CATALOGUE OF ENERGY SOLUTIONS

Wuppertal Institute (WI)

WP 3

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Abstract	The present document is a complete and partner-validated draft of the Sustainable Energy Solutions catalogue which will be made available to the public in 2023 in a professionally designed publication format. The catalogue is composed of ten factsheets. Each factsheet focuses on a specific sustainable energy solution or cross-cutting aspect that is relevant within the SESA Living Labs. Factsheets cover both technological and business aspects of the solution, as well as other key dimensions that are relevant for the target audiences.

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List of Abbreviations

ABC	Anchor Business Community
AC	Alternating current
AEI	Africa Electrification Initiative
AMI	Advanced Metering Infrastructure
BMS	Battery management system
BoS	Balance-of-system, Balance-of-system
CCKP	Climate Change Knowledge Portal
CCPT	Clean Cooking Planning Tool
CO	Carbon monoxide
CO	Carbon monoxide
CSM	Cylinder Smart Meter
DC	Direct current
EaaS	Energy-as-a-service
ECREEE	ECOWAS Regional Centre for Renewable Energy and Energy Efficiency
EEE	Electrical and electronic equipment
EoL	End of life
EPC	Energy Performance Contracting
EPR	Extended Producer Responsibility
ESCO	Energy Service Company
ESMAP	Energy Sector Management Assistance Program
ESS	Energy storage system
EU	European Union
EV	Electric vehicle
FFS	Fee-for-service
FIT	Feed-in Tariff
GDP	Gross domestic product
GFDRR	Global Facility for Disaster Reduction and Recovery
GHG	Greenhouse gas
GIS	Geographic Information System
GIZ	Gesellschaft für internationale Zusammenarbeit
ICE	Internal combustion engine
ICT	Information and communication technologie
IoT	Internet-of-Things
IPCC	Intergovernmental Panel on Climate Change

LEIA	Low Energy Inclusive Appliances
Li-ion	Lithium-ion
LPG	Liquified Petroleum Gas
MEPS	Minimum Energy Performance Standards
MSME	Micro, Small and Medium Enterprise
MTF	Multi-Tier Framework
NGO	Non-Governmental Organisation
NREL	National Renewable Energy Laboratory
OEM	Original Equipment Manufacturers
OGS	Off-grid solar
OSA	Operating Services Agreement
PAYGO	Pay-as-you-go
PM	Particulate Matter
PPA	Power Purchase Agreement
PPP	Public-private partnerships
PREO	Powering Renewable Energy Opportunities
PSA	Purchase and Sale Agreement
PSS	Productive Service System
PUE	Productive use of energy
PV	Photovoltaic
SAIL	Sustainable Agriculture Investments and Livelihoods
SESA	Smart Energy Solutions for Africa
SHS	Solar Home System
SLB	Second-life batterie
SME	Small and medium-sized enterprise
SPIS	Solar-powered irrigation system
SSA	Sub-Saharan Africa
SUMP	Sustainable Urban Mobility Plans
SWP	Solar Water Pump
TNC	Transportation Network Companie
UCT	University of Cape Town
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
WEF	Water-Energy-Food

ITDP	Institute for Transportation and Development Policy		WHO	World Health Organization
IWMI	International Water Management Institute		WI	Wuppertal Institute
KPI	Key-Performance-Indicator			

SESA Smart Energy Solutions for Africa

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Executive Summary

The present document is a complete and partner-validated draft of the Sustainable Energy Solutions catalogue which will be made available to the public in 2023. The catalogue has a two-fold aim:

- Internally: informs the implementation of SESA validation and replication sites (WP 4) and supports them by providing an introduction to the solutions that can be used in engagement with different actors (e.g., local government, civil society).
- Externally: informs and inspires outside audiences regarding the range of potential solutions and lessons learned during SESA implementation.

The catalogue is composed of ten factsheets. Each factsheet focuses on a specific sustainable energy solution or cross-cutting aspect. Factsheets cover both technological and business aspects of the solution, as well as other key dimensions that are relevant for the target audiences.

The catalogue is to be updated with lessons learnt from the implementation of the living labs over 2023 and 2024.

The development of the catalogue is led by Wuppertal Institute (WI) but each factsheet was co-created with inputs from stakeholders. Review rounds were central to the development process.

The list of factsheets was developed in consultation with partners, drawing from an identification of the main themes recurring in the living labs.

Introduction

SESA (Smart Energy Solutions for Africa) 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.

The present document is a complete and partner-validated draft of the Sustainable Energy Solutions Catalogue. The final version, incorporating further details from the Living Labs, will be made available to the public in 2023 in a professionally designed publication format.

The energy solutions catalogue has a two-fold aim:

- Internally: informs the implementation of SESA validation and replication sites Work Package (WP) 4 and supports them by providing an introduction to the solutions that can be used in engagement with different actors (e.g., local government, civil society).
- Externally: informs and inspires outside audiences regarding the range of potential solutions and lessons learned during SESA implementation. This is achieved with the support of WP 6 (Exploitation and Dissemination)

Approach to the task

Between January and March 2022, the goals, scope and format of the Sustainable Energy Solutions Catalogue were discussed among WP3 partners, and a guiding concept note was developed. As a result of the discussion, the key features of the catalogue can be summed up as follows:

- provides basic facts about the solutions tested within SESA, as well as relevant cross-cutting aspects
- targets African businesses and practitioners, policy makers and civil society, especially at a local level
- is composed of 10 factsheets, each covering a specific sustainable energy solution or cross-cutting topic of relevance for solutions tested within SESA (Figure 1).

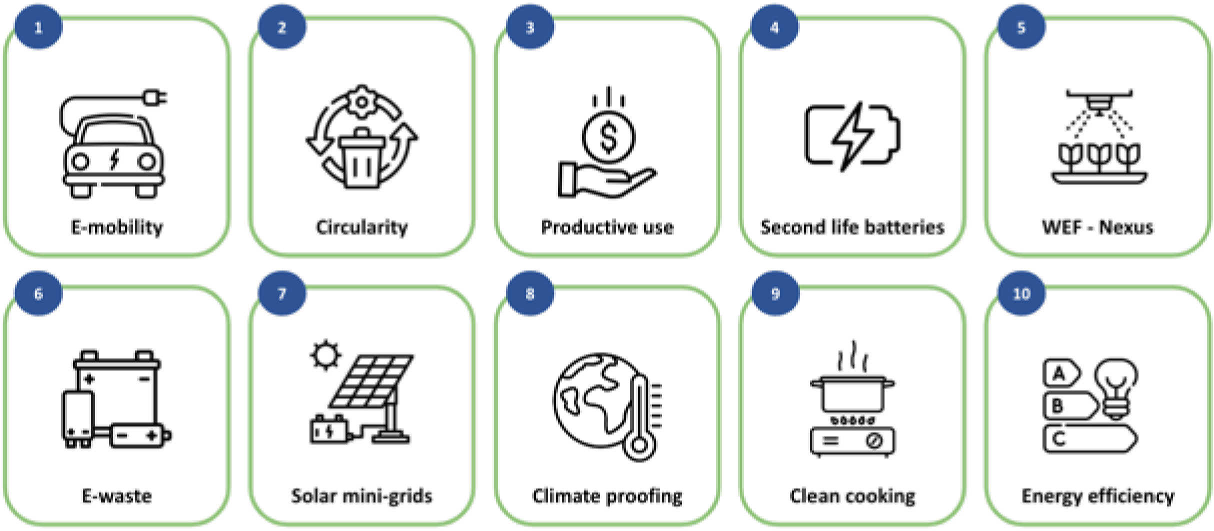

Figure 1. Overview of the Factsheet contents

Moreover, the following timing and approach considerations were agreed upon:

