger appliances. Smart grids provide users with energy usage information, enabling them to make decisions about their electricity consumption, save energy, and reduce bills.
- **Small businesses, manufacturing companies and tertiary sector** shall rely on renewable electricity microgrids, to power their operations and business activities, enabling increased productivity and economic growth. Additionally, energy sector companies, such as grid operators, renewable providers, energy services providers, can be essential stakeholders to deploy cost-efficient solar smart microgrids.
    - Industrial and commercial consumers: Industries and businesses can benefit from smart grids by optimizing their energy consumption patterns, participating in demand response programs, and managing energy costs more effectively.
    - Renewable energy providers: Smart grids enable better integration of renewable energy sources, such as solar and wind power, by allowing real-time monitoring and control of generation and distribution. This benefits both large-scale renewable energy projects and distributed generation systems.
    - Energy service providers: Companies offering energy management and efficiency services can use smart grid data to develop customized solutions for consumers (residential, industrial, and commercial ones) and optimize their energy usage.
    - Electricity utilities and grid operators: Electricity utilities and grid operators are key stakeholders and primary beneficiaries of smart grids. They can use smart grid technology to monitor and optimize the distribution network, reduce losses, improve outage management, and enhance overall grid reliability.
    - Microgrid and mini-grid operators: In areas with limited or unreliable grid connectivity, smart grids can help manage microgrids and mini-grids more efficiently, ensuring a stable and balanced energy supply.
- **Municipalities and government facilities** may be part of a microgrid to provide reliable electricity for public services like lighting, information spot provision, public buildings, community facilities (i.e., gathering spaces), or public e-mobility fleet powering.
- In the **agricultural sector**, smart grids can support agriculture by providing more efficient energy supply for irrigation systems, crop processing, and other agricultural activities. These agricultural activities can be shifted based on a demand-side management mechanism, when electricity prices are cheaper or solar energy is available.
- **Educational institutions** may be also part of a microgrid to guarantee more reliable electricity. It serves for educational purposes for universities and schools, allowing students to learn about energy systems, data analytics, and sustainable technologies.
- **Healthcare facilities**, such as hospitals and healthcare centers, can benefit from more reliable and resilient energy supply provided by smart grids, reducing the breakdowns, and ensuring uninterrupted operation of critical medical equipment.
- **Transport service companies,** especially e-mobility charging infrastructure operators can be involved in a microgrid, and shifting intelligently the demand for charging, and ensuring efficient distribution of electricity to charging stations or charging needs.

3.6.2 Estimated technology costs

The cost of a smart microgrid in Africa can vary widely depending on various factors such as the size (from a single or small consumers up to larger communities or industrial complexes), complexity, location, technology choices (renewable and fossil-fuel technologies), and specific requirements of the microgrid project (control and automation systems), government incentives (subsidies, grants, etc.). Microgrids are designed to be tailored to the needs of the community or facility they serve, which can result in significant variations in costs.

Figure shows the normalized costs of projects in the United States as a function of the capacity of the project, reported by NREL (Giraldez et al., 2018). The results seem to indicate that there is some economy of scale for projects between 2 MW and 10 MW of installed generation capacity. The commercial microgrid projects in the database are almost all less than 3 MW, and they drive the higher costs reported for this market segment, maybe due to its higher security of supply. The normalized microgrid cost up to 10 MW ranges from 1 to 13 million $/MW.

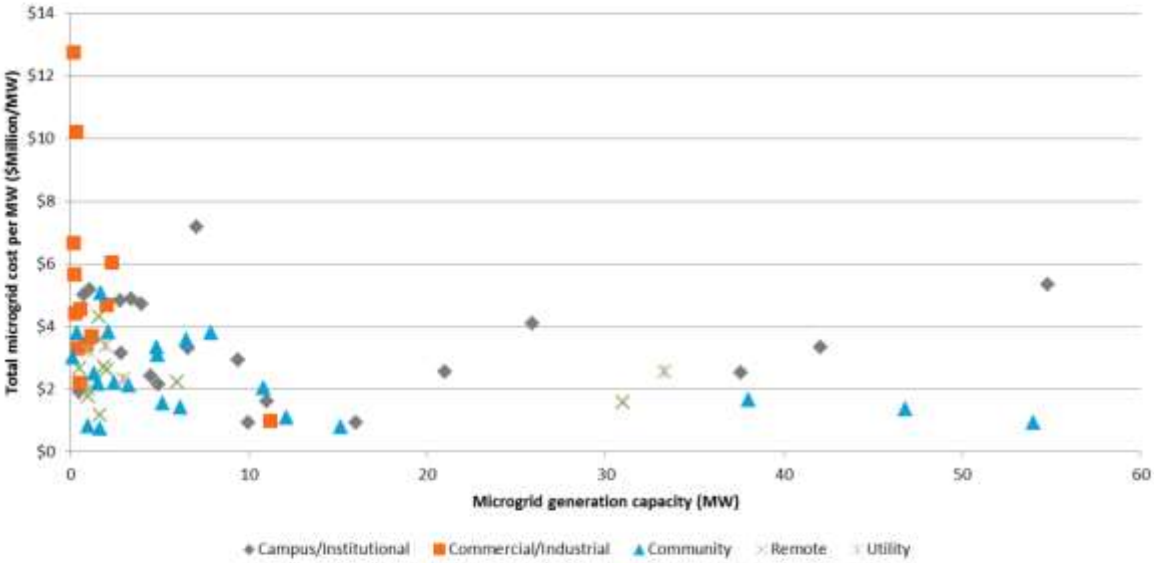


Figure 51. Normalized microgrid costs by size of the project and by market segment in USA. Source: nrel

Solar PV cost data in Africa are not systematically collected or made available to policy makers, resulting in difficulties in setting realistic policy support levels that are efficient and effective. IRENA report about the solar PV in Africa (IRENA, 2016) gathered cost breakdown of several mini-grid systems between 5 kW and 1 MW, that were commissioned between 2011 and 2014. Figure shows the Balance of System (BoS) cost breakdown divided into: PV module, inverter, battery, other hardware, and soft costs (including project development, design and procurement, permitting, financing, warranty, commissioning, and transportation costs, among others).

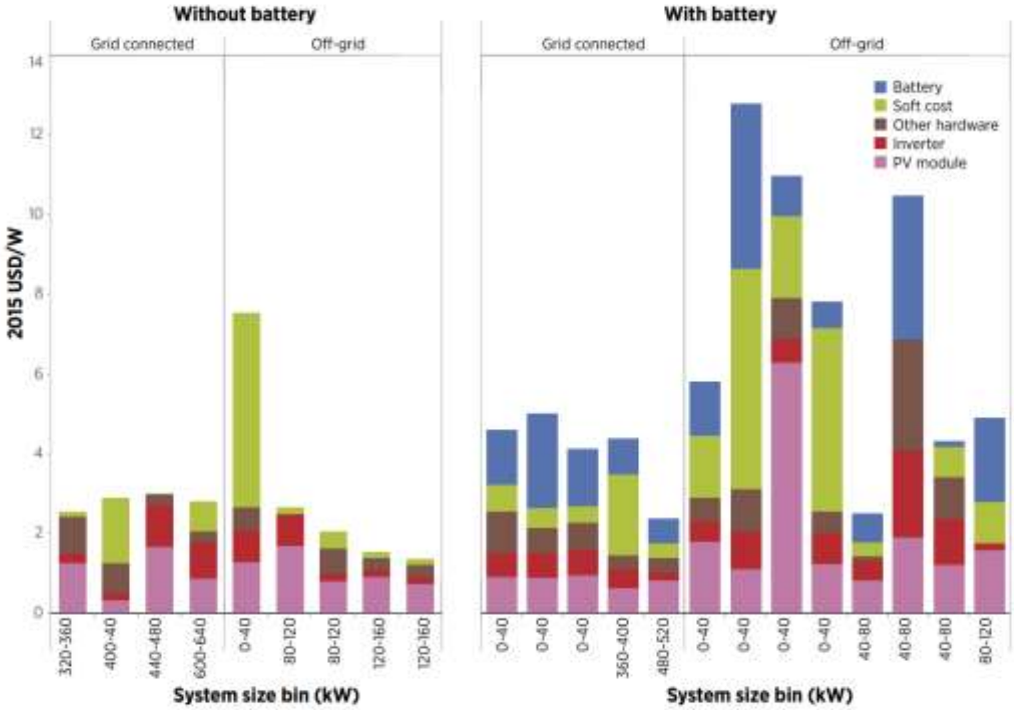


Figure 52. Solar PV mini-grid total installed cost and breakdown by cost component, 2011-2015. Source: IRENA

The total installed costs of these projects range between 2.5 and 3 $/W and benefit from their relative scale in order to help keep costs low. The grid-connected mini-grids present an installed cost, in the range of 2.4 without battery to 5 $/W with battery storage. The grid-connected mini-grids exhibit higher installed costs, in the range of 2.4 (without battery) to 5 $/W (smaller grid-connected minigrids up to 40 kW, with battery storage). As can be observed, the grid-connected minigrids without batteries normally has higher system size than other options. These project, also called *'fuel saver'* systems, are often scaled to maximize the solar PV fraction of demand, without the use of batteries, in order to reduce diesel costs, and having the utility grid support.

Off-grid mini-grid projects with batteries show a larger variation in total costs, particularly due to the variation in battery costs, and soft costs. Here, the economy of scale of soft cost is significant. Indeed, soft costs range from 0.4 $/W to 5.5 $/W for smaller mini grids (up to 40 kW). In general, the consulted off-grid mini-grids exhibit higher installed costs, in the range of 1.5 (higher size) to 8 (smaller size) without battery. When battery installation is considered, the off-grid mini-grids exhibit even higher installed costs, in the range of 2-11 (higher size) to 6-13 (smaller size).

Another study published by ESMAP and The World Bank (ESMAP, 2017) evaluated 16 minigrids projects in several African and Asian countries, with a power output from 10 to 230 kW. The CAPEX cost per kW ranges from 2 to 12 $/W. Figure depicts the CAPEX breakdown by several categories (in $/kW, $/kWh, $/kVa, or $/customer): generation, storage, and other hardware and soft costs. The median cost values are 1.4 $/W for generation facilities, 0.8 $/W for conversion and hardware, 200 $/kWh for storage, 0.8 $/W for project development, and 0.5 $/W for logistics, among others.

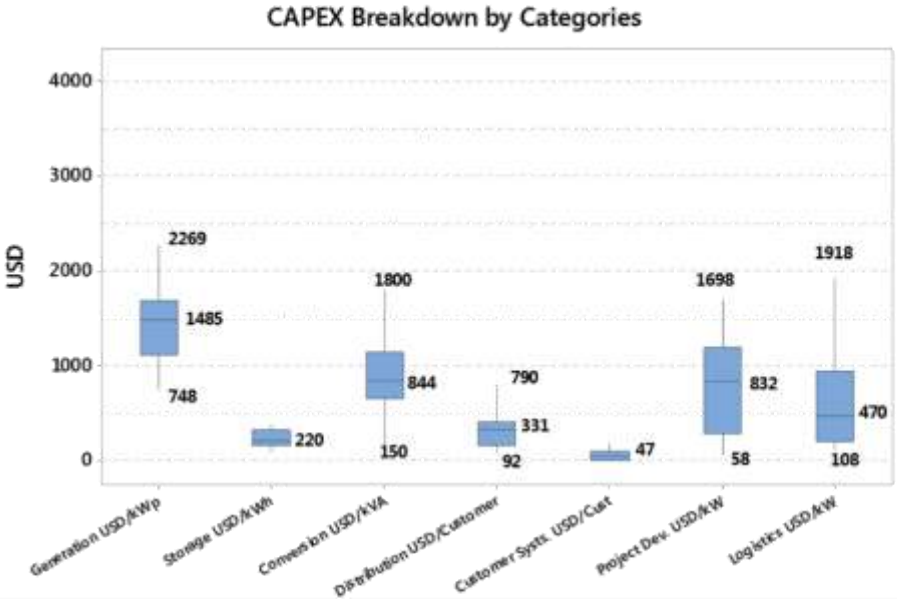


Figure 53. PV minigrid functional category CAPEX median values. Source: ESMAP & The World Bank

3.6.3 Summary of Smart microgrid functionalities

PV systems are mostly considered as renewable technologies in the scope of smart microgrids. Main requirements of PV systems are covered in subsection 3.1 (PV panels, PV structure, and PV inverter), while this subsection 3.6 addresses the functionalities of the smart microgrids which are composed of multiple energy resources, technologies, demand response, and control systems.

This subsection 3.6 defines a list of **advanced functional requirements in the framework of the smart microgrids**, ordered by their innovation degree, which shall be addressed in view of the more efficient management of decentralized and highly variable renewable generation.

This section 3.6 presents the **innovative energy solutions and their functional requirements** in relation to grid monitoring, network infrastructure, microgrid power control system, smart microgrid energy management systems, demand-side management, forecasting module, grid operating modes, AC/DC topology, ICT-based communications, coordinated protections, etc.). The following diagram aims to classify the main functionalities of smart microgrids per level of novelty and relevance in African Living Labs. Each functionality will be described henceforth.

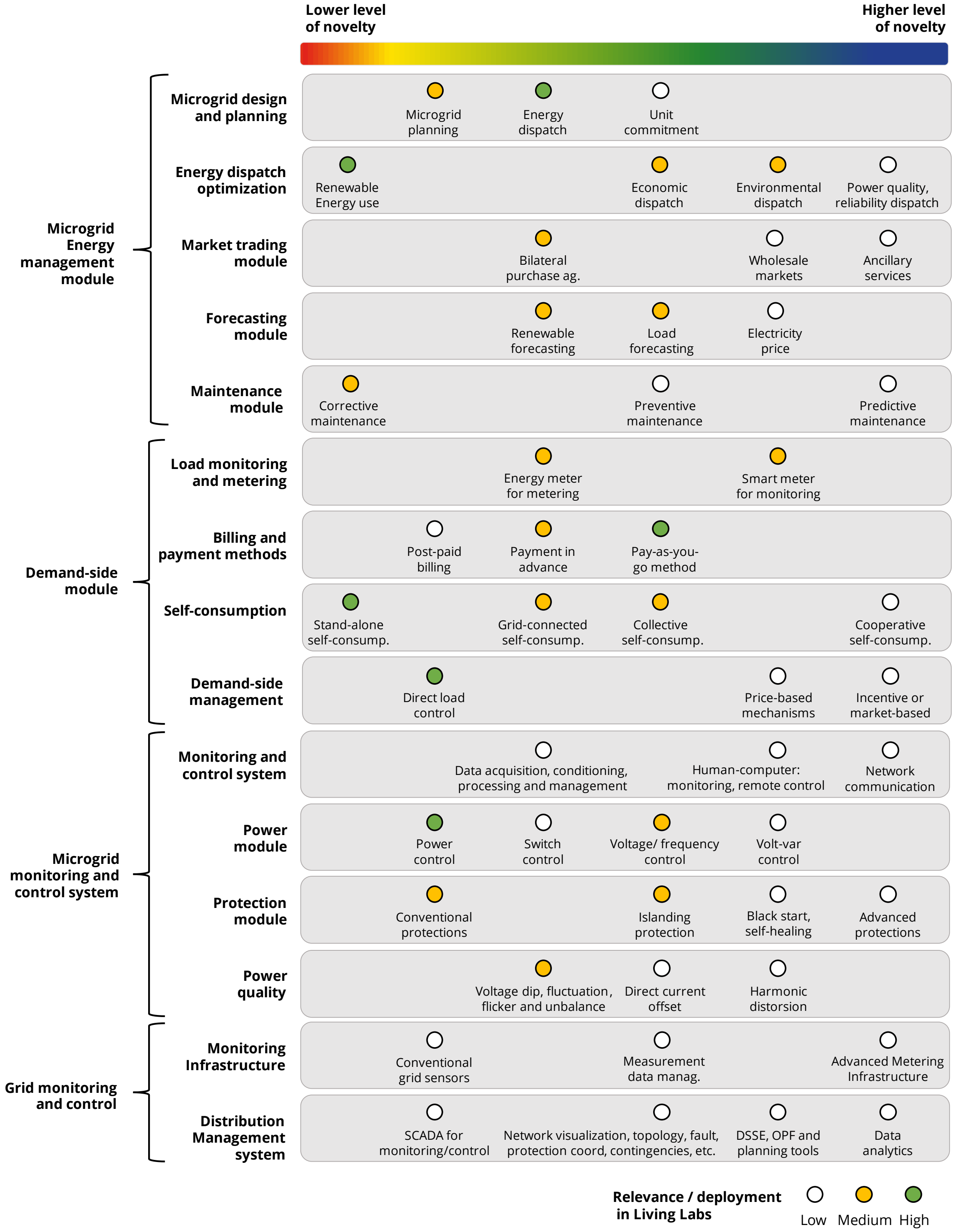


Figure 51. Classification of Smart Microgrids functionalities from lower to higher degree of novelty (from left to right) and relevance/deployment (low -white-, medium -yellow-, and high -green-) in African Living Labs.