- The catalogue should be a user-friendly and visually engaging knowledge product available through the SESA toolbox (WP1), also downloadable in pdf version. The ten factsheets will be published as ten separate documents (hence the need to repeat a number of sections, so that each factsheet can stand alone, e.g., "About the Sustainable Energy Solutions Catalogue)
- A complete version of catalogue is to be developed by Month 15 and published as a professionally designed publication in early 2023. The contents will then be updated with lessons learnt from the implementation of the living labs in late 2023 and 2024.
- The development of the catalogue is led by WI, but each factsheet is co-created with inputs from the 12 partners that contribute to Task 3.1. Review rounds are central to the development process.
- The ten factsheets follow a common structure:
    - About the Sustainable Energy Solutions Catalogue (section appears in each factsheet)
    - Introduction
    - Technology
    - Business and financing models
    - Socio-economic and sustainability impacts
    - Scaling up
    - Solutions in SESA
    - Examples of application in the African context
    - Climate proofing
    - Relevant tools and capacity building materials
    - Bibliography

1 Sustainable e-mobility

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1.1 About the Sustainable Energy Solutions Catalogue

The Sustainable Energy Solutions Catalogue provides an introduction to the solutions deployed during the SESA project. The catalogue targets energy practitioners, policy makers and civil society, especially at local level. In the catalogue, readers can find key facts about specific sustainable energy solutions (technologies, business models, impact areas), or learn about approaches and concepts that help ensure the viability and long-term success of sustainable energy in the African context.

1.2 Introduction

Sustainable electric mobility (e-mobility) encompasses a set of solutions in which innovative electric vehicle technologies and business models are combined to improve mobility services in cities, peri-urban and rural areas. They can contribute to reducing local air pollution and greenhouse gas emissions, while increasing productivity and access to jobs, improving health and also supporting gender-equality and inclusion. Though e-mobility solutions are only recently emerging in Africa (Figure 2), they are likely to play a key role in the transition to sustainable and inclusive mobility in the region.

This factsheet introduces different facets of sustainable e-mobility solutions and examples of their application, with a particular emphasis and application to the African context.

Figure 2. Electric Boda Bodas (EEP Africa, 2020)

1.3 The technology

Sustainable e-mobility solutions are based on different types of electric vehicle technologies related to vehicles, but also to charging infrastructure, power sources (preferably renewable), energy storage, and Information and Communication technologies (ICT).

1.3.1 Electric vehicles

Electric vehicles (EVs) are fully or partly propelled by **electric motors**, using energy stored in **rechargeable batteries** and obtaining their electricity from an external source (see Figure 3).

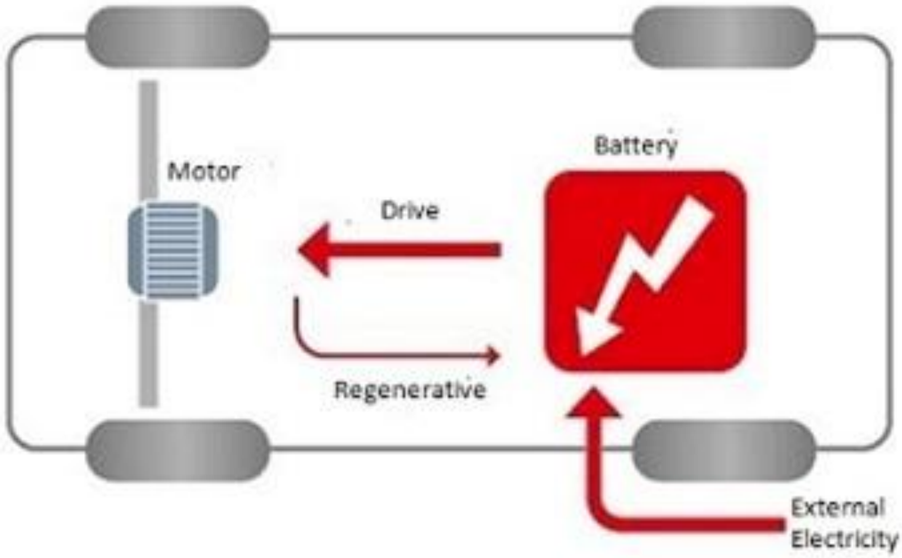

Figure 3. Schematic description of Battery Electric Vehicle (Omazaki Group, 2019)

The following are some of the key technological features of e-mobility:

Regenerative braking is unique to EVs and enables the vehicle's kinetic energy to be recovered and converted into electrochemical energy during braking in the batteries (deceleration or downhill running). Through this mechanism, the electric vehicle´s energy efficiency can be improved. By not burning petrol, gasoline or diesel, these vehicles produce zero emissions or no harmful air pollutants such as suspended particles while running.
The factsheet focuses on electric light duty vehicles such as e-motorcycles (or “e-boda-boda”, as they are often called in the East-African context), e-tuk-tuks or tricycles, e-bicycles, and e-cargo bikes (Conzade et al., 2022). These are the most common types of EVs deployed in African urban and rural areas, where 2- and 3-wheeled vehicles represent an important means of transport. It is estimated that by year 2040, 2-and 3-wheelers will make up between 45-57% of the total vehicle fleet in Sub-Saharan Africa (SSA) (Conzade et al., 2022).

Vehicle conversion from internal combustion engine (ICE) to electric engine: often, an ICE vehicle can be converted into an EV. For this, an electric motor and a battery, for example a lithium-ion battery, needs to be installed, while the regular motor and fuel tanks need to be removed (Thomas et al., 2020). EV conversion is a common approach in e-mobility businesses (See also Business Models).

In the context of e-mobility, the **driving range** of an EV plays an important role. The driving range is the distance that an EV can be driven with the energy stored in its battery. It can depend on the battery capacity and the battery ageing, how the vehicle is driven, external conditions such as hot weather and the weight of the vehicle (Evenergi, 2022), and the driving route. The driving range influences the choice of vehicle and vice versa. It also directly influences the choice of the business model that is used, for example **battery swapping** is a viable option to support driving range, especially for off-grid, rural areas (see also Business Models) (Roam Motors, 2021).

While the focus of this factsheet is on fully electric mobility, it is important to note that other technologies such as hybrid EVs - where part of the power comes from an ICE - and fuel cell vehicles are currently under development for the African market (ESI Africa, 2022a).

1.3.2 Power Source

The source of electricity to power EVs, defines the economics and environmental impact of any e-mobility solution. When the electricity is generated from renewable energy sources such as solar photovoltaics (PV), the greenhouse gas emissions of the vehicle are significantly lower than in a conventional petrol or diesel-fuelled vehicle. Additionally, cities are less polluted, so there is better air quality and the costs for used energy are lower than with petrol or diesel for the same distance (Atlas Renewable Energy, 2021). The locally sourced renewable energy reduces the fossil fuel import in the country. Two major ways of producing low-carbon electricity for electric mobility application are:

- **Off-grid:** Solar PV mini-grids are often used to charge EVs in African semi-rural and rural areas, and often combined with other uses for the electricity, such as household self-consumption or productive use applications (ESI-Africa, 2022b). Solar mini-grids (Figure 4) often include a diesel generator as a source of back-up power. The charging of EVs can also be managed strategically to optimise the economic dispatch of generator assets to meet the loads of the minigrid. For more details, see also the Productive Use of Energy (PUE) factsheet.
- **Grid-tied:** Powering EVs through grid electricity is the most common technological option. Importantly, the grid-based electricity mix of many African countries has a high share of renewables. However, grid reliability poses a challenge, and significant investments may be required before this option is viable (TechCabal, 2021).

Figure 4. PV Minigrid in Niger State, Nigeria (Soventix, 2022)

1.3.3 Energy storage

The key component of EV technology is the battery – its type and capacity. Battery costs alone can make up to one-third of total vehicle costs (Status 2021, König et al., 2021) and ultimately represent a key criterion for the economic viability of the solution. Lithium-ion (Li-ion) batteries, which are mainly produced in Asia, currently dominate the African market, with new technology trends such as silicon or lithium anodes, solid state cells or new cathode materials on the horizon (Siemens Stiftung, 2020). Key battery technologies include:

- **Li-ion batteries** have several advantages and are therefore commonly used for EV batteries. They have one of the highest energy densities of any battery technology today and can deliver large amounts of current for high-power applications for EVs. They also have comparatively low maintenance, and do not require scheduled cycling to maintain their battery life. The prices of Li-ion batteries are constantly falling, having dropped by roughly 89% since 2010 (Sono Motors, 2021). As research in electrochemistry is booming, the prices will most probably keep on falling, making EVs using Li-ion batteries more affordable.
- **Lead-acid batteries** are more affordable up front, but they require regular maintenance and have a shorter lifespan than Li-ion batteries (Unbound Solar, 2020). The informal recycling or improper handling of used lead-acid batteries has considerable health and environmental impacts.
- **Solid-state batteries** are an emerging option for next-generation traction batteries promising low cost, high performance and high safety (Kurzweil & Garche, 2017)**.**

When an EV battery reaches end of life (EoL), holding only a set percentage of its original storage capacity ('retained capacity'), it is often still usable in less demanding energy-storage applications like consumer devices or even in EVs (ION Energy, 2019) (see Sustainability impacts and e-waste and 2nd Life battery factsheets).

1.3.4 Charging Infrastructure

An adequate and proper planning of EV charging infrastructure is a prerequisite for the widespread adoption of e-mobility solutions (Mukeredzi, 2021). There are different charging technologies, such as wired (conductive) and wireless systems. They can be placed at public or private/home charging stations. Battery swapping, mainly for light duty vehicles, is a viable solution in off-grid or weak grid markets.

The selection of charging infrastructure technologies influences business models (see Business Model section).

1.3.5 ICT components

ICT and **Internet-of-Things (IoT) -based technologies** are key **enablers** for sustainable electric mobility and are at the core of the innovative business models that are being deployed in African cities and rural areas, for example in the SESA living labs (See SESA examples section).

Real-time battery charge levels, location of nearest charging infrastructure, route options to optimise battery performance and energy price in a given charging area are some of the examples of information that makes the whole EV system efficient and economically viable (Alahmad, 2016). Meters and sensors are not only integrated in the vehicle but also in the power source (e.g., solar mini-grids) and storage systems (IoT-based battery monitoring, remote immobilisation capabilities).

In terms of shared mobility, **digital platforms** - app-based, and on-demand transportation services that connect the driver and the users - are emerging in e-mobility, similar to those used in Transportation Network Companies (TNCs) like taxifier, Uber, and Lyft (Sovacool et al., 2022).

The success of mobile or cashless payment options for e-mobility also relies heavily on ICT systems.

1.4 Business and financing models

E-mobility businesses in the African context use a range of models that are designed to respond to the existing barriers of EV adoption, especially in emerging markets: high up-front costs for lithium-ion batteries and EVs, limited availability of charging infrastructure and limited driving range (Weiller et al., 2015).

Many EV business models in Africa are centered around passenger services such as boda-bodas (2-wheelers) and tuk-tuks (3-wheelers), which serve as taxis. Other business models target the transport of goods in light-duty vehicles, or vehicles that are used by service providers, healthcare services, or tourist guides.

Business models vary significantly depending on the type of customer and local market context. User needs and the ability to pay are crucial initial factors to be considered while designing an appropriate and sustainable business model. All business models can help create skills locally.

The following are some key common elements of e-mobility business models in the African context.

1.4.1 Vehicle sharing

E-mobility business models in the African context rely strongly on shared economy approaches to make the solutions affordable to users. Direct sales of EVs to private households are rare and sharing a vehicle is common. ICT facilitates the shared vehicle approach. Vehicle-sharing apps offer around the clock access to vehicles to registered customers, and the user only pays for the mobility service. An example for this is the South African company Jumpin Rides.

1.4.2 Battery swapping and leasing

Battery-swapping (Figure 5) is an essential element of e-mobility business models in off-grid and weak-grid contexts. In this approach, charged batteries (for example charged via solar mini-grids) are rented out to electric 2- or 3- wheelers´ drivers until they are discharged, and the driver returns to a battery swapping station. This is a viable model for commercial riders who do not have much time between vehicle charges (Mobile Power, 2022). Swapping batteries in small 2- and 3-wheel vehicles is relatively easy and time-efficient. The advantage of battery swapping is a shorter vehicle downtime (in the range of minutes), compared with a current three to four hour charging time, depending on the type of charger.

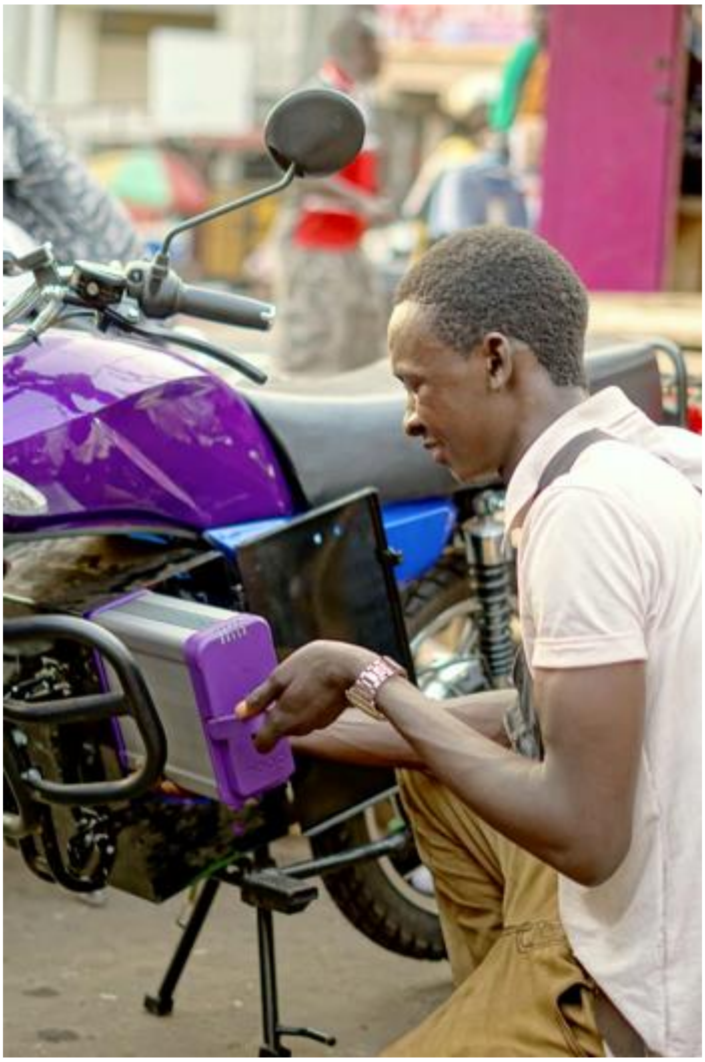

Figure 5. Mobile Power battery swapping (Mobile Power, 2022)