3.6.4 Terminology and classification

3.6.4.1 Microgrid technologies

Microgrids are composed of diverse technologies, which meet technical requirements, ranging from generation facilities, storage systems, power electronic devices, and the consumption loads.

Firstly, the **generation facilities** mainly used in microgrids can be divided into two main categories (Hirsch et al., 2018): non-renewable (including gas microturbines, diesel generators, combined heat and power plant, and other fossil-fuel based technologies) and renewable generation sources (e.g., wind turbines, solar photovoltaic, small-scale hydropower, and fuel-cells).

Secondly, the **distribution network** (USAID, 2018) at medium or low voltage level (MV/LV) is composed by the grid infrastructure and assets, such as electrical lines (overhead or underground), poles, protections, or transformers if needed. The distribution system can use a variety of voltages, either alternating current (AC), direct current (DC) configuration, and either single- or three-phase power (generally LV networks are 400/230Vac, 50Hz). For small microgrids, electrical lines might be only considered to connect generation and consumption points.

Thirdly, **energy storage** are essential elements to improve the performance and operation of the microgrid, specially of the stand-alone ones. Energy storage is able to perform multiple functions such as reducing the renewable curtailment by absorbing the surplus power during off-peak hours and dispatch stored energy at times of high demand (Hossain Lipu et al., 2022), including frequency control, smoothing the output of renewable energy sources (Ceja-Espinosa et al., 2017), operating as a back-up device and voltage support (Xiao et al., 2017), and improving power quality and grid stability (Ovaskainen et al., 2019). Electrochemical storage (known as batteries), flywheel and pumped-hydro storage are the main selected technologies, which should be designed according to the power and energy needs of the microgrid.

Fourthly, the **consumption loads** are defined by the use case, which may cover lighting, residential loads, educational buildings, hospitals, and equipment for productive uses (water pumping and purification, irrigation, cooling and drying solutions, etc.) and electromobility applications (charging needs for electric vehicles). Depending on the type of loads (AC and/or DC), the architecture of the microgrid should be designed properly. According to their flexibility, loads can be divided into (un)controllable, (in)flexible, shiftable, and (un)interruptible.

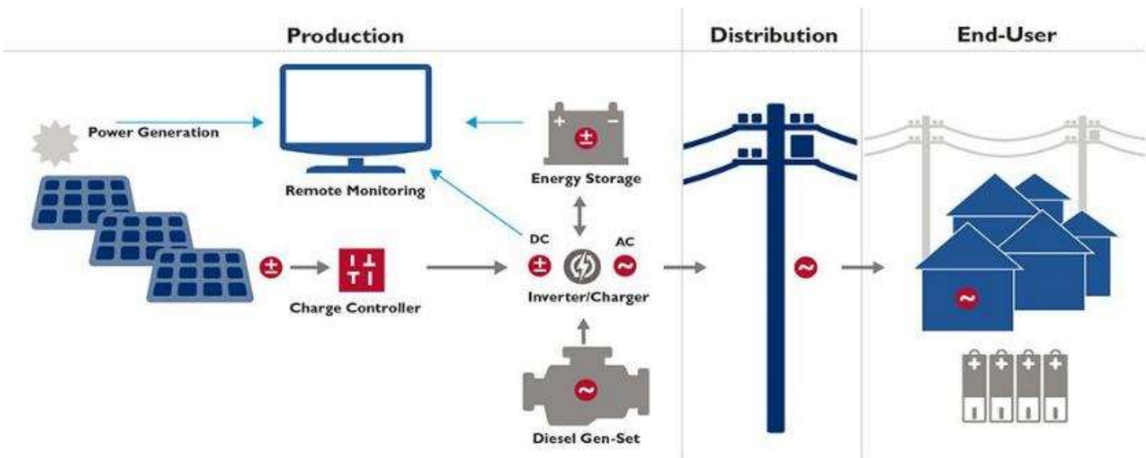


Figure 52. Components of a solar minigrid (USAID, 2018)

3.6.4.2 Microgrid entities

The following terminology should be presented to well understand the role of each agent in the microgrid design, planning, and O&M (Blair & de Martini, 2020), (Moreno Díaz et al., 2017):

- **Microgrid asset owner** is an entity that owns distributed generation, storage or demand management resources, assets, or infrastructure used to form and operate a microgrid. The microgrid asset owner seeks for reasonable return of the microgrid investment.
- **Microgrid operator** is an independent entity that is responsible for the operation, maintenance, and development of the microgrid, then, for the safe operation consistent with applicable interconnection rules. This role can be performed by the DSO in the area or by an independent microgrid DSO. A microgrid operator may also act as an aggregator, to provide energy, ancillary and/or grid services, as well as to operate the portfolio that enables reaching dispatch objectives and recovering investment and operational costs.
- **Microgrid aggregator** is an entity that operates a portfolio of distributed energy resources on behalf of others to provide energy, ancillary and/or grid services in wholesale markets and/or for the utility grid, in normal conditions as well as during island operation.

3.6.4.3 Microgrid ownership

With respect to microgrids, a business model defines the way in which a microgrid project or business is planned, implemented, and executed to meet strategic objectives (i.e., affordable renewable energy access to the rural community). The business model of large-scale generation assets or self-consumption installations have more predictable revenue stream and costs stream in countries with existing and stable regulation. However, the microgrid projects within the African context are at a disadvantage, due to the size of small-scale microgrids, the regulation still in progress, higher financial risks, limited grid infrastructure, the willingness to pay for users, etc.

Depending on the nature and diversity of the owner, the microgrid ownership can be classified as gathered (one owner), federated (multiple owners) or networked (community) (Boche et al., 2022):

- **Gathered microgrids**: The microgrid can be owned by a public entity (government utility ownership) or otherwise a private or third-party entity. Under this category, the anchor-business-community, the concept of design, build, own or finance, operate and maintain (DBOOM) and pay-as-you-go models are usually deployed in a gathered microgrid.
- **Federated microgrids**: The microgrid belongs to multiple owners, for example being a mixed ownership between public and private companies. Moreover, the community or some customers may own, govern and/or take care of the operation of the microgrid. Many business models are covered under this category in which the ownership is shared or transferred (microgrid-as-a-service (MaaS) business model, Power Purchase Agreement (PPA), Purchase and Sale Agreement (PSA), or Operating Services Agreement (OSA), etc.).
- **Networked microgrids**: The community owns and operates the microgrid, especially in standalone or self-consumption facilities. The customer-owned (consortium) model is included under this category, which places all financial and operating risk on the customer.

3.6.4.4 Microgrid archetypes

Another classification can be done by the nature of the owner and/or operator (Blair & de Martini, 2020), (SEPA, 2020):

- **Privately microgrids** involve private generation and storage assets and operational control of the microgrid by the private microgrid operator. Third-party multi-user microgrid operation involves a third-party microgrid operator that assumes the utility's operational responsibility. The operator controls for the segment of the distribution system used in the microgrid, as well as the microgrid controller used to balance loads and resources when in islanded mode. The third-party microgrid operator in this model is responsible for safe operation of the distribution segment and coordinating microgrid operations and maintenance with the utility distribution operator.
- **Utility microgrids:** The utility is the sole owner and controller of the microgrid distribution and generation and storage assets. The utility retains operational responsibility and controls for the distribution system as well as the microgrid controller used to balance loads and resources, in islanded mode. Utility multi-user microgrids may be developed in response to a utility resilience planning identified need or local community request.
- **Utility-private microgrids** are those where the utility and private developer(s) each contribute assets and share control responsibilities between the parties. In many cases, utility-private joint ownership models are a natural occurrence that allow for the utilization of the existing private distributed resources to be leveraged for the localized community and business needs. The utility retains operational responsibility and controls for the distribution system employing a grid-side controller. A customer or third-party (microgrid aggregator) has operational control of the energy resources, also in islanded mode.

3.6.4.5 Microgrid modes

Microgrids are classified into isolated microgrids and non-isolated microgrids. Isolated microgrids (also named as off-grid microgrids) have no electrical connection to a wider electric power system (IEC, 2018). Non-isolated microgrids can act as controllable units to the electric power system and can operate in the following two modes: (1) grid-connected mode, and (2) island mode.

Additionally, the microgrid can operate in two modes: in the **grid-connected mode**, the main objective is to follow the economic or environmental dispatch optimization and be synchronized with the main grid (which provides voltage and power support) and ensure energy balance among resources. For example, economic optimization dispatching operation can reduce the cost of electricity by optimizing the charging and discharging of the energy storage system, maximizing the local self-consumption, controlling the loads, and scheduling other resources.

While in the **island mode** (when there is a grid fault or in off-grid microgrids), the essential objective is a stability dispatch optimization in the short term, which provides direct control to the electronic converters to maintain voltage and frequency. The secondary control aims to restore the voltage and frequency up to the reference values and to enhance the power quality. In the long term, optimal dispatching for isolated microgrid shall include to guarantee the uninterrupted power supply of critical loads (i.e., hospitals), reduce environmental or system operating cost, etc.

Figure 53. Solar PV minigrid in Zambia (CrossBoundary Energy Access, 2020).

3.6.4.6 Microgrid typology

Based on the microgrid topology, they can be classified as AC, DC, or hybrid microgrids. **AC microgrid** is mostly used, being an easily adapted and robust solution, with direct connection of load to the main grid in grid-connected mode. However, it may require many conversion steps and power electronic devices to synchronize with the main grid, which can result in lower efficiency, reliability, and high level of harmonics in case of connecting to a weak utility grid. In contrast, **DC microgrid** might be a suitable option in African context, as its independency from the main grid voltage, frequency, and harmful fluctuations, using an interlinking AC/DC converter. The integration of DC loads and storage devices is simpler, with improved efficiency and power losses. However, protection schemes, compatibility issues and DC standards are their weaknesses. More information about the microgrid architectures can be found in (Martin-Martínez et al., 2016), (M. Rizzato Lede et al., 2017) and (Boche et al., 2022), and AC standards in (Rebollal et al., 2021).

The nature and requirements of the loads, the existing and planned distributed energy resources, the existing grid and communication infrastructure, the protection devices and control, the investment costs, among other criteria, will mostly determine the suitable AC/DC architecture.

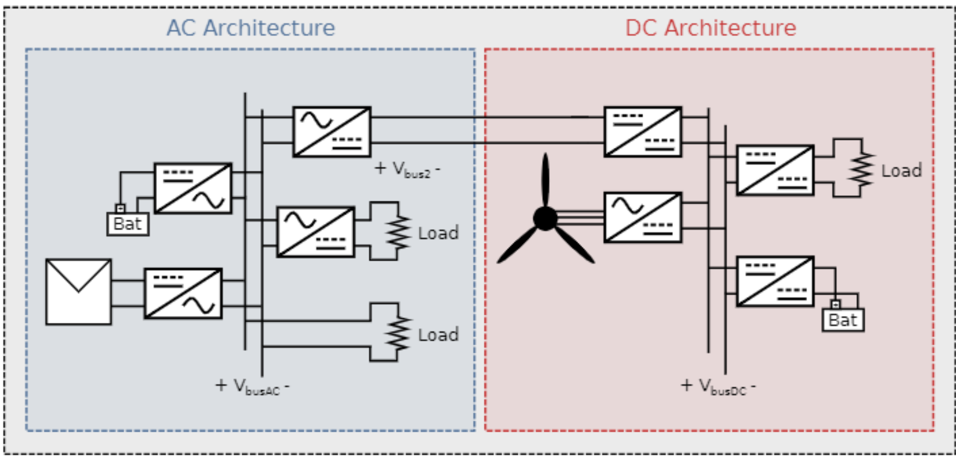


Figure 54. AC and DC architecture of a hybrid microgrid (Boche et al., 2022).

3.6.5 Microgrid Energy Management System

Microgrid Energy Management System (MEMS) is the system responsible for operating and controlling energy resources and loads of the microgrid. That is, it aims to manages power and energy exchanges between the energy resources in the microgrid and the utility grid in view of a strategic objective or functionality in a medium or long-term time horizon (i.e., an economic or environmental dispatch optimization to reduce the use fossil fuels, to reduce the electricity cost for the users or the investment costs through asset planning, to provide grid services to the main grid, to implement some demand response mechanisms in which the users adapt consciously their consumption, to reduce the polluting emissions of CO2 or associated emission cost, etc.).

The microgrid energy management system is implemented in the central or master microgrid controller, a physical device or system, which defines the operation setpoints of the controllable resources and provides the control signals to, generally, other slave controllers of the converters.

The *IEC 62898* establishes the main requirements for microgrids (IEC, 2022):

- *IEC TS 62898-1:2017* provides guidelines for planning and specification of AC microgrid projects, including (i) resource analysis; (ii) generation and load forecast; (iii) microgrid and DER planning; and (iv) evaluation of microgrid projects, and so on.
- *IEC TS 62898-2:2018* provides guidelines for operation of AC microgrids, with loads and distributed energy resources (DER) at low or medium voltage level. *IEC TS 62898-2* applies to operation and control of microgrids, including: (i) operation modes; (ii) energy management system; (iii) communication and monitoring procedures; (iv) electrical energy storage; (v) protection principle (non-isolated, isolated, anti-islanding), synchronization and reclosing, power quality; and (vi) commissioning, maintenance, and test.
- *IEC TS 62898-3-2* (under development) will focus on the technical requirements for MEMS.

3.6.5.1 Microgrid scheduling module

Microgrid design and planning

The microgrid planning and scheduling aims to meet demand reliably and economically from the long-term planning optimization to the daily energy dispatch (Papadimitrakis et al., 2021):

- **Microgrid planning:** The aim is to minimize the investment-related cost and operation-related cost combining different generation and storage technologies and dimensioning adequately the installed capacity of each of them.
- **Unit commitment**: It may be responsible for the minimization of both fuel and start-up cost, mostly oriented to fossil-fuel or diesel generators, with a weekly or monthly basis. The operational constraints comprise of: (a) system power balance, (b) spinning reserve requirements, (c) unit minimum up and down time and (d) unit generation limits.
- **Energy dispatch**: Afterwards, energy dispatch aims an efficient allocation between power demand and supply, carried out for day-ahead horizon with hourly intervals. The objective function aims to minimize the total fuel cost as described in [16]. The energy dispatch inside a microgrid can be done following quality, environmental, or economic objectives.

Energy dispatch optimization

The dispatch optimization of a microgrid has the objective of managing power and energy exchanges between the energy resources in the microgrid and the utility grid in view of several strategic objectives or functionalities in a medium or long-term time horizon, which shall include:

- **Power quality, reliability, and stability dispatch optimization:** Under this dispatch optimization, the output of controllable distributed energy resources (DERs) is optimized to deliver high power quality for a safe and reliable operation of the microgrid.
- **Environment dispatch optimization**: The environmental dispatch considers the reduction of the CO2 or other pollutant emissions, either to reduce the cost of the emissions (due to the carbon price or other local regulation policy) or to achieve an environmental-based goal (e.g., a maximum value of emissions).
- **Renewable energy use optimization**: Under this dispatch optimization, the objective is to maximize the utilization of local renewable generation for self-consumption, reduce the level of dependence from the external grid, and reduce the use fossil fuels.
- **Economic dispatch optimization**: The economic dispatch pays attention to (1) reduce the electricity cost for the users considering the operating cost per technology and the cost of the CO2 emissions, (2) to optimize the market schedule considering the purchase and sale price of energy, (3) to provide grid services to the main grid for extra revenues, (4) to implement some demand response mechanisms in which the users adapt consciously their consumption, and (5) reduce the investment costs through asset planning.

The previous objectives are not exclusive, as the dispatch optimization can be multi-objective. The general constraints mainly include:

- **System operation constraints**: generation-load balance, power flow control, thermal or power limitations, environmental constraints, or security and quality constraints.
- **Robustness constraints**: based on stochastic, uncertain, or unforeseen issues.
- **Technical constraints**: output limitations, technical constraints and economic model of resources, market rules and constraints, etc.

Market trading module:

When the microgrid is connected to the main grid, the delivery and imported power shall be traded via markets. The Southern African Power Pool (SAPP) was created in 1995 to promote regional coordination in the planning, system operation and monitoring, and common electricity market rules, and able to trade electricity with member states and to bolster energy security (IRENA, 2022). East African Power Pool (EAPP) was established in 2005 to develop energy resources in Eastern countries, regional interconnections and to ease power supply to all people (Kyriakarakos, 2022). Nowadays, there are five African power pools Central African Power Pool CAPP, Comité Maghrebin de l´électricité (COMELEC), Eastern Africa Power Pool (EAPP), Southern African Power Pool (SAPP), and Western African Power Pool (WAPP).

Recently in 2021, the African Single Electricity Market (AfSEM) is intended to connect energy strategies and take coordinated activities through a harmonisation of regulatory frameworks in Africa (IRENA, 2022) to achieve a fully integrated, competitive, and harmonized electricity market, being crucial for both on-grid and off-grid electrification in rural areas (Kyriakarakos, 2022).

(IRENA, 2019) supports these regional markets, which imply harmonised rules in the wholesale market, ancillary service market and capacity markets across the region, take advantage of the interconnections, and share energy resources over large regions. The MEMS can manage the energy trading for the following services, ordered by level of innovation and maturity:

- **Bilateral purchase agreements**: Long-term bilateral power purchase agreements (PPA) are the early stage of the trading arrangements, with heterogeneous agreed rules among peers. Generators and consumers in the microgrid may sign PPA agreements, without the intervention of a traditional electricity supplier or electricity retailer through the market.
- **Wholesale markets**: The microgrid operator can trade energy in the wholesale market (day-ahead and intraday) to guarantee the security of supply, by buying electricity or selling the possible excess local generation. The MEMS should procure electricity from the wholesale markets to minimise the community's expected costs, meet the energy dispatch objectives, manage internal resources, and deal with operation and price uncertainties.
- **Ancillary services**: Additionally, microgrids can improve the reliability of the energy supply inside and outside the microgrid. The ancillary services are usually required for the transmission (TSO) or distribution system operators (DSO) to maintain the grid stability and power quality (Martínez-Ramos et al., 2018). The MEMS should lead the dispatch strategy to control the internal energy resources to meet ancillary services in line with their specific market design, rules, bid features, and real-time requirements. For grid-connected microgrid, congestion management, frequency regulation and load following, black start, reactive power and voltage control, loss reduction, and (non)spinning and replacement reserves might be considered (Hirsch et al., 2018). In standalone microgrids, it could be required to emulate rotating inertia and provide primary frequency response.

3.6.5.2Forecasting module

The microgrid energy management system should require a forecasting module, focused on predict the renewable generation, load profile, and market price under different time scales (seasonal, week, day-ahead, nowcasting, etc.), different time resolution (daily, hourly, quarter-hourly, minute, etc.) and geographic/spatial scales. The forecast outputs support the decision-making process of the dispatch optimization in the short and long term.

MEMS shall be capable of receiving forecasted data (from a forecast provider, web-based service, etc.) or, otherwise, calculating autonomously power and/or weather forecasting, based on historical meteorological and measurement data from local generation or consumer profiles.

- **Renewable forecasting** should need information about historical generation profiles; historical and actual (or predicted) weather forecast; renewable technology features (i.e., PV tracking, power curve of a wind turbine); seasonal, temporal, and location data.
- **Load forecasting** should need information about historical consumption profiles; historical weather and actual weather forecast; consumer type and behaviour (residential, industrial, etc.); current (or predicted) occupancy; seasonal, temporal, and location data.
- **Electricity price forecasting** should need information about historical electricity prices; historical and current (or predicted) generation mix; type of market or grid service and their intrinsic features; weather, seasonal, temporal, and location data.

IEC TR 63043:2020 describes common practices and state of the art for renewable energy power forecasting technology, including general data demands, renewable energy power forecasting methods and forecasting error evaluation, focusing on solar and wind generation.

3.6.5.3Microgrid maintenance module

In African context, there are more fault events, system failures, and extreme weather conditions, among other issues, so specialized maintenance procedures should be adopted to **ensure stable, reliable, efficient, and safe operation** over the system lifespan of 20 years and beyond. With an adequate maintenance methodology, operational lifetime of the assets is enlarged, system performance and renewable exploitation is optimized. O&M execution model can be divided into in-house and third-party (external O&M contractor). Generally, maintenance strategies are classified as corrective, preventive, and predictive maintenance actions (Keisang et al., 2021):

- **Corrective/reactive maintenance actions:** It entails unscheduled remedial actions undertaken to rectify failures, breakdowns, underperformance, or any signs of inability. It is a risky maintenance, in which the service performance and lifespan of the equipment may be compromised. It relies on availability of replacement parts and ability to repair the failure. Repair works should be done during night or low irradiation hours, if possible.
- **Preventive maintenance actions:** To lower the probability of failure or an unacceptable level of degradation. Scheduled maintenance is characterized by strategically planned, intervallic, and specific scheduled intervention measures to maintain equipment in the specified operating condition, mostly according to manufacturer's recommendations.
- **Predictive maintenance actions:** Appropriate mitigation measures are taken (repair or replacement) following the prediction of possible system failure, in which remedial actions are performed with any incipient failure or fault condition are observed or forecasted. The key is to identify hidden anomalies, irregularities, or malfunctions. Although anticipated maintenance activities are carried out to optimize performance, it requires high investment cost for data control, monitoring, analytics, software, and hardware assets.

3.6.5.4 Demand-side module

MEMS should be aware of the microgrid load characteristics, such as inflexible, critical, and controllable/flexible loads (reducible, interruptible, transferable, shiftable, etc.). The conventional consumers are passive actors, as mostly inflexible, who consume energy when they need it in exchange of a cost in accordance with an electricity tariff, in order to cover the investment and operational costs incurred by the owners, investors, and operators of the microgrid.

In contrast, demand-side resources are resources on the customer side of the meter that can be relied on to respond to market conditions of the microgrid or external grid. In that way, the MEMS can control loads and storage systems in order to manage demand. The MEMS can include a module oriented to a demand-side integration strategy, being focused on ensuring the efficient and effective use of the microgrid resources or external grid to improve the dispatch objectives, long-term viability of the microgrid or, even, support the external grid through ancillary services.

MEMS should monitor power consumption, especially the most representative loads, to carry out the dispatch optimization according to optimization objective, while the wholesale market participation, other grid services and, if needed, the demand-side mechanisms are taken in mind.

Therefore, this section covers the functional requirements of the load monitoring and metering, the billing and payment methods, the customer tariffs oriented to recover the microgrid investment which are typically selected by passive consumers; and finally, demand-side management mechanisms for more active consumers.

- Load monitoring and metering
- Billing and payment methods
- Customer tariffs design
- Self-consumption
- Demand-side mechanisms

Load monitoring and metering

Load monitoring equipment measures current, voltage and energy, using from conventional meters to smart meters with advanced communication and control functionalities. Load metering enables determining the energy consumed to be invoiced.

- **Energy meter:** A energy meter is an electrical device that measures the electrical power being consumed and this allows to determine the energy consumed over time.
- **Smart meter**: A smart meter is an electronic device that records information such as electric consumption data, voltage levels, current, and power factor. Smart meters communicate the information to the consumer for greater clarity of consumption behaviour, and electricity suppliers for system monitoring and customer billing from every 15 minutes to one hour. General requirements for metering equipment are presented in *IEC 62052-11* and for tariff-control and load-control equipment in *IEC 62052-21*. The main functionalities and capabilities of smart meters are presented below (ENA, 2010):
    - 4-quadrant measurement capability
    - Two-way remote communication
    - Data storage and on-demand provision
    - Outrage detection, synchronization, and restoration
    - Basic power quality monitoring functionalities
    - Capability to support tariff metering
    - Capability to support demand-side management

Billing and payment method

Regarding the time to pay, the traditional utility model for grid-connected customers is post-paid, where consumers are billed i.e., in a monthly basis, but it usually requires reliable payments, smart-meters and remote control. Consequently, the more popular approach for micro-grids is prepaid (**payment in advance**), based on a given tariff or any other contract (Weston et al., 2018).

The most adequate business model for cost recovery in the African context is the **pay-as-you-go** (PAYG) model, from which the customers pay for the energy that they really use, aimed at accelerating the progress on the energy access in small and remote microgrids (Asmus & Lawrence, 2016). In this model, the service can be paid in advance or in customizable monthly, weekly, or daily instalments, adapted to the customers' use or their willingness to pay.

Self-consumption approaches

Microgrids integrates in most cases generation facilities and energy storage systems, which can be located at home level or in a centralized way to support the microgrid users. The owner of these systems (e.g., the own prosumer or microgrid operator) influences the kind of self-consumption and business model of the microgrid (Wu et al., 2022). The solar self-consumption is the ratio between the solar electricity consumed by the loads and the total solar production.

- **Self-consumption**: In household-level, the consumer generates renewable electricity for its own consumption, who may store energy in the storage system and/or sell it to the grid utility (in grid-connected mode). There are several methods for determining the value of excess power generation, including net metering and feed-in tariff schemes. Net metering is the use of a bidirectional meter to measure a customer's net energy consumption over the billing period (own consumption minus the surplus energy). With feed-in tariffs, a payment is received for all electricity injected into the main grid (Stadler et al., 2016).
- **Collective self-consumption for energy sharing:** The collective self-consumption among the microgrid users, collective energy balance and energy sharing at the community-level is proposed, in which a group of prosumers connected in an microgrid can exchange electricity for a locally joint energy production and consumption. Generally, microgrid operator is responsible for the controllable energy sharing to improve the community self-consumption level and cost-effective wholesale energy trading and achieve a reliable grid interaction. It shall be pay attention to local legal regulation in this regard.
- **Cooperative self-consumption**: Wider cooperation of different microgrids can be promoted, mainly in the framework of energy communities. MEMS can manage cross-border balance of supply and demand among microgrids. Generally, a more decentralized control approaches are considered for this case. A hierarchically controlled microgrid is suggested, in which local agents are internally controlled by a central controller (i.e., microgrid operator) and then, microgrids could trade energy with neighbouring microgrids through local energy markets, e.g., auctions or peer-to-peer market (Stadler et al., 2016).

Demand-side management

Changes in the patterns of the consumers can be tailored to improve the level of self-consumption, to consume in cheaper off-peak hours, to avoid a local congestion or overload, to improve dispatch optimization of the microgrid (either economic, environmental, or technical), among others. In centralized control, an aggregator maintains the load pattern of the consumer which does not consider the consumer satisfaction level. In the decentralized controller, the consumers can change their consumption pattern to afford the demand quoted by the utility. The distributed control, the microgrid communicates between the grid and among the other microgrids and consumers, to decide the power flow to the load based on the local power generation, demand flexibility, power availability from other microgrids, and power taken from the grid. Anyway, the purpose depends mainly on the topology and operating modes of the microgrid. Demand-side management mechanisms can be designed according to these modes:

- **In grid-connected operation mode**: the load can be shifted according to the electricity prices to reduce energy costs, be shifted to obtain a maximal local use of renewable generation, to provide grid or ancillary services to the grid, or to reduce the peak demand.
- **In islanding operation mode**: to determine the priority and scheme of load shedding, to balance power generation and demand load, or to perform load control operation to ensure stable operation of the microgrid which unbalanced power generation and load.

The demand-side flexibility shall be rewarded (Serna Torre & Hidalgo-Gonzalez, 2022), in most cases economically (a reduction on the bill, a reduced electricity price, or a revenue for the provision of grid services), but also by any other benefit (free maintenance, additional user service, etc.) depending on the business model. Table 7 summarizes the main Demand-side management mechanisms regarding different approaches and types (Silva et al., 2022), (Kanakadhurga, 2022), (Nageswara S.V. Rao et al., 2018), classified in direct and indirect control, the latest one, in incentive-based (especially for dispatchable resources) and price-based (designed especially for non-dispatchable resources).

Table 7. Classification of demand-side management mechanisms by direct and indirect control

Approach	Type	Demand-side management mechanism
Direct control	Direct load control	Peak clipping / Load shifting / Valley filling / Load Growth / Flexible load curve / Strategic conservation
Indirect control	Incentive-based: market-based and classical program	Capacity Market Program / Emergency program / Reserve / Contract agreements / Connection agreement / Demand Bidding and Buyback / Interruptible or Curtailable Service
	Price-based	Time-of-Use / Time-of-Day / Critical Peak Pricing / Peak Time Rebate / Real Time Pricing / Dynamic Pricing / Network tariffs

Afterwards, a short description is provided by demand-side mechanism:

Direct Load Control: customer's loads are turns off remotely by the operator on short notice.

- **Peak clipping**: the usage of power during the peak-load hour is decreased
- **Valley filling:** customers are encouraged to use their equipment during off-peak hours
- **Load shifting:** the electricity usage is shifted from the peak-load hours to off-peak hours. Load shifting is the combination of peak clipping and valley filling. With the increasing number of EVs usage, the load shifting could be done with the effective interaction between EVs and the power grid
- **Load Growth:** the load-shape changes as an increase in sales by the utility. Load growth was linked with the planning for future development and increase in the reserve capacity.
- **Strategic conservation:** total energy consumed over a year is reduced
- **Flexible load curve:** the electricity usage during different times is redistributed by shifting the demand from peak-hour to an off-peak hour to reduce the peak to average ratio

Incentive-based: encourage consumers to actively participate through any kind of incentives.

- **Bilateral programs:**
  - **Interruptible or Curtailable Service:** loads can be curtailed subject to tariffs or contracts that provide a bill credit or a rate discount.
  - **Load as Capacity Resource**: an amount of load is curtailed in case of contingence
  - **Contract agreement:** based on a bi-lateral agreement
  - **Connection agreement:** subject to any grid code or requirement
- **Market-based programs:**
  - **Emergency Demand Response program**: reduction of the load consumption due to an emergency event.
  - **Demand Bidding and Buyback:** a demand resource can offer a price for load reductions or an amount of load to be curtailed at a given price.
  - **Capacity Market Program:** provide capacity payments to customers for their agreement (i.e., annually, by auctions, etc.) to curtail when directed
  - **Non-Spinning Reserves**: demand-side resource available in ten minutes or more
  - **Spinning Reserves**: demand-side resource available for imbalances.
  - **Regulation Service**: increase or decrease loads in response to real-time signals.

Price-based: motivate customers for changing their consumption patterns based on the prices.

- **Time-of-Use Pricing**: which reflect average cost of power generation during time intervals
- **Time-of-Day Pricing:** offers three dayparts with different supply prices

- **Critical Peak Pricing**: high prices in time periods due to contingences or high prices
- **Critical Peak Pricing with Control**: a combination of direct load control with a pre-specified high price during critical peak hours
- **Peak Time Rebate**: customers earn a rebate (discount) if they consume less than a baseline in a determined number of hours on critical days
- **Real-Time Pricing**: reflection of price changes in the wholesale market
- **Dynamic Pricing:** variable prices that incentivize consumers to shift loads to times e.g., with renewable overproduction or when energy is cheap
- **System Peak Response Network Tariff**: reduction of loads during peaks as a way of lessening transmission charges.

3.6.6 Microgrid Monitoring and Control System

(Rebollal et al., 2021) summarizes the main microgrid standards and guidelines for grid connection and operation technical requirements, including: interconnection criteria, operating conditions, control capabilities, power quality, protection functions and reference variables.

The *IEC 62898* establishes the main requirements for microgrids (iec, 2022):

- *IEC TS 62898-2:2018* provides guidelines for operation and control of AC microgrids, with loads and distributed energy resources (DER) at low or medium voltage level. *IEC TS 62898-2* applies to operation and control of microgrids, including: (i) operation modes; (ii) energy management system; (iii) communication and monitoring procedures; (iv) electrical energy storage; (v) protection principle (non-isolated, isolated, anti-islanding), synchronization and reclosing, power quality; and (vi) commissioning, maintenance, and test.
- *IEC TS 62898-3-1:2020* provides guidelines for the specification of fault protection, transient and dynamic disturbance control in microgrids. Protection and disturbance control aim to ensure safe and stable operation of the microgrid under fault and disturbance conditions.
- *IEC TS 62898-3-4* (under development) will focus on the technical requirements for MMCS (Bsigroup, 2020), including functional requirements, such as: data acquisition and processing, and management, human-computer interface, time synchronization, switch control of devices, islanding detection, active and reactive power control, and black start.