1.4.3 Consumer financing: PAYGO, lease-to-own and pay-per-use

In recent years, the Pay-as-you-Go (PAYGO) consumer financing model, which is already common in Solar Home Systems, has been increasingly adapted to e-mobility in Africa. The PAYGO model is suitable for customers who cannot afford paying for EVs upfront, but can pay in customisable monthly, weekly or daily instalments when the customer wants to use the service or is able to pay for the service. The companies therefore not only provide the product and services, but they also provide the necessary finance to consumers (Energypedia, 2022). The customer can also use the PAYGO approach to finance the purchase of the vehicle ("lease-to-own"), meaning the customer finally owns the asset at the end of a certain period.

The pay-per-use or fee-for-service () concept is also relevant for e-mobility. It does not include eventual ownership, but it is interesting for many customers, most of all if a vehicle is not used on a daily basis (Siemens Stiftung, 2020). The downside of the FFS approach is the high investments required, namely purchasing and installing of devices as well as establishing the necessary service infrastructure. It takes a long time to amortise the investments through the revenues of services (Energypedia, 2022).

Mobile money payment systems often go hand-in-hand with PAYGO and FFS business models.

1.4.4 E-conversion

A common element of e-mobility business models is that they rely on the conversion of conventional ICE vehicles into EV (Page, 2022). It is relatively easy and cost-effective to convert a small vehicle with an ICE into an EV (see Technology Section). This reduces costs and time of fleet development, and allows businesses to match the EVs to local users' needs. Moreover, it can create technical skills of local people.

E-conversion also contributes to circular economy approaches, as it includes the retrofitting of former non-electrical cars and therefore saves resources (see SESA examples section below, and Circular Economy factsheet).

1.5 Socio-economic and sustainability impacts

The impacts of sustainable e-mobility solutions cover the areas of health, climate change, circular economy, gender-equality and inclusion, among others. These areas are treated here.

1.5.1 Health

Across Africa, rapid urban population growth is leading to an increase in vehicle emissions. The lack of public transport paired with imports of high-emission vehicles contributes to the increasing health impacts of the transport sector in the region. Premature deaths in Africa from outdoor air pollution increased by almost 60% between 1990 and 2017 (Gurzu, 2021).

The particulate matter (PM) emissions of e-bikes on a person-km basis are lower in comparison to other transport modes, even when including lifecycle emissions (Bakker, 2019). Nevertheless, the choice of electricity source significantly influences the local pollution effects of EV mobility. The most significant improvements emerge when EVs use electricity produced through renewable energy sources.

Sustainable e-mobility can contribute to reducing greenhouse gas emissions from the transport sector. In Thailand, it is estimated that replacing conventional motorcycles with e-motorcycles would result in a 42% to 46% reduction of two-wheeler life cycle greenhouse gas (GHG) emissions (Bakker, 2019).

1.5.2 Circular Economy

An increased uptake of e-vehicles can potentially lead to an increase in extraction of scarce minerals (see more about this in the Second-life Batteries and Circularity factsheets), as well as to growing e-waste and battery waste streams. The latter are already a significant challenge in many African countries. Apart from the electronic waste produced in Africa itself, countries of the global South have become the primary destination for used electrical and electronic equipment (EEE) exports by countries of the global North (Asante et al., 2019).

Appropriate treatment of e-waste avoids health risks caused by the exposure to harmful substances (WHO, 2022). Efforts are underway to develop the needed legislation, infrastructure, value chains and skills for sustainable end-of-life treatment of e-waste and used batteries in Africa, and many e-mobility businesses integrate solutions to this challenge (See E-waste factsheet).

One key disposal option is battery reuse. Lithium-ion batteries, which are commonly used for EVs, still maintain 70-80% of their initial capacity at the end of their life-cycle. The remaining capacity of a battery can be used for less demanding applications, for example consumer devices or energy-storage application (See 2^{nd} life Li-ion batteries factsheet) (ION Energy, 2019). Also, batteries can be recycled and raw materials extracted for second use (EPA, 2019).

1.5.3 Gender equality and inclusion

Lack of time, financial resources, vehicle frequency or a higher risk of exposure to crime and violence are some of the factors impeding access to mobility (SUTP, 2018). Especially for women, the universal access to mobility is essential to reach educational and health facilities and gain access to markets (Women Feed Africa, 2022).
Sustainable e-mobility solutions can potentially increase inclusion in the provision of mobility services.

Different business models for e-mobility in the African context are geared towards women as drivers or passengers and aim to meet the specific needs of low-income households, rural populations or marginalised groups. E-mobility startups that focus on women living in rural areas (e.g., Mobility for Africa (MFA), see Figure 6) try to encourage female drivers/passengers by providing affordable renewable-energy charged vehicles (Mobility for Africa, 2022). (See also: “Gender Sensitive Mini-Bus Services & Transport Infrastructure for African Cities: A Practical Toolkit” in section: Relevant tools & Capacity building material).

Figure 6. Sustainable e-mobility solutions can potentially increase inclusion in the provision of mobility services. Mobility for Africa project (EEP Africa, 2022)

1.5.4 Employment creation

E-mobility can potentially create employment opportunities, in particular through local assembly, manufacture, conversion and maintenance of vehicles. Local vehicle assembly can potentially create national and regional supply chains for the manufacturing process (Conzade et al., 2022).
Local EV manufacture has the advantage of designing the vehicles meeting local needs and conditions. The lack of affordable mobility solutions hinders people from accessing jobs so that by implication, affordable mobility facilitates the participation in the job market (Siemens Stiftung, 2020).

1.6 Scaling-up

The African continent has one of the lowest motorisation levels in the world, while at the same time it is facing one of the fastest vehicle growth rates. Sustainable e-mobility has significant replication potential: in six countries that make up around 70 % of Sub-Saharan Africa's annual vehicle sales and 45 % of the region's population (South Africa, Kenya, Rwanda, Uganda, Ethiopia, and Nigeria), the vehicle fleet is expected to grow from 25 million vehicles today to approximately 58 million by 2040 (Conzade et al., 2022). This represents a rapid growth in vehicle demand.

Another opportunity for the replication of sustainable e-mobility solutions is the large young population open to new technologies. Realising the replicability potential will require investments in the local value chain as well as skills development, legislation and enabling environment. In order to enhance the uptake of e-mobility, policies play an important role (Siemens Stiftung, 2020). In general, a mix of financial incentives, traffic regulations and infrastructure measures can be beneficial to reach the goal of widespread use of e-mobility. In early-stage markets, policies for e-mobility should be directed towards overcoming entry barriers in the market. This can be achieved by expanding EV model availability, the affordability of EVs, acceleration of EV deployment across public and private fleets, the development of a widespread charging infrastructure as well as the raising of public awareness.