The Microgrid Monitoring and Control System (MMCS) can be classified as follows:

- **Integrated MMCS**: MEMS and MMCS are normally merged into one embedded device, named as microgrid controller in case of small user-side microgrid (i.e., less than 10kW).
- **Stand-alone MMCS**: MEMS and MMCS are normally separated in the range of MWs. The MMCS is the executive layer of MEMS, works on the primary and secondary control of microgrid (from millisecond to seconds), and mainly contains data servers, workstations, routers, information safety devices, SCADA, communication system, distributed generation controller, microgrid central controller, and load controller. While the MEMS is the intelligence layer and works on the tertiary control (from minutes to hours).

This section does not cover fault protection, transient and dynamic disturbance control, neither specific product requirements for measuring relays and, protection equipment. This section is oriented to the MEMS functionalities for the smart microgrids, as follows:

3.6.6.1 Database module

The microgrid shall be able to collect analogue and digital real-time data, process and manage them. After data acquisition and processing and management, data shall be sent to the power module of the MMCS, battery management system (BMS), or microgrid central controller (MEMS).

The data module presented in this section covers the following functionalities (Song et al., 2017):

- **Data acquisition**: it collects analogue and digital real-time data from the distributed generation, load, switches, transformers, and reactive power compensation devices.
- **Data conditioning**: The processing module performs signal conditioning using an anti-aliasing filter, converts analogue signals into digital form with timestamps by means of a phase-locked oscillator and aligns phase data based on the GPS time reference.
- **Data processing**: it calculates and analyses the acquired data. After the analogue signals are scaled and conditioned, an analogue-to-digital converter converts the signals into digital form, and the processing module processes the data based on the metadata and the other applications. MMCS shall be capable of performing data source selection, automatic simple calculation¸ logical assessment of status signals, statistical analysis of power quality, and integrity check of the collected data. MMCS shall be capable of storing the collected data, e.g., event sequence record.
- **Data management**: it should have the functions of database maintenance, data synchronization, offline file storage, database backup and database recovery and provide the data interface with other internal and external applications (BMS, MEMS, etc.). The database management should be run in real-time or quasi-real time according to:
    - Real-time database management should be used for the communication and processing of real-time data and should ensure support for real-time applications.
    - Quasi-real-time database management can be used for historical data storage and statistics, storing alarm events, models, and other no real-time data.

Additionally, other additional functionalities are well used in microgrid control:

- **Smart sensors functionalities:** Self-description, self-identification, self-diagnosis, self-calibration, self-testing, self-validation, location-awareness, self-compensation, multi-sensing are additional intelligent capabilities of smart sensors (Song et al., 2017).
- **Time synchronization**: MMCS shall be capable of receiving the time synchronization signal by an internal clock with optional external time reference (i.e., via satellite or network time protocols: GNSS, 1 PSS, PTP, GPS or NTP) and synchronizing the time of each device, equipment, and controller within the microgrid. This functionality is needed to condition analogue signals into digital form with timestamps.
- **Human-computer interface**, which includes the real-time monitor screen and interface which is capable of remote control, mode switching, manual data entry, alarm signals prompting, switching actions, protection actions, and telemetry to be used by the microgrid operator. The human-computer interface shall include graphical maps, flashing lamps, or sound alarms, which enable to quickly identify the failure or disfunction.
- **Network communication system**: The communication system (Zheng et al., 2021) is an integral part of a microgrid and it integrates smart grid features in terms of control and monitoring features of the microgrid. Several protocols are employed in microgrid control systems to enable communication between the system components and intelligent electronic devices (Song et al., 2017). The most widely used is the standard IEC 61850 via an ethernet using the Transmission Control Protocol/Internet Protocol (TCP/IP).

Table 8. Main communication protocol in a microgrid (Song et al., 2017), (Martin-Martínez et al., 2016)

Smart sensor or system	Interface protocols standards	Network connection	
		Wired	Wireless
Smart sensors (SS)	IEEE 802, IEEE 1815, IEC 21451, IEEE 1451	Modbus-TCP/IP, UDP, PLC, Optical fibre, RS232	3G, 4G, Wifi ZigBee, WiMAX
Phasor measurement unit (PMU)	IEEE 1344, IEC 61850 IEEE 802, IEEE C37.118.2	Modbus-TCP/IP, UDP, PLC, Optical fibre, RS232	3G, 4G, Wifi WiMAX
Merging units, phasor data concentrators (PDC)	IEC 61869, IEC 60044, IEC 61850, IEEE C37.244	Modbus-TCP/IP, UDP, PLC, Optical fibre,	3G, 4G, Wifi
MMCS - MEMS	Modbus-TCP, IEEE 802 IEC 60870, IEC 61850	Modbus-TCP/IP, Ethernet RS232, PQTT	3G, 4G, Wifi
MEMS – DSO center	IEEE 1815 (DNP3), IEC 60870, IEC 61850	Modbus-TCP/IP, Ethernet RS232, DNP3	3G, 4G, Wifi Web API

3.6.6.2Power module

The microgrid can operate in two modes with particularized power control in the MMCS:

- **Grid-connected mode**: the main objective is to follow the economic or environmental dispatch optimization and be synchronized with the main grid and ensure energy balance among resources, through a P/Q control. This grid-mode control also aims to guarantee the power quality and stability at the point of common coupling (PCC) from the utility grid.

  Generally, the voltage source inverters (VSI) of renewable generators and batteries are controlled in power control mode (PCM), through i.e., droop control). Batteries can absorb the active/reactive power from the power grid or output the active/reactive power to the utility grid. In grid-connected mode, the voltage and frequency of the microgrid is supported by the utility grid, so the converters will be operated as grid-following mode, which adjusts the injected power with respect to the grid voltage at the PCC.

- **Island mode** (when there is a grid fault or in off-grid microgrids): the objective is mostly a stability dispatch optimization, which provides direct control to the electronic converters to maintain voltage and frequency, known as V/f control (in voltage control mode, VCM). This island control of converters aims to establish, maintain, and restore the voltage and frequency up to the reference values and to enhance the power quality. The master converter of the microgrid is operated as grid-forming mode. Batteries, controllable generators via power converters, and load shedding are of great important to maintain the energy balance of the microgrid and guarantee the security of supply.

Detailed primary control of power is presented in (Sadees et al., 2022), (Ekanayake et al., 2020), (Jasim & Jasim, 2022) for AC microgrids, and (Gao et al., 2019) for DC microgrids.

The MMCS should be monitor and control the frequency, voltage, and power as follows:

- **Switch control of devices**: MMCS shall be capable of controlling the controllable resources and switches, adapt their output based on the active and reactive power control, and turn on and off the loads, generators or other resources based on the MEMS control setpoint. During the mode switching (from island to grid-connected mode and vice versa), the controllable resources can be also controlled to maintain the normal operation (described in 'Protection module' section). Based on the level of innovation, the mode switching can be classified as follows: manual, local, site, and remote control.

- **Voltage monitoring and regulation**: It is necessary to monitor and maintain the voltage during steady state operation of an isolated microgrid inside an accepted operation range, via a V/f control (voltage control mode, VCM) applied to the converters.
- **Frequency monitoring and regulation**: It is necessary to monitor and maintain the frequency during steady state operation of an isolated microgrid inside an accepted operation range, via a V/f control (voltage control mode, VCM) applied to the converters.
- **Active and reactive power control**: The power control is implemented in grid-mode and island mode in order to control the active and reactive power in real time of distributed generators, battery storage or controllable loads, according to the microgrid energy management systems (MEMS) or manual command. This outer power control layer is responsible also to operate the MG according to the local regulations and grid code requirements at the point of common coupling (PCC).
- **Volt-var control**: Additionally, MMCS should optimally set Volt-Var operation in microgrid. The inverters will absorb or produce reactive power to decrease or increase voltage as needed. Additionally, STATCOMs are fast-acting devices capable of providing or absorbing reactive current and thereby regulating the voltage at the point of connection to a power grid. During microgrid grid-connected mode, it is recommended to adopt power factor control or reactive power control mode, to improve the grid quality, reduce line losses, improve the grid hosting capacity, and avoid active curtailment (Callegari et al., 2021).

3.6.6.3 Protection module

The presence of low inertia inverters, microgrid suffers from instability problems. Additionally, protection system design faces significant challenges due to bi-directional flow and, even worse, lower fault current levels due to the inverter-connected energy resources in islanded mode. Traditional protective relays might not guarantee accurate protection. The microgrid protection should take into account reliability, selectivity, sensitivity and speed.

Figure 8 summarized the development in protection devices, protection techniques, issues and communication systems from distributed systems to smart microgrids (Chandra et al., 2021).

<u>Protection techniques</u>

Hereafter, the protection schemes will be addressed. In each protection scheme, relays compare the measured data (voltages, currents, power, and frequency) against pre-determined thresholds (Gopalan et al., 2014). When the threshold is exceeded, trip signals are sent to the breakers.

- **Voltage-based protection:** The premises of voltage-based relaying scheme has primarily been established considering under and over-voltage phenomena. This scheme protects against both internal and external faults relative to any protective zone. The faulted zone is tripped if the disturbance voltage exceeds the threshold corresponding to the fault type. However, it ignores high impedance faults and symmetrical faults.
- **Overcurrent protection:** Overcurrent protection technique principally uses specific time-current discrimination characteristics of the overcurrent relay for operation. When a fault occurs in grid-connected microgrids, the fault currents within the microgrid will be high enough for the overcurrent relays to trigger. However, the fault currents will be significantly lower in islanded mode due to the limited contributions from the inverter-connected sources, which will be insufficient to activate the overcurrent relays.

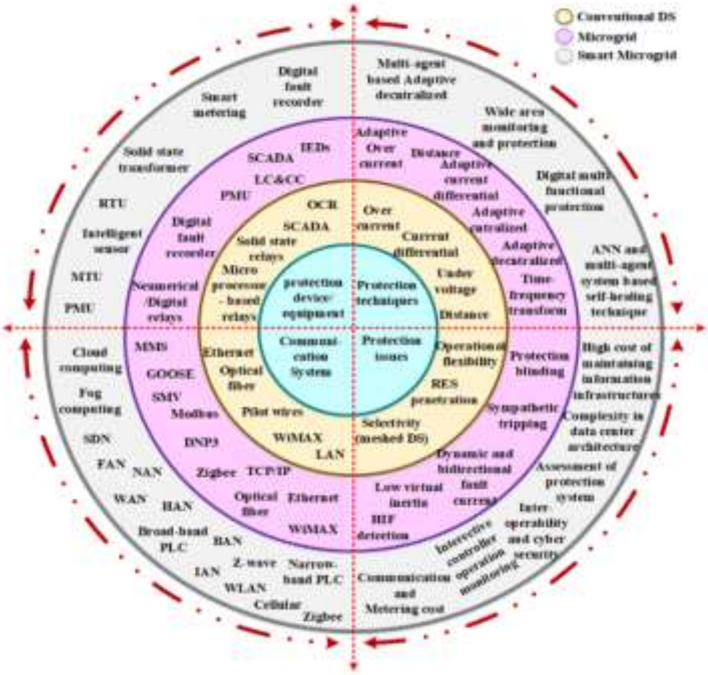


Figure 8. Successive development from distributed systems to smart microgrids considering in protection devices, protection techniques and communication systems (Chandra et al., 2021).

- **Differential protection**: This method primarily measures the current that is flowing into the feeder and coming out of the feeder. During a fault, the fault current flows from both sides to the fault point. Differential relay operating current is proportional to the vector difference of current entering and leaving the protected object/zone, and when it exceeds the pre-determined threshold, the relay operates.
- **Distance protection**: Depending on the adequate measure of fault impedance, distance protection facilitates broad zone protection for both forward and reverse fault. The reach setting of the protected zones with their corresponding time grade tripping of the relay.
- **Adaptive techniques:** Adaptive protection is employed to refurbish or update the settings of protection device according to system operating or resources state, as general idea. This automated resetting process is an online activity and requires a fast and reliable algorithm to calculate the suitable relay settings and high-speed communication infrastructure for real-time information sharing between intelligent electronics devices.
- **Other advanced techniques**:
    - Traveling wave-based protection predicts system perturbation and transient has further exaggerated the microgrid protection process, which is established based on current and voltage traveling waves and uses mathematical morphology filters.
    - Harmonic estimation and injection-based approach is based on the harmonic content into the current and voltage signal, where the Total harmonic distortion (THD) in the inverter output voltage is measured and compared with a pre-defined reference THD value to identify the fault.
    - Admittance relay is proposed based on the line admittance measurement when the fault happens downstream of the feeder with the distributed generator.

Regarding future protection trends, smart microgrid predominantly uses intelligent electronic devices, time-synchronized PMUs, digital fault recorders, advanced metering infrastructure, and advanced communication to acquire real-time knowledge of microgrid operating state. This protection is covered in more detail in the section "Grid monitoring and control".

Islanding detection and protection

Islanding allows the autonomous operation of microgrid, when disconnected from the utility. This independent operation potentially facilitates the uninterrupted power supply to downstream loads and inhibit fault propagation from downstream to upstream. However, unplanned or unintentional islanding decisively hamper voltage and frequency stability, power quality, and protection requirements (relay settings) (Chandra et al., 2021). Generally, change in active power causes change in frequency while change in reactive power causes change in voltage. In islanding mode, generally power generation and load demands are not in balance, voltage magnitude and frequency fluctuate. Therefore, islanding can be detected by monitoring the rate of change of frequency, voltage fluctuation, and phase change.

- **Islanding detection** includes real-time detection on power outage, desynchronization of the upstream distribution system and secure disconnection from the utility grid.
- **Mode switching:** Operation mode transition includes transition from grid-connected mode to island mode and transition from island mode to grid-connected mode. The MMCS shall be capable of controlling the controllable resources and switches at point of common coupling (PCC) to maintain the normal operation during the mode switching. The MMCS must support voltage and frequency disturbances caused during the change of operating mode. The transition to island mode can be performed intentionally or can be an unexpected event. When there is an intentional transition, the duration of the intentional island is agreed between the stakeholders implicated. An unexpected transition is caused due to a fault in the upward grid (Moreno Díaz et al., 2017).
- **Sequence of operations:** MMCS shall be able to control the equipment according to a predefined sequence (i.e., for reconnection, black start) in the mode switching states from island to grid-connected mode and vice versa, by realizing basic function including start-up for grid connection or the closure of main connector for island operation.
- **Reclosing or reconnection mode with synchronization:** Before reclosing, synchronization should be achieved, which requires that the microgrid resources are equal or close to the utility grid voltage, phase angle and frequency.

Black-start and self-healing

MMCS can perform black start control, which can realize the self-recovery of the system after the stability control fails due to a shutdown, power failure or outage (Stefanidou-Voziki et al., 2022).

- **Black start**: Black start is the ability to initiate power sources and loads to ensure microgrid can initiate and reach normal operation from non-energized island operation. The MMCS shall be able to sequentially control the equipment according to a selected black start strategy, power supply configuration, and black start delay setting. The MMCS shall be able to perform manual step-by-step control via remote control to select power supplies with self-starting capability to provide the reference of voltage and frequency.
- **Self-healing**: Self-healing means that the system is capable of continuing the power supply (at least partially) after any kind of disturbance. Self-healing functionality covers the following steps: (1) the protection system firstly locates the fault accurately, (2) disconnects the faulted section and (3), the intelligent automation functions take care of restoring the power supply to the healthy network. Self-healing feature can also consider reconfiguring the network (switching states) and re-routing the supply in certain fault cases.

3.6.6.4 Power quality

MMCS should monitor power quality in microgrids, by collecting threshold-crossing of voltage, power factor, and harmonic data, and control the microgrid by the MMCS. The microgrid operation shall not cause unacceptable disturbances to the microgrid's users and other network users.