1.7 Sustainable e-mobility solutions in SESA

Implemented in nine African countries, the EU-funded SESA project is developing and testing solutions to accelerate the green energy transition and energy access in Africa. The focus of the project is on the exploration of innovative technologies and services in urban and rural contexts. SESA partners in various countries are working on sustainable e-mobility solutions. Their activities are briefly outlined below.

1.7.1 E-bikes in Kisumu and Homabay counties, Kenya

Figure 7. E-motorcycle at the Katito Hub in Kisumu County, Kenya (Own image, 2022)

The social enterprise **WeTu** in Kenya, founded by the Siemens Stiftung, works on innovative solutions for e-mobility, safe drinking water and solar lighting and charging. It already owns and operates seven solar powered hubs in Kisumu County, close to Lake Victoria.

The main objective in the SESA living lab Kenya is to develop a modular demonstration project to provide sustainable energy access solutions that are relevant for validation and replication in both urbanized and rural contexts in Africa, creating opportunities to generate sustainable **off-grid electricity**, with **sector linkages** such as fishing, water pumping, water purification, **e-mobility** and waste management and combining energy solutions with local Info Spots for access to information, on energy, climate change and digital skills. The proposed modular demonstration case aims to address the three main innovation focus areas in energy transitions, namely access, productive use, and a circular economy.

Within SESA, WeTu activities are carried out at two project sites, Kisegi, a rural village in Homa Bay county, and Katito, a peri-urban community in Kisumu County. Both demonstrations are solar charging hubs that incorporate PV modules, central Li-ion battery storage, and balance-of-system (BoS) to increase energy accessibility for a range of electrical needs within the local community, among others the provision of **e-motorcycles in the peri-urban demonstration site in Katito** (see Figure 7). The two-wheeler motorcycles for the two demonstration sites are converted from **internal combustion engines** to **electric drive trains.**

1.7.2 Electric Vehicle Components in Alicedale and KwaNonzwakazi, South Africa

In the South African validation demonstration project, the activities are located in the Eastern Cape township of Alicedale and the semi-rural area KwaNonzwakazi on the outskirts of Alicedale. The main beneficiaries of the activities will be the local community of KwaNonzwakazi. Although the area has access to electricity, the supply is unreliable and there are prolonged blackouts. Access to reliable, affordable transport is a challenge as a majority of the population cannot afford to pay costs for transport. Furthermore, there is a lack of access ICT infrastructure, cost of access and cost of devices.

The demonstration innovation will include **electric vehicle batteries** and stationary storage applications, as well as the provision of infospots for internet access. The off-grid community energy hubs will **support a range of local community activities**. The demonstration site will aim to test, validate and replicate a containerized off-grid renewable energy system consisting of energy storage, together with a **small fleet of micro-utility electric vehicles.** The demonstration will extend the productive use of renewable energy for the community, and also **offer sustainable charging of a small fleet of micro utility vehicles**.

Also, the validation site will show the value and repurposing potential of electric vehicle batteries for stationary storage applications.

The overarching goal of the aim of the project is to investigate the performance of these batteries, the technical and financial viability of such systems, as well as the scalability and replicability of this use case. The demonstration will also identify the commercial case for local authorities to invest in these solutions and study the repurposing potential of retired EV batteries for energy storage and as a means to create new jobs.

1.7.3 E-motorbikes and e-scooters for female students in Marrakech, Morocco

E-mobility is considered a fundamental aspect of Morocco´s energy transition. Marrakesh traffic is inseparable from motorcycles, which will, also in future scenarios, remain the most common mode of transport, especially among the middle- and low-income households. Fossil fuel powered transportation causes severe pollution, making Marrakesh the second most polluted Moroccan city. Marrakesh is also a university city in the region (University Cadi Ayyad), hosting a large group of students from the small surrounding villages. Current local transportation modes, such as buses, are often expensive and unreliable, causing many Moroccan students, mainly female students, to drop out of university without a diploma. The overall objective of this urban demonstrator is to provide **electric motorcycles for female students** from around Marrakech.

Within SESA, **Green Energy Park**, a solar energy testing, research and training platform located in BenGuerir, plans to equip 40 female riders with 40 by August 2023. Furthermore, the provision of 10 e-scooters is planned, together with charging cables and a scooter leasing app. The fleet will work through an **e-share concept**. The energy for charging the batteries for the vehicles will come from solar panels installed in a **mini-grid**, and the charging infrastructure works through a **battery swapping system**, supported by a **digital platform for tracking and monitoring** of performances, e-payment integration and publicity.

1.8 Examples of application in the African context

Zembo (Zero Emission Motorcycle Boda), Kampala (Uganda)

The idea: Zembo sells and leases electric motorcycles to boda-boda drivers and recharges batteries in its solar stations.

The power source:
- High capacity, lithium technology battery
- Recharged in solar stations.

The business model:
- Lease-to-own: drivers lease the motorcycles with a payment period of two years to reach full ownership
- Affordable weekly fees, free maintenance services, and battery recharging rates lower than regular fuel costs

The impact:
- Assembly of motorcycle parts in Kampala: improvement of local technical skills and high-quality on-site maintenance and repairs
- Boda-boda lower both fine particles and CO2 emissions, as well as noise pollution

For further information visit:
- https://www.zem.bo/
- https://eepafrica.org/electric-boda-bodas-case-study/

Roam (previously: Opibus), Nairobi, Kenya

The idea: Opibus started by converting off-road vehicles to run on electric motors, before converting buses and designing its own electric motorcycle

The power source:
- Solar- powered lithium technology batteries

The business model:
- Conversion process of ICE vehicles to EVs. The conversion process (depending on the type of vehicle) takes from 10 to 14 days, and it is not cheap
- The company maintains that significant costs can be recovered throughout the operation of the EV
- E-motorcycles come with a detachable battery for battery-swapping
- Electric buses recharged in off-grid solar power stations

The impact:
- Job creation through local design and manufacture
- Replication potential through attracting attention and partnering with Uber

For further information visit:
- https://www.roammotors.com/
- https://edition.cnn.com/2022/03/01/africa/opibus-kenya-electric-mobility-bus-motorcycle-car-spc-intl/index.html

Bodawerk., Kampala, Uganda

The idea: Bodawerk power packs enable different e-mobility solutions and energy storage applications

The power source:
- Smart Battery that is based on cylindrical Lithium-Ion cells
- Built-in battery management system (BMS) to turn on/off and check the batteries charge and health via Bluetooth

The business model:
- Conversion of existing ICE vehicles to EVs by replacing the petrol-powered drivetrain with an electric one
- Subscription-based business model: assembly of lithium-ion battery packs to rent to e-boda boda drivers

The impact:
- Education through mentoring program
- Women empowerment through women owned businesses
- Inclusion of disabled people through e-wheelchairs

For further information visit:
- https://bodawerk.com/
- https://enpact.org/blog/news/bodawerk-uganda-sustainable-energy/#/

ThinkBikes, Ibadan, Nigeria

The idea: ThinkBikes is a micro-mobility company that is manufacturing 2- and 3-wheelers locally for last mile transportation of goods and people.