(Van den Broeck et al., 2018) summarizes the status of current standardization (focusing on IEC 61000 and IEEE 159), and whether a definition and/or indicator for each power quality issue is provided. Power quality standards are covered in IEEE 519:2014 standard which defines the voltage and current harmonics distortion criteria for the design of electric power systems (it addresses steady-state limitation, transient conditions limits, and power quality measure at the point of common coupling); IEEE1159:2019 recommends practice for monitoring electric power quality; IEC 61000-4-7 for harmonics and inter-harmonics measurements; IEC 61000-4-30 for power quality measurement methods; and IEC 61000-4-15 for flickering measurement methods.

- **Voltage fluctuations** are defined as systematic variation of the voltage waveform envelope or voltage changes below the threshold values. Voltage fluctuations may cause periodic peak voltages that outreach the tolerable voltage range.
- **Harmonics distortion:** The distortion limits are evaluated for daily and weekly percentile short time and different ranges of voltage and current, according to the power quality standards presented previously. Total harmonic distortion (THD) is the ratio of the root mean square of the harmonic content, including the harmonic components, up-to the 50th order. For example, IEEE 519-2014 recommends that general systems between 1 kV and 69 kV have no more than 5% voltage THD, and the largest single harmonic no more than 3% harmonic distortion of the fundamental voltage. IEC 61000-2-2 for compatibility levels suggests a threshold value per harmonic order, i.e., less than 6% harmonic voltage distortion of the fundamental voltage with the 5^{th} harmonic.
- **Voltage flicker:** Flicker are considered an objectionable voltage fluctuation when causes human discomfort or equipment malfunction, and leads to low-frequency light intensity oscillations, for example an instability of the visual sensation. In particular, IEC 61000-4-15 gives a functional and design specification for flicker measuring systems and indicates the correct flicker perception level for all practical voltage fluctuation waveforms.
- **Three-phase voltage unbalance**: In low voltage distribution systems and microgrids the load current can be mostly unbalanced, affecting the power quality and reliability (overcurrent, voltage unbalance, degraded load sharing accuracy). Voltage unbalance factor (i.e., the ratio between the negative- or zero- sequence and positive-sequence voltage) is limited to 2% in UNE-EN 50160:2015 and 3% in IEEE 1159:2019
- **Direct current offset**: While DC offset in AC may cause transformer saturation and associated heating and stressing of the insulation, an AC offset in leads to reactive currents in the network causing additional losses and possibly intolerable voltage variations. IEEE 1547 standard states that the distributed resources in an AC microgrid shall not introduce a dc current bigger than 0.5 % the full rated output current at the point of coupling.
- **Voltage dip or sag** is a temporary reduction of the voltage at a point in the electrical system below a threshold, while **voltage swell** is defined as a temporary increase of the voltage at a point in the electrical system above a threshold.

3.6.7 Grid monitoring and control

New technologies and smart functionalities on the field of distribution grid monitoring and control enable higher grid observability, end-user metering, rapid diagnosis, and advanced functionalities for controllability and management of the distribution grids.

3.6.7.1 Monitoring Infrastructure

Smart sensors

Sensors are used to measure a wide variety of physical parameters in power generation, transmission lines, substations, distribution lines, energy storage, and customers. **Smart sensors (SSs) have more capabilities than analog sensors** and they can provide real-time data bidirectionally and status of the grids for real-time monitoring, protection, and control of grid operations (in transmission and distribution networks), through functionalities such as signal conditioning, analog-to-digital conversion, and data processing capability, follow some logic functions, and/or make some decisions (Song et al., 2017), (Nageswara S.V. Rao et al., 2018).

- **Current and voltage sensors**, named as current transformers (CT) and voltage transformers (VT), used to measure 50/60 Hz alternating current (AC) waveforms.
- **Phasor Measurement Units** (PMU) is a device that provides synchronized phasors from the input voltage and/or current waveform signals together with a time synchronizing reference signal, composed by the measure phasors and phase angle differences in real time. Synchro-phasors are used for advanced applications i.e., state estimation and monitoring system dynamics. The main interface standard for PMUs is *IEEE C37.118.2:2011* and *IEC 61850-90-5:2012* for communications at electrical substations.
- **Phasor Data Concentrators** (PDC) collects phasor data and discrete event data from PMUs and other PDCs, buffer them for a short time period (no store) and transmits data to other applications. The main functionalities of PDCs are among others: data aggregation, data validation, transfer protocols, data format, data latency, rate conversion, data buffering, performance monitoring, redundant and duplicate data handing, etc. The main standard for PDC functionalities and communications is *IEEE C37.244:2013*.
- **Merging Units** (MU) sample AC signals in one or multiple phases, convert these analog voltage and current signals to digital values, merge (align) multiple phases together based on time synchronization, and transmit the sampled values to i.e., protection relays. They are usually installed in substation automation systems for collecting and forwarding voltage and current data to electronic devices for protection and control applications.
- **Smart meter**: A smart meter is an electronic device that records information such as electric consumption data, voltage levels, current, and power factor. Smart meters communicate the information to the consumer for greater clarity of consumption behaviour, and electricity suppliers for system monitoring and customer billing from every 15 minutes to one hour. General requirements for metering equipment are presented in *IEC 62052-11* and for tariff-control and load-control equipment in *IEC 62052-21*.
- **Meteorological and other sensors:** temperature sensors, humidity sensors, accelerometers, rain gauges, internet protocol (IP) network cameras, pyranometers and pyrheliometers (solar irradiance), weather stations, gas sensors, occupancy sensors, etc.

Measurement Data Management

Measurement Data Management (MDM) means the efficient management and organization of vast quantities of measurement data. It is the prerequisite for ensuring this data is available in a suitable form for further long-term use, processing, and analysis. In most cases, the data originates in various formats from a variety of measuring instruments and test standards. the data needs to be indexed with meaningful descriptions: these are known as metadata. Metadata includes (but is not restricted to) details about the test object, measurement equipment used, physical units, time, measurement setup as well as test objectives and procedures. Users can quickly and safely extract relevant content from test data for downstream data analytics.

Advanced Metering Infrastructure

Advanced Metering Infrastructure (AMI) is a new metering technology characterized by a high-speed two-way communication from the smart meters (from the end users) to the utility (ISGF, 2017), or microgrid operator to a lesser extent. The AMI enables to monitor real-time consumption (from appliance and electric other equipment), to share data to the utility for control actions and the retailer for the post-paid billing, but also to address remote control, demand forecasting, fault detection, load balancing, dynamic pricing, and demand response mechanisms (Desai et al., 2019).

Three main area networks are being considered (Nageswara S.V. Rao et al., 2018):

(i) **the wide area network** (WAN) is an interconnected network which devices capable of sensing outgoing measurements and incoming control signals to ensure real-time awareness of grid stability and visibility. Synchrophasor devices like PMUs (phasor measurement unit) and PDCs (phasor data concentrators) are one of the most prominent WAN devices,

(ii) **medium or neighborhood area network** (MASN/NAN) is located in sub-transmission and distribution networks in which the grid modernization and digitalization move toward a decentralized electricity infrastructure, and enable to manage transactive energy mechanisms for balancing and grid reliability services, and,

(iii) **the local or home area network** (LASN/HAN) includes AMI that engages in energy consumption data collection, net metering, market analysis and transactive energy at the customer levels, building automation, control monitoring, and demand-side management.

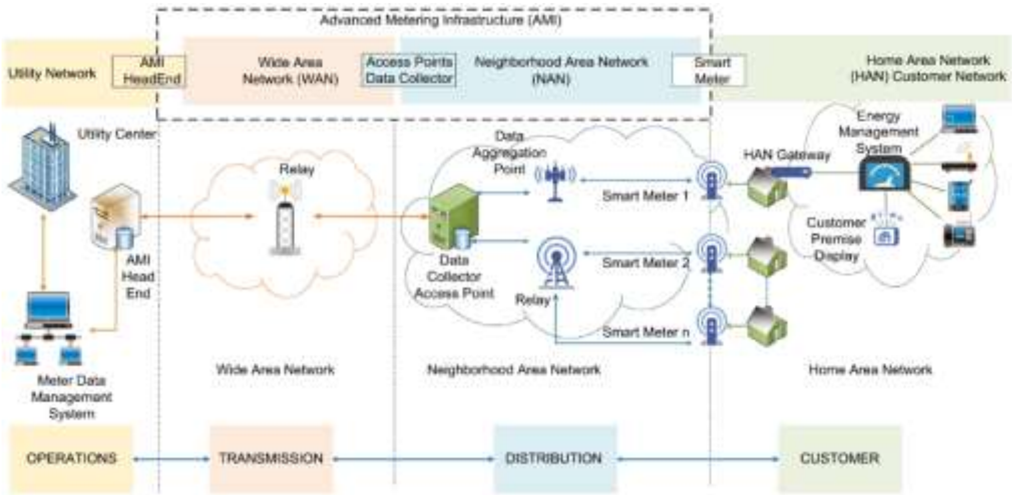


Figure 55. Overview of the Advanced Metering Infrastructure (Desai et al., 2019)

3.6.7.2 Distribution Management System

Supervisory Control and Data Acquisition System

Supervisory Control and Data Acquisition System (SCADA) is a system that monitors, supervises, and controls a geographically distributed process. SCADA refers to a system that collects data from various sensors and meters at a power plant, network system or in other remote locations and then sends this data to a central computer which then manages and controls the system, having the ability to monitor an entire system in real time which runs with relatively little human intervention (ISGF, 2017). Therefore, this includes all equipment and functions for acquisition, processing, transmission, and display of the necessary process information. SCADA can be divided in two parts: a hardware system for the data acquisition g, communication, control (both grid-connected and island modes) and operation (including the Human Machine Interface), and a software system for the data storage, elaboration, visualization, optimization, alarm management (Kermani et al., 2021), supervisory, data tagging, time synchronization, data logging and recording, load monitoring and data analytics, etc. (ISGF, 2017).

A common list of SCADA quality codes and other standards for power systems management, information exchange and interoperability are presented in *IEC 62361-2:2013*.

<u>Advanced Distribution Management System</u>

Advanced Distribution Management System (ADMS) was initially proposed to manage ag (Sohn & Yun, 2016), for planning purposes (Sohn & Yun, 2016) and simple SCADA system. Figure 560 presents a commercial Advanced Distribution Management System provided by etap.

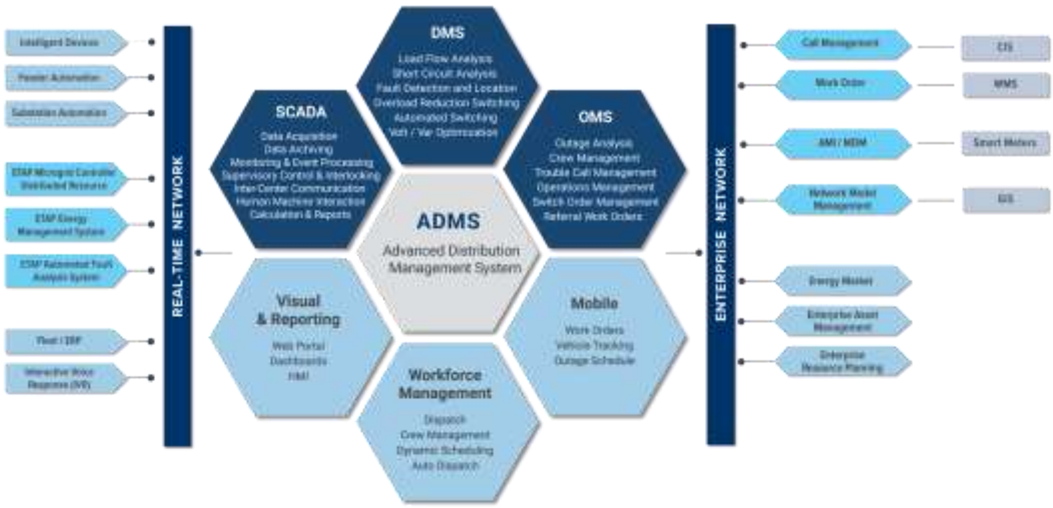


Figure 560. Overview of the Advanced Distribution Management System provided by Etap (Etap, 2022).

Hereafter, the main functionalities covered in the Distribution Management System are presented:

- **Network visualization**: Visualization of the essential tasks to understand the capabilities and limits of a given network, identify and solve specific network issues (Fischer & Keim, 2021). On the one hand, geographical information of the network is given for grid representation itself. On the other hand, topological network view represents the connectivity of the network among nodes, lines, phases, stations, etc. A simplification of the previous approach is the single line diagram to display operating status and simple parameters. Voltage magnitudes, power flow and other electrical data can be also drawn above the grid plane, and in bar charts, 3D surfaces, scatter plots, etc.
- **Topology identification**: It may be unknown or unreliable due to the lack of inventory, registration, notified changes, grid reconfigurations, or maintenance operation (García et al., 2023). The knowledge of the loads' connection phase in multi-phase power networks is important for DSOs to achieve a balanced grid, in which several heuristic approaches are being proposed, such as voltage-based algorithms and Bayesian inference method.
- **Fault diagnosis, isolation, and restoration**: This functionality covers the fault diagnosis (recognition of the occurrence of a fault & the identification of the fault type and location), the process of isolating the faulted part of the network and the grid reconfiguration to

return to normal operating conditions (Stefanidou-Voziki et al., 2022). It reduces the number of customers affected by an outage by automatically sensing faults and circuit lockouts to identify and isolate the faulted circuit sections. It then restores power to all of the unfaulted circuit section's affected customers by automatically switching them to adjacent sections of the line. The main classification methods applied to this functionality are i.e., impedance–based, traveling–wave, artificial intelligence (AI), hybrid, and sparse and distributed measurements.

- **System protection and coordination**: Generally, the distribution systems in the medium voltage level where relay protection is applied, while the protection at the low voltage level is still mainly based on fuses (Kauhaniemi & Voima, 2015). In the presence of bi-directional power flows, distributed energy resources, and meshed grids, advance equipment and coordination is needed through bidirectional overcurrent, differential, and distance relays.
- **Contingency analysis**: It is a "what-if" scenario simulator that evaluates, provides, and prioritizes the impacts of the power system, resulting from an unplanned outage event (a loss or failure of a small part of the power system, generator, transformer, etc.) (Hughes Cosponsor, 2002). CA is used as an off-line study tool to evaluate future outrages, identify any overloads, and prepare proper pre-planned recovery scenarios.
- **Volt/var optimization:** In a process called volt/var optimization, ADMS calculates the amount of active and reactive power on a line, with the final objective of reducing the distribution system losses (oracle, 2011). It then reduces the effect of the loss-producing reactive power by switching on devices like capacitor banks or shunt control in locations close to the loads consuming the reactive power (e.g., electric motors, fluorescent lights).
- **Conservation voltage regulation** (CVR): It can be also reduced the demand and energy consumption through conservation voltage regulation (oracle, 2011). This is an extension of volt/var optimization used to fine-tune the end-use customer voltage levels. CVR provides yield major benefits, especially when utilities operate under a regulatory mechanism that incentivizes load reduction to improve overall grid efficiency.
- **Utility planning tools**: the DSO is responsible of operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity it is becoming increasing essential to fully leverage digital methods in order to support decision-making process to optimized investment planning, and maximized asset lifecycles.
- **Grid state estimation (DSSE)**: State estimation techniques at the transmission level are widely used to represent a consistent state of the overall network based on a set of available field measurements. These state estimation techniques should evolve and be adapted to the distribution networks (Ahmad et al., 2018) (especially at low voltage grids) due to lower observability (limited field measurement), unbalanced grids and electrical parameters. The output of the grid state estimation tool is a more accurate state the whole network, with the knowledge of all nodal voltages and power flows in a consistent way.
- **Optimal Power Flow (OPF):** Optimal Power Flow is increasingly necessary to manage the distribution network faster, accurate, and efficiently, being subject to the system topology model, security constraints and control limits (Frank et al., 2012). The optimal power flow problem seeks to control the generation/consumption of generators/loads to optimize certain objectives such as the total network losses, while it is possible to some extent economic dispatch models, demand response mechanisms, direct load control, volt/var optimization, and preventive actions to solve congestions beforehand.
- **Data diagnostics and analytics**: An effective monitoring, diagnostic and data analytics of electric power system assets could provide analytical support to asset management, analytical support to decision-makers, implement life-cycle costs analytics, asset health analysis and provide adequate support for the asset maintenance and planning.

3.7 Allowing Climate Proofing

Climate proofing is a term that refers to a process of mainstreaming climate change into mitigation and/or adaptation strategies and programs. The goal of climate proofing is to ensure that climate-related risks and opportunities are integrated into the design, operation, and management of the infrastructure with the objective of reducing them to acceptable levels through long-lasting and environmentally sound, economically viable, and socially acceptable ones (UN-Habitat, 2021). In order to reach that objective, projects have to be screened for climate risks, vulnerabilities and opportunities at early design stages of project development. It involves taking proactive steps to minimize the negative effects of climate change and ensure that a particular system or activity can continue to function effectively under changing climatic conditions.

The advantages of climate-proofing are numerous and include the following ones:

- **Increased Resilience**: Climate-proofing enhances the ability of systems, infrastructure, and communities to withstand and recover from the adverse impacts of climate change, such as extreme weather events, rising temperatures, and sea-level rise.
- **Risk Reduction**: By identifying vulnerabilities and implementing appropriate measures, climate-proofing reduces the risk of damage, disruptions, and economic losses caused by climate-related events.
- **Long-Term Cost Savings**: Investing in climate-proofing measures can lead to long-term cost savings by preventing or minimizing damages that would otherwise be costly to repair. This is particularly relevant for critical infrastructure, such as transportation networks and energy systems.
- **Sustainable Development**: Climate-proofing supports sustainable development by ensuring that development projects and urban planning consider the long-term effects of climate change. This helps avoid maladaptation and potential negative consequences down the line.
- **Protection of Ecosystems**: Climate-proofing measures often include protecting and restoring natural ecosystems, which can have multiple benefits, including supporting biodiversity, enhancing water management, and providing natural buffers against climate impacts.
- **Community Health and Well-being**: Climate-proofing can improve the health and well-being of communities by reducing the risks associated with climate-related health impacts, such as heatwaves, flooding, and disease outbreaks.
- **Enhanced Food and Water Security**: Climate-proofing strategies can help ensure food and water security by safeguarding agricultural systems, improving water management, and mitigating the risks of droughts and floods.
- **Adaptation to Changing Conditions**: Climate-proofing enables societies to adapt to changing climate conditions, thereby maintaining economic activities, livelihoods, and quality of life.
- **Global Climate Goals**: Climate-proofing efforts contribute to achieving global climate goals by reducing greenhouse gas emissions, enhancing energy efficiency, and promoting the use of renewable energy sources.
- **Regulatory Compliance**: Many regions and countries are implementing regulations and policies that require climate resilience and adaptation measures. Climate-proofing ensures compliance with these regulations.
- **Enhanced Social Equity**: Climate-proofing projects can be designed to prioritize vulnerable communities, ensuring that the benefits of resilience and adaptation are equitably distributed.

* **Innovation and Technology Development**: Climate-proofing often requires the development and implementation of innovative technologies, fostering technological advancements and creating new opportunities for economic growth.

In summary, climate-proofing is a strategic approach to addressing the challenges posed by climate change, offering a range of benefits that contribute to the overall sustainability, resilience, and well-being of societies and ecosystems. Figure 57 provides an overview of the climate-proofing process of infrastructure, as a guideline provided by the European Commission.

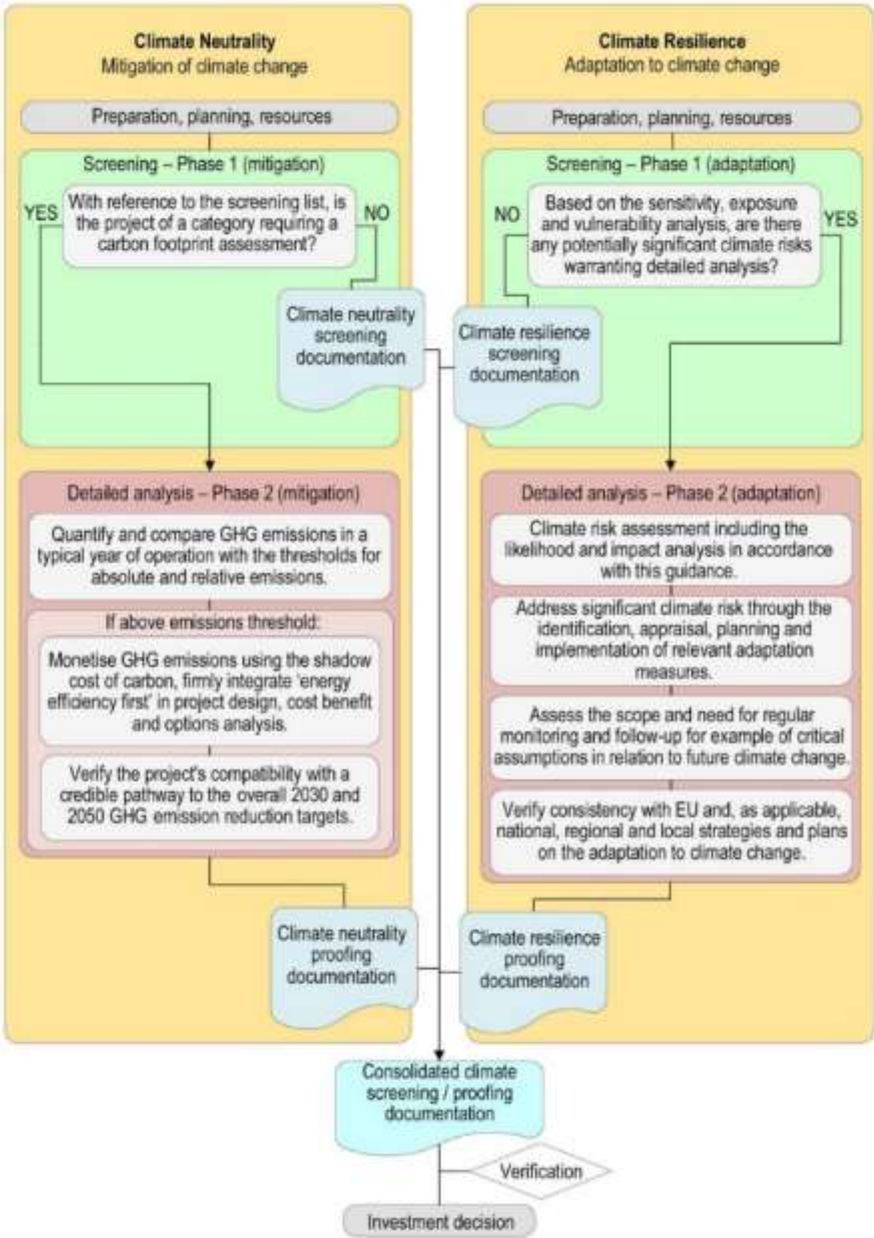


Figure 57. Overview of the climate-proofing process of infrastructure (European Commission, 2021)

It is essential to clearly identify – and consequently to invest in – infrastructure that is prepared for a climate-neutral and climate-resilient future. During the operation and maintenance of infrastructure, it may often be relevant to revisit the climate proofing and any critical assumptions.

Although Africa is the minor contributor to global emissions, the consequences of climate change will impact higher than in the rest of the world, being less resilient against climate risks, and more vulnerable to coastal flooding and water stress (IEA, 2022).

Focusing on climate resilience and adaptation, energy solutions and innovations will have to operate under changing climate conditions. Ensuring performance with long term perspective implies assessing functionality related to projected climate conditions. To enhance energy solutions resilience, both structural and non-structural adaptation solutions can be considered:

- **Structural adaptation** of energy solutions implies considering future climate projections in the design process of physical infrastructure with the aim of implementing improved technologies and designs to cope with climate related hazards.
- **Non-structural adaptation** of energy solutions implies optimizing their operation under climate change conditions. This may include improved monitoring, early warning, emergency response, personnel training, strategies/plans, etc.

These climate proofing solutions allow:

- Inform decision making in strategy definition and planning processes.
- Optimization of proposed solutions design, to be adapted to present and future climate conditions of pilot sites (pilot needs, resources availability, etc.).
- Optimization of implemented solutions operation, allowing good performance in both, present and future climate conditions.
- Anticipate and be prepared to face extreme events caused by climate change.
- Avoiding or minimizing damages (and related economic losses and casualties/injuries) caused by extreme events caused by climate change.

To achieve this, the following steps should be considered:

1. Monitoring daily data from both, energy systems and weather conditions, to allow not only the optimization of implemented solutions performance and the anticipation to face extreme events caused by climate change, but also the improvement of data provision for feeding future climate projections in the area and the provision of information for effective adaptation planning.

- Specific sensing or access to data from energy systems relevant to obtain high quality information to characterize their real performance and anticipate potential failures.
- Specific sensing or access to data from weather stations near pilot sites to obtain improved observations, improved local/regional data and denser data networks as well as the recovery of historical data.
- Data gathering and processing.

2. Climatic hazard assessment from the analysis and processing of historical data, daily monitored information and simulated climate projections.

- Climate historical data, observations (monitored) and projections data gathering at pilot level.
- Climate data processing to obtain relevant indicators and definition of alarm thresholds. These are specifically defined for each type of energy innovation system and climate hazard.
- Identification of "hotspots" or areas where climate change could have stronger impacts based on defined thresholds. These are the locations to avoid when planning a new facility.

Where this is not possible, a detailed climate risk analysis should be conducted to assess the level of risk the facility could face and to define appropriate adaptation measures (see "3. Climate impact diagnosis and adaptation").

3. Climate impact diagnosis and adaptation in view of the identified "hotspots". Potential climate impact is evaluated on those energy systems potentially exposed to the identified hazards and adaptation measures are defined.

- Climate risk level of energy innovations is assess based on their level of exposure and vulnerability to identified hazards. The ones that could face higher levels of risk are prioritized.
- For the ones prioritized, climate projections should be included in their design process to reduce their vulnerability level and make them more resilient. This will allow improving their performance during the whole lifetime.
- When system design can't be adapted to the identified climate risks, other type of adaptation measures can be defined to reduce the exposure level (p.e. system raise to avoid flooding).
- To optimize their operation, non-structural adaptation measures (monitoring, emergency response, training, strategies/plans, etc.) could also be designed and implemented.

Even though the implemented measures will depend on the specific solution to be installed and the location and context, some general guidelines can be anticipated. An example is shown below, focusing on climate proofing of sustainable e-mobility solutions (European Commission, 2013; IAEA, 2019; Tecnalia, 2020; wbg, 2019):, but more details and examples are provided in deliverable 3.1"Catalogue of Energy Solutions":

- The main threats to solar microgrids could be related to the rapid changes in cloud cover that affect the stability of the grid, but also uncertainty on the irradiance, temperature and precipitation in the long term would affect the design (in terms of size) and viability of the project. Extreme wind, storms, air sand, and extreme temperatures could cause physical damage to the infrastructure when exposed, without forgetting floods, landslides, and forest fires.
- For solar photovoltaic systems, where temperature increases or significant heat waves are expected, it will be useful to select solar modules with small temperature coefficient, that is, whose efficiency is not reduced to a large extent with high temperatures. String or micro inverters should be selected, being efficient against cloud coverage and easy to cool down.
- High ambient temperature is the most important factor that influences battery aging and can cause its premature failure (Riello UPS, 2022). They have a rated design life capacity based on an optimum operating temperature, so that, increases in temperature above this recommendation, results in a reduction in service life. This fact should be taken in mind in the selection of batteries and adapt their operation and maintenance conditions.
- More robust design specifications to withstand more extreme conditions.
- In general, climate change is likely to increase energy demand in the future. This potential increase should be taken into account in the design stage, making the infrastructure more flexible to easily adapt to meet future requirements. On the other hand, adaptation measures are also recommended at end-use level. The improvement of end-use efficiency for buildings, and energy-intensive appliances will reduce energy consumption, requiring less solar capacity and minimizing the need for upgrading existing infrastructure.

4 Key remarks

This document is conceived as a kind of **'technology innovation roadmap'**, which contains the main technical and functional requirements, ordered by the degree of innovation, if possible, and the relevance of each energy innovation to be involved in SESA demonstration actions.

In particular, the **main outcomes** of this Deliverable 3.2 are the following:

- Selection of the main energy innovation in SESA Living Labs.
- Mapping of potential end-users' groups for each energy innovation, covering households and rural communities, small businesses, tertiary sector, municipalities, the fishing and agricultural sector, educational and healthcare facilities, and e-mobility service companies.
- A guideline of the technical and functional requirements (ordered by degree of novelty).
- Checklist of functionalities per energy innovation, in a brief and concise manner.

Consequently, the targeted audience of this Deliverable 3.2, within the SESA project, are the **responsible entities of the Living Labs** and project development partners, who will drive the implementation plans, and are responsible to select the appropriate technologies, systems, or solutions; and at the end, successfully deploy the demonstration actions in the Living Labs.

Additionally, this report is quite interesting for other living labs of the replication countries of SESA project, as well as be of support also for public and private sector professionals, such as equipment providers, project developers and local authorities beyond the SESA project. These **stakeholders shall take advantages of the lesson learned and degree of novelty** of the current or upcoming solutions to be deployed by the demonstration Living Labs of SESA project. Indeed, this deliverable could help and facilitate the possible future functional replicability and scalability in other regions; or upgrade of the energy solutions deployed in the Living Labs.

- Identify the potential energy technologies that are usually demanded by end-user groups.
- Inspire the Living Labs to enlarge the features and capabilities of the energy technologies initially considered, and to increase the degree of innovation in the planned actions.
- Identify which functionalities and features are considered in the energy solutions which will be deployed in Living Labs.
- Select the most technically suitable (available technology which satisfies the user needs) and economically affordable (within the cost margins and budget) energy solutions.
- Track what is the degree of innovation they reach, after the release of this Deliverable.

To foster the tracking of deployed functionalities, a questionnaire (**checklist**) is included in the Annex I, that summarizes all functionalities in a brief and concise manner, being useful for:

- The update of the additional technologies and their corresponding functional domain or functionalities that could be added in Living Labs for their deployment along the project.
- The checking, recording, and tracking of the functionalities that will be finally deployed in the Living Labs. This process could be of relevant value, not only to assess the range of energy solutions functionalities deployed, but also to evaluate their degree of innovation achieved; and to identify and evaluate future upgrade of additional energy innovations.

This checklist would be kept alive after the release of D3.2. In this regard, an editable Excel form which includes this checklist of functionalities per energy innovation will be available in the SESA repository, by allowing a controlled access.

5 Bibliography

5.1 Solar Photovoltaics

iea. (2022). *Africa Energy Outlook 2022*.

IEC 62548-2016, (2016).

IEC TS 62738-2018, (2018). https://webstore.iec.ch/publication/26942

IRENA. (2016). *Solar PV in Africa: Costs and markets*. www.irena.org

IRENA. (2022). *Renewable energy market analysis: Africa and its regions*.

pvXchange. (2022, November). *Price Index*. https://www.pvxchange.com/Price-Index

Ramasamy, V., Zuboy, J., O'Shaughnessy, E., & Feldman, D. (2022). *U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks, With Minimum Sustainable Price Analysis: Q1 2022*. https://www.nrel.gov/docs/fy22osti/83586.pdf

5.2 Second–life energy storage systems

Deloitte, (2017). *A decarbonized transport model for Spain in 2050.*

TÜV SUD, (2019). A second life for lithium-ion battery modules, TÜV SUD, 2019.

Arora, S., Abkenar, A.T., Jayasinghe, S.G., Tammi, K., 2021. Chapter 5 - EV Battery Pack Engineering—Electrical Design and Mechanical Design, in: Arora, S., Abkenar, A.T., Jayasinghe, S.G., Tammi, K. (Eds.), Heavy-Duty Electric Vehicles. Butterworth-Heinemann, pp. 105–134. https://doi.org/10.1016/B978-0-12-818126-3.00004-X

Arrinda, M., Sánchez, D., Oyarbide, M., Macicior, H., Zubiria, A., 2022. Development of the State of Warranty (SOW) for Electric Vehicles. World Electr. Veh. J. 13, 135. https://doi.org/10.3390/wevj13080135

Asian Development Bank, 2018. Handbook on Battery Energy Storage System. Asian Development Bank, Manila, Philippines. https://doi.org/10.22617/TCS189791-2

Ayetor, G.K., Mashele, J., Mbonigaba, I., 2023. The progress toward the transition to electromobility in Africa. Renew. Sustain. Energy Rev. 183, 113533. https://doi.org/10.1016/j.rser.2023.113533

Ayetor, Godwin Kafui, Mbonigaba, I., Mashele, J., 2023. Feasibility of electric two and three-wheelers in Africa. Green Energy Intell. Transp. 2, 100106. https://doi.org/10.1016/j.geits.2023.100106

BATTERY ENERGY STORAGE SYSTEMS CAPABILITY GUIDE, Littelfuse, 2023.