The power source:
- Two Lithium-ion battery packs, using recycled materials (1.68-kWh power packs are assembled locally using recycled 18650 cells)

The business model:
- Up-front sale of 2- and 3- wheelers with recycled batteries, manufactured in Nigeria, therefore lowering the price
- Leasing service/subscription business in which its customers can rent a bike on a daily, weekly or monthly basis
- Business model that will allow customers to buy the bikes without batteries (the most expensive component), and then lease or rent the packs from ThinkBikes

The impact:
- Promotion of circular economy approach, i.e. the recycling of battery cells recovered from old laptops and other technical devices
- Job creation through local design and manufacture

For further information visit:

- http://bike.thinkelectricafrica.com.ng/
- https://www.electronicdesign.com/markets/automotive/article/21216804/electronic-design-nigerias-first-indigenous-ebikes-blaze-a-path-for-electrifying-african-transit
- https://cleantechnica.com/2022/01/20/thinkbikes-nigeria-is-launching-locally-produced-electric-tricycles/

1.9 Climate-proofing

Climate proofing is a term that refers to a process of mainstreaming climate change into mitigation and/or adaptation strategies and programmes (Climate Policy Info Hub, 2022). The goal of climate proofing is to ensure that climate-related risks and opportunities are integrated into the design, operation, and management of infrastructure (UN Habitat, 2021), improving their behaviour under changing climatic conditions. A development project (or other specified natural or human asset) is climate proofed when risks are reduced to acceptable levels through long-lasting and environmentally sound, economically viable, and socially acceptable changes (UN Habitat, 2021). In order to get that, projects have to be screened for climate risks, vulnerabilities and opportunities at early design stages of project development.

Even though the implemented measures will depend on the location and context, some general guidelines can be provided focusing on **climate proofing of sustainable e-mobility solutions.**

High ambient temperature is the most important factor that influences battery ageing and can cause its premature failure (Riello Elettronica, 2022). They have a rated design life capacity based on an optimum operating temperature, so that increases in temperature above this recommendation result in a reduction in service life. This fact should be taken in mind in the selection of batteries and the definition of operation and maintenance program.

Power sources used to charge EVs are also vulnerable to climate conditions (IAEA, 2019) (ADB, 2013). As described in previous sections, low-carbon electricity can be obtained in two ways, through solar PV mini grids or the grid. The main threats to solar PV mini-grids could be related to extreme wind and storm events, changes in radiation and ambient temperature, and phenomena that could cause physical damage to the infrastructure such as floods, landslides, and forest fires. With regard to the grid, the main hazards could be related to extreme ambient temperatures, floods and extreme wind events, landslides and forest fires. It is important to highlight that not all installations will be equally affected, and it is especially important to distinguish between aerial and underground installations, since they are not exposed to these threats in the same way.

Roads and their pavements can also be affected by climate impacts, reducing their safety and security and/or reducing access and mobility due to road closures (ADB, 2011). Main hazards can include flooding, landslides, droughts and extreme temperatures, that should be taken into account in the design of road layouts and construction.

1.10 Relevant tools and capacity building materials

Solutions Plus E-mobility Toolbox

The Solutions Plus e-Mobility Toolbox is an online information portal that supports the development, implementation and monitoring of innovative electric mobility solutions. The

toolbox is a joint product which was developed under the EU Horizon 2020-supported SOLUTIONSplus project. The platform contains tools and information materials in various areas, including: vehicles, business and finance, demonstrations, integration, operation, policy, sustainability, and users.
https://emobility.tools/

Digital toolkit for energy and mobility
This toolkit addresses the energy and mobility nexus and helps to bridge the gap between the transport and energy sectors when developing sustainable, green, and energy-efficient mobility projects. It looks into three policies and global experience available to take action on the transport and energy sector nexus, including "Promote Public Discussion on New Mobility Solutions", "Expand Public Transport Infrastructure", and "Plan for Integrated Multimodal Transport Networks".
https://www.sum4all.org/data/files/digital_toolkit_for_energy_and_mobility_complete.pdf

UNEP Global Electric Mobility Programme
The Global Electric Mobility Programme by UNEP (United Nations Environment Programme)**Error! Bookmark not defined.** supports more than 50 low-and-middle-income countries with the shift from fossil fuel to electric vehicles. The programme encompasses three working areas: electric two and three wheelers, electric light duty vehicles and electric buses. Within the programme, UNEP publishes reports and tools, such as the eMob calculator which estimates the national potential of electric vehicles and calculates the costs associated with a shift to electric mobility. The tools can be accessed on their website.
https://www.unep.org/explore-topics/transport/what-we-do/global-electric-mobility-programme

Sustainable Urban Mobility Plans (SUMP) Toolkit
SUMP is a process based on the definition of common objectives and use of collaborative planning tools to deal with design, implementation, financing, and monitoring of mobility-related measures and projects. This mobility planning approach is successfully being implemented in various contexts and places around the world. This toolkit is targeted at technical planners and consultants in cities where integrated transport concepts called SUMP (Sustainable Urban Mobility Plans) are being developed. It provides information on how a SUMP (or other related strategic mobility planning document) is best structured and which information should be contained to achieve compliance with international SUMP standards.
https://www.changing-transport.org/wp-content/uploads/2020_annotated_outline_sump.pdf

Gender Sensitive Mini-Bus Services & Transport Infrastructure for African Cities: A Practical Toolkit
This toolkit provides minimum standard guidelines and practical tools for creating safer and more accessible public transport systems for women and other vulnerable commuters in African cities. Its content is mainly relevant for minibus transport organisations, policy makers and civil society actors. The toolkit is based on primary and secondary information from two case studies conducted in Nairobi, Kenya, as well as a literature review to identify best practices on gender and urban transport.
https://unhabitat.org/sites/default/files/download-manager-files/Gender%20Toolkit.pdf

International Transport Forum Gender Analysis Toolkit for Transport
The ITF Gender Analysis Toolkit for Transport offers a hands-on method on how to incorporate a gender-inclusive perspective into transport projects, plans and policies. It comprises three tools which together enable an uncomplicated gender analysis, (i) The Gender Checklist, (ii) The Gender Indicators, and (iii) The Gender Questionnaire. The toolkit is useful for everyone who plans,

manages, implements or evaluates transport projects, especially governmental actors, international organisations or contractors.
https://www.itf-oecd.org/gender-toolkit

Toolkit for Child Health & Mobility in Africa:
The Toolkit developed by the University of Cape Town (UCT) and the Institute for Transportation and Development Policy (ITDP) with support from the UN Environment Share the Road program and FIA Foundation. It aims to guide local and national governments, practitioners and citizens in the planning, design and implementation of interventions to improve the health and safe mobility for children. The toolkit combines various interventions, ranging from infrastructure design to funding and advocacy, supported by case studies from around the world.
https://www.childmobility.info/

Climate Proofing Toolkit: For Basic Urban Infrastructure with a Focus on Water and Sanitation
The Climate Proofing Toolkit is a set of steps, tasks and tools that was developed by UN-Habitat, building on the experiences gained in climate change-related programmes by UN-Habitat and development partners. Its overall goal is to make sure that climate-related risks and impacts are considered in the design, construction, location and operation of current and future basic urban infrastructure, with a focus on water and sanitation. Thus, the toolkit is mainly targeting policymakers, planners, practitioners, engineers and utility managers involved in urban infrastructure development.
https://unhabitat.org/climate-proofing-toolkit-for-basic-urban-infrastructure-with-a-focus-on-water-and-sanitation

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2 Productive Use of Energy – Solar power for agriculture

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2.1 Introduction

The term **Productive Use of Energy (PUE)** refers to energy use that **creates value**, for example in the form of **increased productivity** or **income**, **employment creation**, or **reduced hardship** (Lecoque & Wiemann, 2015; Terrapon-Pfaff et al., 2018). While definitions of PUE differ, there are two main reasons why it is pursued: first, it can improve the viability of energy access business models (for example of mini-grids in rural areas) and, second, it is a means to achieve broader socio-economic goals (Havinga & Teule, 2020).