Casals, L.C., Garca, B.A., 2016. Communications concerns for reused electric vehicle batteries in smart grids. IEEE Commun. Mag. 54, 120–125. https://doi.org/10.1109/MCOM.2016.7565258

Connector types for EV charging around the world [WWW Document], URL https://www.evexpert.eu/eshop1/knowledge-center/connector-types-for-ev-charging-around-the-world (accessed 3.20.23).

Das, H.S., Rahman, M.M., Li, S., Tan, C.W., 2020a. Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review. Renew. Sustain. Energy Rev. 120, 109618. https://doi.org/10.1016/j.rser.2019.109618

Das, H.S., Rahman, M.M., Li, S., Tan, C.W., 2020b. Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review. Renew. Sustain. Energy Rev. 120, 109618. https://doi.org/10.1016/j.rser.2019.109618

Dong, Q., Liang, S., Li, J., Kim, H.C., Shen, W., Wallington, T.J., 2023. Cost, energy, and carbon footprint benefits of second-life electric vehicle battery use. iScience 26, 107195. https://doi.org/10.1016/j.isci.2023.107195

ENTSO-E Position Paper on Electric Vehicle Integration into Power Grids, 2021.

Estado actual de la carga del vehiculo electrico en España, FUTURED, 2022.

European Commission. Joint Research Centre., 2018. Standards for the performance and durability assessment of electric vehicle batteries: possible performance criteria for an Ecodesign Regulation. Publications Office, LU.
Guide to micromobility, UL Solutions, 2020.
Hemavathi, S., Shinisha, A., 2022. A study on trends and developments in electric vehicle charging technologies. J. Energy Storage 52, 105013. https://doi.org/10.1016/j.est.2022.105013
Henke, M., Hailu, G., 2020. Thermal Management of Stationary Battery Systems: A Literature Review. Energies 13, 4194. https://doi.org/10.3390/en13164194
Hesse, H.C., Schimpe, M., Kucevic, D., Jossen, A., 2017. Lithium-Ion Battery Storage for the Grid—A Review of Stationary Battery Storage System Design Tailored for Applications in Modern Power Grids. Energies 10, 2107. https://doi.org/10.3390/en10122107
IRENA, 2019. Innovation outlook: Smart charging for electric vehicles.
Jian, L.I.U., 2017. Second use potential of retired EV batteries in power system and associated cost analysis#br#. Energy Storage Sci. Technol. 6, 243. https://doi.org/10.12028/j.issn.2095-4239.2016.0090
Kebir, N., Leonard, A., Downey, M., Jones, B., Rabie, K., Bhagavathy, S.M., Hirmer, S.A., 2023. Second-life battery systems for affordable energy access in Kenyan primary schools. Sci. Rep. 13, 1374. https://doi.org/10.1038/s41598-023-28377-7
Lebrouhi, B.E., Khattari, Y., Lamrani, B., Maaroufi, M., Zeraouli, Y., Kousksou, T., 2021. Key challenges for a large-scale development of battery electric vehicles: A comprehensive review. J. Energy Storage 44, 103273. https://doi.org/10.1016/j.est.2021.103273
Li, J., 2023. Economic analysis of retired batteries of electric vehicles applied to grid energy storage. Int. J. Low-Carbon Technol. 18, 896–901. https://doi.org/10.1093/ijlct/ctad076
Mellon, M., 2022. Fire Protection Systems for Lithium Battery Storage (Part 2) [WWW Document]. Vanguard. URL https://vanguard-fire.com/fire-protection-systems-for-lithium-battery-storage-part-2/ (accessed 3.16.23).
Mwangi, A., 2018. Battery Swapping, Kenyan Perspective and International Best Practices.
Neubauer, J., Smith, K., Wood, E., Pesaran, A., 2015. Identifying and Overcoming Critical Barriers to Widespread Second Use of PEV Batteries (No. NREL/TP--5400-63332, 1171780). https://doi.org/10.2172/1171780
Power to move: Accelerating the electric transport transition in sub-Saharan Africa | McKinsey [WWW Document], 2021. URL https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/power-to-move-accelerating-the-electric-transport-transition-in-sub-saharan-africa (accessed 3.17.23).
Power to move: Accelerating the electric transport transition in sub-Saharan Africa | McKinsey [WWW Document], URL https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/power-to-move-accelerating-the-electric-transport-transition-in-sub-saharan-africa (accessed 8.23.23).
Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) No 2019/1020, 2020.
Rajendran, G., Vaithilingam, C.A., Misron, N., Naidu, K., Ahmed, M.R., 2021. A comprehensive review on system architecture and international standards for electric vehicle charging stations. J. Energy Storage 42, 103099. https://doi.org/10.1016/j.est.2021.103099
Röckle, F., Schulz, T., 2021. Leveraging User Preferences to Develop Profitable Business Models for Electric Vehicle Charging. World Electr. Veh. J. 12, 60. https://doi.org/10.3390/wevj12020060
Şengül, B., Mostofi, H., 2021. Impacts of E-Micromobility on the Sustainability of Urban Transportation—A Systematic Review. Appl. Sci. 11, 5851. https://doi.org/10.3390/app11135851

Tolós, H.R., 2021. Second Life Batteries of Electric Vehicles: Analysis of Use and Management Models.
UL Solutions, 2022. *Guide to micromobility https://collateral-library-production.s3.amazonaws.com/uploads/asset_file/attachment/26650/Guide_to_micromobility_OCT_20.pdf* (accessed 3.17.23)
Un modelo de transporte descarbonizado para España en 2050, Deloitte, 2017.

5.3 E-mobility

Arora, S., Abkenar, A.T., Jayasinghe, S.G., Tammi, K., (2021). Chapter 5 - EV Battery Pack Engineering—Electrical Design and Mechanical Design, in: Arora, S., Abkenar, A.T., Jayasinghe, S.G., Tammi, K. (Eds.), Heavy-Duty Electric Vehicles. Butterworth-Heinemann, pp. 105–134. https://doi.org/10.1016/B978-0-12-818126-3.00004-X
Evexpert. *Connector types for EV charging around the world*, https://www.evexpert.eu/eshop1/knowledge-center/connector-types-for-ev-charging-around-the-world (accessed 3.20.23).
Das, H.S., Rahman, M.M., Li, S., Tan, C.W., (2020b). Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review. *Renew. Sustain. Energy Rev.* 120, 109618. https://doi.org/10.1016/j.rser.2019.109618
Elaadnl, (2017) *EV related protocol study*
ENTSO-E, (2021). *Position Paper on Electric Vehicle Integration into Power Grids*.
FUTURED, (2022). *Current state of electric vehicle charging in Spain*.
IRENA, (2019). Innovation outlook: Smart charging for electric vehicles.
McKinsey, (2021) *Power to move: Accelerating the electric transport transition in sub-Saharan Africa* https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/power-to-move-accelerating-the-electric-transport-transition-in-sub-saharan-africa (accessed 3.17.23)
Rajendran, G., Vaithilingam, C.A., Misron, N., Naidu, K., Ahmed, M.R., (2021). A comprehensive review on system architecture and international standards for electric vehicle charging stations. J. Energy Storage 42, 103099. https://doi.org/10.1016/j.est.2021.103099
Röckle, F., Schulz, T., (2021). Leveraging User Preferences to Develop Profitable Business Models for Electric Vehicle Charging. *World Electr. Veh. J.* 12, 60. https://doi.org/10.3390/wevj12020060
Şengül, B., Mostofi, H., (2021). Impacts of E-Micromobility on the Sustainability of Urban Transportation—A Systematic Review. *Appl. Sci*. 11, 5851. https://doi.org/10.3390/app11135851
UL Solutions, (2022). *Guide to micromobility https://collateral-library-production.s3.amazonaws.com/uploads/asset_file/attachment/26650/Guide_to_micromobility_OCT_20.pdf* (accessed 3.17.23)
Deloitte, (2017). *A decarbonized transport model for Spain in 2050*.
Mwangi, A., (2018). *Battery Swapping, Kenyan Perspective and International Best Practices*.
Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) No 2019/1020, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52020PC0798

5.4 BioCooker

drawdown. (2021). *Technical Summary. Clean Cooking*. https://drawdown.org/solutions/improved-clean-cookstoves/technical-summary
ISO - ISO 19869-2019 - Clean cookstoves and clean cooking solutions — Field testing methods for cookstoves, (2019).
Johnstone, K. (2020). *Stoking finance for affordable cookstoves: Experience from Malawi and Zimbabwe*.

Ranung, S., & Ruud, J. (2019). *Use of Biochar Producing Cookstoves in Rural Kenya: Energy efficiency, air pollution concentrations, and biochar production potential*. www.kth.se/student/utlandsstudier/examensarbete/mfs

5.5 Biodigester

Atelge, M. R., Krisa, D., Kumar, G., Eskicioglu, C., Nguyen, D. D., Chang, S. W., Atabani, A. E., Al-Muhtaseb, A. H., & Unalan, S. (2020). Biogas Production from Organic Waste: Recent Progress and Perspectives. *Waste and Biomass Valorization*, *11*(3), 1019–1040. https://doi.org/10.1007/s12649-018-00546-0

Bedi, A. S., Pellegrini, L., & Tasciotti, L. (2015). The effects of rwanda's biogas program on energy expenditure and fuel use. *World Development*, *67*, 461–474. https://doi.org/10.1016/j.worlddev.2014.11.008

Clemens, H., Bailis, R., Nyambane, A., & Ndung'u, V. (2018). Africa Biogas Partnership Program: A review of clean cooking implementation through market development in East Africa. *Energy for Sustainable Development*, *46*, 23–31. https://doi.org/10.1016/j.esd.2018.05.012

Cudjoe Bensah, E., Mensah, M., & Antwi, E. (2011). Status and prospects for household biogas plants in Ghana-lessons, barriers, potential, and way forward. *International Jorunal of Energy and Environment*, *2*(5), 2076–2909. www.IJEE.IEEFoundation.org

Kabyanga, M., Balana, B. B., Mugisha, J., Walekhwa, P. N., Smith, J., & Glenk, K. (2018). Economic potential of flexible balloon biogas digester among smallholder farmers: A case study from Uganda. *Renewable Energy*, *120*, 392–400. https://doi.org/10.1016/j.renene.2017.12.103

Mukeshimana, M. C., Zhao, Z. Y., Ahmad, M., & Irfan, M. (2021). Analysis on barriers to biogas dissemination in Rwanda: AHP approach. *Renewable Energy*, *163*, 1127–1137. https://doi.org/10.1016/j.renene.2020.09.051

Mulinda, C., Hu, Q., & Pan, K. (2013). Dissemination and Problems of African Biogas Technology. *Energy and Power Engineering*, *05*(08), 506–512. https://doi.org/10.4236/epe.2013.58055

Rozendal, R. A., Hamelers, H. V. M., Rabaey, K., Keller, J., & Buisman, C. J. N. (2008). Towards practical implementation of bioelectrochemical wastewater treatment. In *Trends in Biotechnology* (Vol. 26, Issue 8, pp. 450–459). https://doi.org/10.1016/j.tibtech.2008.04.008

Wang, W., Chang, J. S., & Lee, D. J. (2022). Integrating anaerobic digestion with bioelectrochemical system for performance enhancement: A mini review. In *Bioresource Technology* (Vol. 345). Elsevier Ltd. https://doi.org/10.1016/j.biortech.2021.126519

5.6 Smart Microgrids

Ahmad, F., Rasool, A., Ozsoy, E., Sekar, R., Sabanovic, A., & Elitaş, M. (2018). Distribution system state estimation-A step towards smart grid. In *Renewable and Sustainable Energy Reviews* (Vol. 81, pp. 2659–2671). Elsevier Ltd. https://doi.org/10.1016/j.rser.2017.06.071

Asmus, P., & Lawrence, M. (2016). *Emerging Microgrid Business Models 1. Executive Summary*.

Blair, B., & de Martini, P. (2020). *Community Microgrid Ownership Models*. http://www.okenergytoday.com/2020/09/us-house-committee-approves-rural-electric-cooperative-

Boche, A., Foucher, C., & Villa, L. F. L. (2022). Understanding Microgrid Sustainability: A Systemic and Comprehensive Review. In *Energies* (Vol. 15, Issue 8). MDPI. https://doi.org/10.3390/en15082906

bsigroup. (2020). *IEC TS 62898-3-4 index*. https://standardsdevelopment.bsigroup.com/projects/9020-04757#/section

Callegari, J. M. S., Pereira, H. A., & Brandao, D. I. (2021, May 5). Coordinated Volt-Var Control in Microgrids. *2021 16th International Conference on Ecological Vehicles and Renewable Energies, EVER 2021*. https://doi.org/10.1109/EVER52347.2021.9456615

Ceja-Espinosa, C., & Espinosa-Juárez, E. (2017). Smoothing of Photovoltaic Power Generation Using Batteries as Energy Storage. *IEEE PES Innovative Smart Grid Technologies Conference*. https://doi.org/10.1109/ISGT-LA.2017.8126758

Chandra, A., Singh, G. K., & Pant, V. (2021). Protection of AC microgrid integrated with renewable energy sources – A research review and future trends. In *Electric Power Systems Research* (Vol. 193). Elsevier Ltd. https://doi.org/10.1016/j.epsr.2021.107036

CrossBoundary Energy Access. (2020). *Open Sourcing Infrastructure Finance for Mini-Grids*.

Desai, S., Alhadad, R., Chilamkurti, N., & Mahmood, A. (2019). A survey of privacy preserving schemes in IoE enabled Smart Grid Advanced Metering Infrastructure. *Cluster Computing*, *22*(1), 43–69. https://doi.org/10.1007/s10586-018-2820-9

Ekanayake, U. N., & Navaratne, U. S. (2020). A Survey on Microgrid Control Techniques in Islanded Mode. In *Journal of Electrical and Computer Engineering* (Vol. 2020). Hindawi Limited. https://doi.org/10.1155/2020/6275460

ena. (2010). *energy networks association "ENA Functional Requirements for Electricity Smart Meters."*

ESMAP. (2017). *Benchmarking Study of Solar PV Mini Grids Investment Costs*.

etap. (2022). *Advanced Distribution Management System – ADMS*. https://etap.com/es/solutions/advanced-distribution-management-system

Fischer, M. T., & Keim, D. A. (2021). *Towards a Survey of Visualization Methods for Power Grids*. http://arxiv.org/abs/2106.04661

Frank, S., Steponavice, I., & Rebennack, S. (2012). Optimal power flow: A bibliographic survey I Formulations and deterministic methods. In *Energy Systems* (Vol. 3, Issue 3, pp. 221–258). https://doi.org/10.1007/s12667-012-0056-y

Gao, F., Kang, R., Cao, J., & Yang, T. (2019). Primary and secondary control in DC microgrids: a review. In *Journal of Modern Power Systems and Clean Energy* (Vol. 7, Issue 2, pp. 227–242). Springer Heidelberg. https://doi.org/10.1007/s40565-018-0466-5

García, S., Mora-Merchán, J. M., Larios, D. F., Personal, E., Parejo, A., & León, C. (2023). Phase topology identification in low-voltage distribution networks: A Bayesian approach. *International Journal of Electrical Power and Energy Systems*, *144*. https://doi.org/10.1016/j.ijepes.2022.108525

Giraldez, J., Flores-Espino, F., Macalpine, S., & Asmus, P. (2018). *Phase I Microgrid Cost Study: Data Collection and Analysis of Microgrid Costs in the United States*. https://www.nrel.gov/docs/fy19osti/67821.pdf.