Powering PUE solutions with sustainable energy sources, such as electricity from decentralised solar, is cost-effective and brings added benefits such as increased reliability of supply and reduced emissions. Figure 8 shows the range of possible productive uses in agriculture, industry, commerce and social/public services.

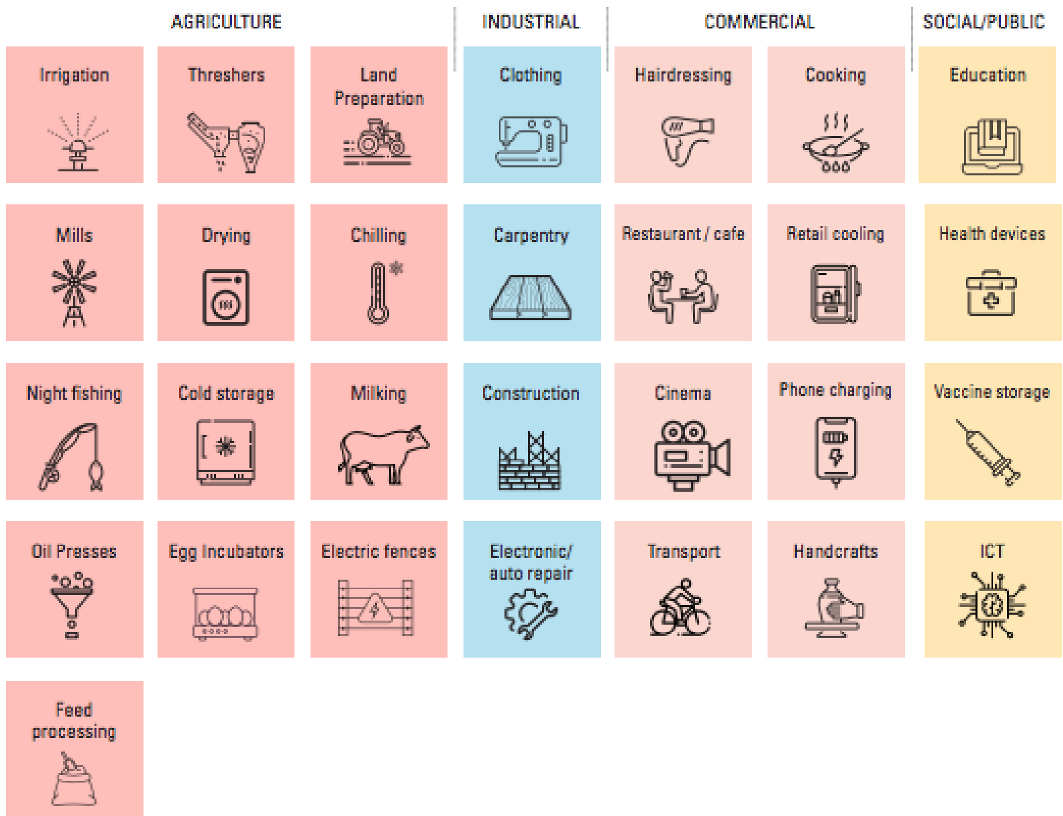

Figure 8. Universe of productive uses relevant for off-grid markets in sub-Saharan Africa (non-exhaustive) (IFC, 2019)

This factsheet introduces different facets of sustainable PUE solutions in the African context, as well as examples of their application. It places a particular emphasis on areas of high potential for PUE in the agricultural sector, namely irrigation, cold storage and milling (IFC, 2019).

2.2 The technology

The technologies that enable sustainable PUE solutions include first and foremost the **energy use appliances** (such as water pumps and irrigation equipment, or fridges for cold storage), but also the power source (solar panels), energy storage (batteries), and Information and Communication technologies (ICT). This section reviews three key applications as well as cross-cutting aspects such as ICT and the energy efficiency of PUE appliances.

2.2.1 Solar-powered water pumping and irrigation

The main components of solar water pumps (SWPs) and solar-powered irrigation systems (SPIS) are the power source (chiefly the solar panel and load controller), the pump, the water storage system (if any) and the irrigation equipment (see Figure 9). The solar system provides electricity to the pump, which delivers water from a well, stream, or another source directly into an irrigation system or into a storage tank or reservoir. SWPs and SPIS do not generally require a battery because irrigation typically takes place during daytime (Energypedia, 2020).

Figure 9. Application of a solar-powered irrigation system (SunCulture in IFC (2019))

Due to the reduced PV technology cost, the cost of SWPs fell by 80% over the past two decades (Efficiency for Access, 2019). Over their lifetime, SWPs can bring significant savings to smallholder farmers compared to a diesel-powered pump (when considering the cost of the fuel). However, the upfront investment, even for small solar water pumps of ~500 W or less (USD 600-800 in 2018), is a barrier to adoption and many business models seek to address this (see Table 1 and Business model section).

Table 1. Overview of typical solar water pump power and cost ranges (based on (Efficiency for Access, 2019)

	Power range	Cost range (USD)
Small	~ 500 W or less	USD 600 to 800
Medium	2-4 kW	1,000 to over 3,000

In a SPIS, the irrigation appliance is customised to the type of crop, topography of the farm, water demand and water proximity (Efficiency for Access, 2019). Equipment for water-efficient irrigation (such as sprinklers, drip lines) can be capital-intensive, whereas the equipment for surface irrigation (where the entire field is flooded, or water is applied to crops via small channels) is more affordable (Bolwig et al., 2020). However, flood irrigation is 20-60% more water-intensive than drip irrigation, which might be an exclusion criterion especially in arid areas (MIT GEAR LAB, 2022).

For more information on SWPs and SPIS see also: Water-Energy-Food Nexus factsheet.

2.2.2 Solar cold storage

The use of solar energy to power cooling technologies has high potential to reduce post-harvest losses and expand access to markets, therefore raising revenues of farmers. Cold storage is needed for different products: fruits and vegetables, meat and fish, milk and dairy. Each product has different cold storage requirements, from -21°C for fish to 15°C for certain fruits (Efficiency for Access, 2022a).

There are three main types of refrigerating appliances that can be powered by solar energy: fridges, freezers and cold rooms. Solar direct-drive refrigerators can be connected to PV panels and do not need electric batteries to operate. Currently, however, vapour-compression units powered with a solar energy system with electrical batteries are more common in the off-grid solar market (SEforALL & clasp, 2021). Cold rooms are refrigerated spaces with controlled temperatures which can be powered from multiple power sources, including solar systems. A typical off-grid walk-in cold room consists of a solar PV array, a battery and/or thermal storage unit, a cooling unit and insulation materials, and remote monitoring equipment (Efficiency for Access, 2021).

So far, solar cold storage technologies face a number of challenges such as the lack of reliability standardisation and high investment and maintenance costs. Business models seek to bridge the affordability gap, especially for smallholder farmers (see Business Model section).