Gopalan, S. A., Sreeram, V., & Iu, H. H. C. (2014). A review of coordination strategies and protection schemes for microgrids. *Renewable and Sustainable Energy Reviews*, *32*, 222–228. https://doi.org/10.1016/j.rser.2014.01.037

Hirsch, A., Parag, Y., & Guerrero, J. (2018). Microgrids: A review of technologies, key drivers, and outstanding issues. *Renewable and Sustainable Energy Reviews*, *90*, 402–411. https://doi.org/10.1016/j.rser.2018.03.040

Hossain Lipu, M. S., Ansari, S., Miah, Md. S., Hasan, K., Meraj, S. T., Faisal, M., Jamal, T., Ali, S. H. M., Hussain, A., Muttaqi, K. M., & Hannan, M. A. (2022). A review of controllers and optimizations based scheduling operation for battery energy storage system towards decarbonization in microgrid: Challenges and future directions. *Journal of Cleaner Production*, *360*, 132188. https://doi.org/10.1016/j.jclepro.2022.132188

Hughes Cosponsor, J. (2002). *The Integrated Energy and Communication Systems Architecture Volume II: Functional Requirements*. www.epri.com

iec. (2018). *IEC TS 62898-2:2018: Microgrids - Part 2: Guidelines for operation*.

iec. (2022). *IEC - SC 8B Decentralized electrical energy systems: Work programme*. https://www.iec.ch/dyn/www/f?p=103:23:0::::FSP_ORG_ID:20639

IRENA. (2016). *Solar PV in Africa: Costs and markets*. www.irena.org

IRENA. (2019). *Innovation landscape for a renewable-powered future: Solutions to integrate variable renewables*. www.irena.org/publications

IRENA. (2022). *Renewable energy market analysis: Africa and its regions*.
ISGF. (2017). *Smart Grid Handbook for Regulators and Policy Makers*.
Jasim, A., & Jasim, B. (2022). Grid-Forming and Grid-Following Based Microgrid Inverters Control. *Iraqi Journal for Electrical and Electronic Engineering*, *18*(1), 111–131. https://doi.org/10.37917/ijeee.18.1.13
Kanakadhurga, D., & Prabaharan, N. (2022). Demand side management in microgrid: A critical review of key issues and recent trends. In *Renewable and Sustainable Energy Reviews* (Vol. 156). Elsevier Ltd. https://doi.org/10.1016/j.rser.2021.111915
Kauhaniemi, K., & Voima, S. (2015). *Functional requierement of smart grid protection*.
Keisang, K., Bader, T., & Samikannu, R. (2021). Review of Operation and Maintenance Methodologies for Solar Photovoltaic Microgrids. *Frontiers in Energy Research*, *9*. https://doi.org/10.3389/fenrg.2021.730230
Kermani, M., Adelmanesh, B., Shirdare, E., Sima, C. A., Carnì, D. L., & Martirano, L. (2021). Intelligent energy management based on SCADA system in a real Microgrid for smart building applications. *Renewable Energy*, *171*, 1115–1127. https://doi.org/10.1016/j.renene.2021.03.008
Kyriakarakos, G. (2022). Harmonizing the Electricity Markets in Africa: An Overview of the Continental Policy and Institutional Framework towards the African Single Electricity Market. *Sustainability*, *14*(17), 10924. https://doi.org/10.3390/su141710924
M. Rizzato Lede, A., G. Molina, M., Maximiliano Martinez, M., & E. Mercado, P. (2017). Microgrid architectures for distributed generation: A brief review. *IEEE PES Innovative Smart Grid Technologies Conference*. https://doi.org/10.1109/ISGT-LA.2017.8126746
Martínez-Ramos, J. L., Marano-Marcolini, A., García-López, F. P., Almagro-Yravedra, F., Onen, A., Yoldas, Y., Khiat, M., Ghomri, L., & Fragale, N. (2018). Provision of Ancillary Services by a Smart Microgrid: An OPF Approach. *International Conference on Smart Energy Systems and Technologies (SEST)*.
Martin-Martínez, F., Sánchez-Miralles, A., & Rivier, M. (2016). A literature review of Microgrids: A functional layer based classification. In *Renewable and Sustainable Energy Reviews* (Vol. 62, pp. 1133–1153). Elsevier Ltd. https://doi.org/10.1016/j.rser.2016.05.025
Moreno Díaz, L., Luis, J., & Ramos, M. (2017). *State of the Art for the Design and Sizing of Electric Microgrids*.
Nageswara S.V. Rao, Richard R. Brooks, & Chase Q. Wu. (2018). Proceedings of International Symposium on Sensor Networks, Systems and Security. In *Proceedings of International Symposium on Sensor Networks, Systems and Security*. Springer International Publishing. https://doi.org/10.1007/978-3-319-75683-7
oracle. (2011). *Advanced Distribution Management*.
Ovaskainen, M., Öörni, J., & Leinonen, A. (2019). Superposed control strategies of a BESS for power exchange and microgrid power quality improvement. *IEEE International Conference on Environment and Electrical Engineering*.
Papadimitrakis, M., Giamarelos, N., Stogiannos, M., Zois, E. N., Livanos, N. A. I., & Alexandridis, A. (2021). Metaheuristic search in smart grid: A review with emphasis on planning, scheduling and power flow optimization applications. In *Renewable and Sustainable Energy Reviews* (Vol. 145). Elsevier Ltd. https://doi.org/10.1016/j.rser.2021.111072
Rebollal, D., Carpintero-Rentería, M., Santos-Martín, D., & Chinchilla, M. (2021). Microgrid and distributed energy resources standards and guidelines review: Grid connection and operation technical requirements. *Energies*, *14*(3). https://doi.org/10.3390/en14030523
Sadees, M., Vijayakumar, K., & Roselyn, J. P. (2022). Effective Control Strategies for Islanded and Grid-Connected Modes of Operation in Microgrid. *Journal of Applied Science and Engineering (Taiwan)*, *25*(5), 721–730. https://doi.org/10.6180/jase.202210_25(5).0002
SEPA. (2020). *How to Design Multi-User Microgrid Tariffs*. www.sepapower.org.

Serna Torre, P., & Hidalgo-Gonzalez, P. (2022). Decentralized Optimal Power Flow for time-varying network topologies using machine learning. *Electric Power Systems Research*, *212*, 108575. https://doi.org/10.1016/j.epsr.2022.108575
Sohn, J.-M., & Yun, S.-Y. (2016). Software Functional Requirements and Architectures of Microgrid Energy Management System. *KEPCO Journal on Electric Power and Energy*, *2*(2), 269–272. https://doi.org/10.18770/kepco.2016.02.02.269
Song, E. Y., Fitzpatrick, G. J., & Lee, K. B. (2017). Smart Sensors and Standard-Based Interoperability in Smart Grids. *IEEE Sensors Journal*, *17*(23), 7723–7730. https://doi.org/10.1109/JSEN.2017.2729893
Stadler, M., Cardoso, G., Mashayekh, S., Forget, T., DeForest, N., Agarwal, A., & Schönbein, A. (2016). Value streams in microgrids: A literature review. In *Applied Energy* (Vol. 162, pp. 980–989). Elsevier Ltd. https://doi.org/10.1016/j.apenergy.2015.10.081
Stefanidou-Voziki, P., Sapountzoglou, N., Raison, B., & Dominguez-Garcia, J. L. (2022). A review of fault location and classification methods in distribution grids. In *Electric Power Systems Research* (Vol. 209). Elsevier Ltd. https://doi.org/10.1016/j.epsr.2022.108031
usaid. (2018). *What are the technical components of a mini-grid?* https://www.usaid.gov/energy/mini-grids/technical-design/components
van den Broeck, G., Stuyts, J., & Driesen, J. (2018). A critical review of power quality standards and definitions applied to DC microgrids. *Applied Energy*, *229*, 281–288. https://doi.org/10.1016/j.apenergy.2018.07.058
Weston, P., Kalhoro, W., Lockhart, E., Reber, T., & Booth, S. (2018). *Financial and operational bundling strategies for sustainable micro-grid business models*. www.nrel.gov/publications.
Wu, Y., Wu, Y., Cimen, H., Vasquez, J. C., & Guerrero, J. M. (2022). Towards collective energy Community: Potential roles of microgrid and blockchain to go beyond P2P energy trading. In *Applied Energy* (Vol. 314). Elsevier Ltd. https://doi.org/10.1016/j.apenergy.2022.119003
Xiao, S., B. Shadmand, M., & S. Balog, R. (2017). Model predictive control of multi-string PV systems with battery back-up in a community dc microgrid. *IEEE Applied Power Electronics Conference and Exposition (APEC)*. https://doi.org/10.1109/APEC.2017.7930861
Zheng, D., Zhang, W., Netsanet Alemu, S., Wang, P., Bitew, G. T., Wei, D., & Yue, J. (2021). The concept of microgrid and related terminologies. *Microgrid Protection and Control*, 1–12. https://doi.org/10.1016/B978-0-12-821189-2.00008-5

5.7 Climate proofing

European Commission. (2013). *An EU Strategy on adaptation to climate change*.
European Commission. (2021). *Technical guidance on the climate proofing of infrastructure in the period 2021-2027*.
iaea. (2019). *Adapting the Energy Sector to Climate Change*. https://www-pub.iaea.org/MTCD/Publications/PDF/P1847_web.pdf
iea. (2022). *Africa Energy Outlook 2022*.
Riello UPS. (2022). *Riello UPS: Lifespan of UPS batteries*.
Tecnalia. (2020). *Guía para el análisis detallado de riesgo climático. Caracas: CAF*. http://scioteca.caf.com/handle/123456789/1631
UN-Habitat. (2021). *Climate proofing toolkit for basic urban infrastructure, with a focus on water and sanitation*. www.unhabitat.org
wbg. (2019). *Overview of Engineering Options for Increasing Infrastructure Resilience*. https://documents1.worldbank.org/curated/en/620731560526509220/pdf/Technical-Annex.pdf

Annex I: Reference checklist of functionalities

Complementary to the identification of functionalities developed in the previous section, this Annex 1 provides a concise checklist of functionalities, structured by the involved technologies, and their possible application or final use (residential, agriculture, business, etc.), in order to allow the registering and tracking of the actual deployment of these functionalities in the different Living Labs.

This form also includes the present matching between those technologies and the living labs that are considering their deployment.

The list of technologies, their possible application, their related functionalities, and their matching with the Living Labs will be permanently reviewed and updated during the rest of the SESA project according to the actual technologies and their application finally deployed.

The following tables include that mentioned reference checklist of functionalities as a guideline for the evaluation of its deployment in the Living Labs.

TECHNOLOGY	TECHNICAL & FUNCTIONAL REQUIREMENTS	DEPLOYMENT STATUS (indicate the innovation level or features of the functionalities)									COMMENTS
		Kenia	Morocco	South Africa	Ghana	Malawi	Namibia	Nigeria	Rwanda	Tanzania	
Solar photovoltaic (PV) system (general functionalities)	General Functionalities										
	Basic measurements										
	Atmospheric condition sensing										
	PV panels monitoring										
	Inverter monitoring										
	Inclination of PV panels										
	Movements of PV structure										
	Maintenance										
	Remote monitoring										
	User interfaces										
	Irradiance/production forecast										
	Solar PV for water-energy nexus technologies (agriculture)										

TECHNOLOGY	TECHNICAL & FUNCTIONAL REQUIREMENTS	DEPLOYMENT STATUS (indicate the innovation level or features of the functionalities)									COMMENTS
		Kenia	Morocco	South Africa	Ghana	Malawi	Namibia	Nigeria	Rwanda	Tanzania	
	PV location/integration issues										
	PV inclination (season needs)										
	Pumping needs-oriented control										
	Solar PV for residential or public services										
	PV orientation/inclination (i.e., roof)										
	Maintenance (usually preventive)										
	BIPV integration strategies										
	Energy needs-oriented control										
	Solar PV for e-mobility										
	PV location/integration issues										
	Energy needs-oriented control										
	<Other applications>										
Batteries (general functionalities)	**General Functionalities**										
	Technical datasheet information										
	Battery monitoring & control level										
	User interfaces										
	Battery thermal management system										
	Fire suppression system										
	Electrical safety functionalities										
	Maintenance										
	Second-life batteries										

TECHNOLOGY	TECHNICAL & FUNCTIONAL REQUIREMENTS	DEPLOYMENT STATUS (indicate the innovation level or features of the functionalities)									COMMENTS
		Kenia	Morocco	South Africa	Ghana	Malawi	Namibia	Nigeria	Rwanda	Tanzania	
	Second-life battery development procedure										
	Second-life battery characterization										
	Batteries for Solar energy storage										
	Inverter and local grid compatibility										
	User app for remote monitoring										
	Tailored EMS for PV and local grid code compliance										
	Battery metering device										
	Stationary batteries in electric charging infrastructure										
	Inverter and EV charging protocol compatibility										
	Tailored EMS for peak shaving and local grid code compliance										
	Higher environmental degree										
	Battery metering device										
	Batteries for electric mobility										
	Monitoring interfaces with on-board charging management systems										
	Batteries for residential and productive use										
	Monitoring interfaces										
	Residential/productive use adaptation to battery conditions										

TECHNOLOGY	TECHNICAL & FUNCTIONAL REQUIREMENTS	DEPLOYMENT STATUS (indicate the innovation level or features of the functionalities)									COMMENTS
		Kenia	Morocco	South Africa	Ghana	Malawi	Namibia	Nigeria	Rwanda	Tanzania	
	<Other applications>										
e-Mobility	e-Mobility: Electric vehicle										
	e-Mobility battery requirement										
	e-Mobility motor requirements										
	e-Mobility safety requirements										
	e-Mobility charging requirements										
	e-Mobility: Battery swapping										
	Position of the battery										
	Swapping method										
	Compatibility between components										
	Battery pack dimensions										
	Advanced interoperability features										
	Electrical interface protections										
	Data management and cloud storage										
	Adapted communication interfaces										
	Charging prices management										
	User payment method										
	Battery handling systems										
	e-Mobility: Charging infrastructure										
	Support and configuration of different charging modes (power, time, etc.)										
	Availability of connector types										
	Control of the charging process										

TECHNOLOGY	TECHNICAL & FUNCTIONAL REQUIREMENTS	DEPLOYMENT STATUS (indicate the innovation level or features of the functionalities)									COMMENTS
		Kenia	Morocco	South Africa	Ghana	Malawi	Namibia	Nigeria	Rwanda	Tanzania	
	Monitoring of the status of the charging infrastructure										
	Monitoring of the charging processes										
	Processing of monitoring data										
	Remote charging management systems										
	Charging prices management										
	Charging roaming										
	Interaction with the customers apps										
	Line system protection features										
	Smart grid charging features										
	Integration with local RES generation										
	Integration with local electricity storage										
	Vehicle to Home (V2H) features										
	Vehicle to Building (V2B) features										
	Vehicle to Grid (V2G) features										
	Vehicle to Vehicle (V2V) features										
Bio-cooker, cookstoves (Clean cooking)	Feedstock compatibility										
	Measurement/control of PM and CO										
	Fuel/Biomass intake management										
	Flame control										
	Intake consumption monitoring										
	Cooking time control										
	Waste management: Char collection										
	Char production measurement										

TECHNOLOGY	TECHNICAL & FUNCTIONAL REQUIREMENTS	DEPLOYMENT STATUS (indicate the innovation level or features of the functionalities)									COMMENTS
		Kenia	Morocco	South Africa	Ghana	Malawi	Namibia	Nigeria	Rwanda	Tanzania	
	Electricity production										
	Durability/maintenance										
Biodigesters	Waste compatibility										
	Feedstock treatment and feeding										
	Acidity (pH) monitoring and control										
	Temperature monitoring/control										
	Mixing technique and control										
	Chemical Oxygen Demand ratio										
	Hydraulic Retention Time (HRT)										
	Organic Loading Rate (OLR)										
	Inoculation technique and control										
	Voltage source										
Smart Microgrids	Microgrid design and planning										
	Energy dispatch optimization										
	Market trading										
	Forecasting										
	Maintenance										
	Load monitoring and metering										
	Billing and payment method										
	Self-consumption										
	Demand-side management										
	Monitoring and control systems										
	Microgrid power control										
	Microgrid protection										

TECHNOLOGY	TECHNICAL & FUNCTIONAL REQUIREMENTS	DEPLOYMENT STATUS (indicate the innovation level or features of the functionalities)									COMMENTS
		Kenia	Morocco	South Africa	Ghana	Malawi	Namibia	Nigeria	Rwanda	Tanzania	
	Microgrid power quality										
Climate Proofing	Monitoring daily data from energy systems										
	Monitoring weather conditions										
	Climatic hazard assessment										
	Climate impact diagnosis										
	Climate adaptation										

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