2.2.3 Solar grain milling

Mills process grains like maize, rice, sorghum or millet into flour (see Figure 10). Solar-powered mills can be purpose-built or retrofitted (replacing the diesel engine with an electric motor) and may operate with or without a battery unit. Battery-coupled solar grain mills are driven by direct current (common voltage levels are 12 and 24 V) and the system consists of PV panels, batteries, charge controller and the mill (Energypedia, 2022). While battery-coupled solar mills meet higher health and safety standards compared to diesel-powered mills, their speed can be too low to meet peak customer demand. The main technological challenge for solar milling is to size the energy system appropriately to achieve cost-effectiveness and throughput while maintaining high utilisation rates that increase profitability (Efficiency for Access, 2020).

Figure 10. Application of the Agsol Gen2 mill (Efficiency for Access, 2020)

2.2.4 ICT and IoT in solar PUE

ICT (Information and communication technology) and IoT (Internet-of-Things) technologies play a key role in making solar PUEs applications affordable. For example, many solar water pump models include remote sensing so that the manufacturers can more effectively carry out troubleshooting as well as give advice on optimal use of the pump based on usage data. Geospatial information tools to identify suitable areas for solar irrigation are also emerging (Maina et al., 2021). Finally, PAYGO models for solar-powered pumps also rely heavily on ICT. For example, an appliance may be remotely disconnected in case of lack of payment.

2.2.5 Energy efficiency of PUE appliances

High-quality, efficient, and off-grid appropriate PUE appliances are key to making PUE business models viable. A number of organisations are developing technologies to make PUE appliances efficient and suited for use with off-grid solar standalone systems or mini-grids: the Efficiency for Access Research and Development Fund (Efficiency for Access, 2018) and the Low Energy Inclusive Appliances (LEIA) Programme (Efficiency for Access, 2022b). For example, Agsol (Figure 10), a manufacturer of solar-powered agricultural machinery, active in the East African market, received support from the Efficiency for Access Fund and improved the efficiency for its mill by 32%, while at the same time making it more affordable for customers.

2.3 Business and financing models

Business models for solar PUE solutions are designed to address the challenge of affordability, as the systems have comparatively higher upfront capital investments than conventional diesel-powered systems and appliances (despite being more affordable over the full lifetime). Different approaches to overcome this challenge are introduced below. However, it is important to remember that the design of appropriate business models is very context-specific and should be based on local needs assessments.

2.3.1 Private ownership

A combination of consumer financing (see PAYGO below), grants, long-term credit (including from rural financing networks), and tax exemptions can incentivise private purchases of solar PUE systems. Individual ownership models have the disadvantage of not always reaching the more marginalised farmers whose landholding patterns and income streams may not be sufficient to allow them to invest in solar irrigation. Depending on local contexts, shared ownership (such as co-operatives) is a viable alternative. Evidence from Zimbabwe, Benin and India demonstrates that community-ownership models have been effective (IRENA & FAO, 2021). They, however, require social coherence among all involved farmers, appropriate management and agreement on how to share the use of the appliance, its expenses and the responsibility for maintenance in order to be successful and sustainable (Gebrezgabher et al., 2021).

2.3.2 Service provider model

In the service-provider (or "fee-for-service") model, solar PUE technology is owned, operated and maintained by a third-party entrepreneur. The entrepreneur finances the technology with the help of low-cost finance, grants or other fiscal incentives to then provide PUE services such as solar irrigation to farmers for a fee (Gebrezgabher et al., 2021). In this way, smallholder farmers can pay for irrigation or other agricultural services, for example on the basis of the water they use or the hectares they own. For instance, ColdHubs Nigeria and SokoFresh apply a pay-as-you-store fee for cold storage (see Examples section). The technical, operational and financial risks lie with the service provider while farmers purchase the services on demand. A key advantage of this business model is that service providers can often operate and maintain the technologies more efficiently than individual smallholders. Moreover, the system is used more intensively than in the case of individual ownership (Gebrezgabher et al., 2021). Merrey & Lefore (2018) described several variants of this utility model implemented in Senegal, Morocco, Bangladesh and India. Moreover, it is important to note that agricultural cooperatives can also use the fee-for-service model (i.e., they do not own the system).

2.3.3 Incentives to multiple use

Some solar PUE systems, such as irrigation pumps, tend to be used only during the growing season. Incentivising multiple uses for the systems can improve their overall economics while bringing a wider range of development benefits. For example, in Bangladesh, excess electricity generated by pumps is used for mechanical processes such as husking, threshing, cold storage or aquaculture (IRENA & FAO, 2021).

2.3.4 Consumer financing

Several approaches are used to facilitate the initial investment in a solar PUE system. In the PAYGO model, customers pay 10-20% as upfront cost and the rest in instalments over a period of 1-2 years. This financing approach is already common in the market for Solar Home Systems for households and small businesses, and is increasingly used to support purchase of solar PUE equipment in contexts where no governmental financing support exists (IFC, 2020). In Kenya, "pay-as-you-grow" models adapted to farmers' income cycles are being deployed to improve accessibility and affordability (EEP Africa, 2021). Microfinance is a common approach in rural areas where financial services are limited and appropriate loan products for agricultural lending are not available. In Egypt, the SAIL (Sustainable Agriculture Investments and Livelihoods) project includes a micro-loan facility to enable small enterprises to make climate-smart agriculture investments, including solar-powered irrigation (IRENA & FAO, 2021).

2.4 Socio-economic and sustainability impacts

Productive use of solar energy for agriculture not only has the potential to improve the viability of energy access business models but is also a **means to achieve broader socio-economic goals**. In particular it has the potential of capturing more economic value within rural areas (Johnstone, 2021).

Promoting PUE can improve the viability of solar mini-grid projects, by increasing demand for energy and providing stable demand during the day time.

The use of solar PUE in agriculture can result in **extended operating hours**, **mechanisation**, **product preservation**, **higher productivity**, **improved working conditions** as well as **improved food security** (IFC, 2019; Lecoque & Wiemann, 2015). For example, a Kenyan farmer cooperative saw USD 75 incremental income gains per farmer per month following the purchase of solar milk cooler. A larger cooling plant led to an extra 2 litres of monthly milk consumption per family per month. A survey on the uses and impacts of off-grid refrigerators in Kenya, Tanzania and Uganda concludes that 72% of the interviewed people experience increased income and business growth after using off-grid refrigeration (Efficiency for Access, 2022c).

Solar PUE systems also bring **environmental benefits**, as they can achieve a similar level of performance as fossil fuel-powered appliances without the carbon emissions associated with them. For example, the Futurepump SF2 solar water pump is found to save 196 kg CO2 per year compared to an equivalent petrol pump (REEEP, 2018). Moreover, many PUE applications can potentially **reduce farmers' water consumption when used in conjunction with more efficient irrigation techniques** (see Climate Proofing section).

Realising the positive impacts of solar PUE requires taking a holistic approach that ensures quality capacity-building and access to markets (Johnstone, 2021; Terrapon-Pfaff et al., 2018). The solar-powered mini-grids on Lake Victoria islands in Tanzania provide an example of an integrated approach to fostering PUE in minigrid projects. The operating company, Jumeme, identifies existing economic activities in the communities that can be boosted with the power from the minigrid, while at the same time fostering new economic activities, facilitating access to outside markets and attracting new investments into the communities. Such an approach requires significant resources and expertise, as well as strong community engagement (SEforALL, 2020).

Fostering solar PUE also involves a series of risks, especially those that are linked to unequal impacts on employment and income generation. It is vital to explicitly design PUE initiatives and business models so that they achieve equitable impacts and benefit the poorest and most vulnerable, and to monitor that they do so. For example, Simusolar takes an active approach to understanding the specific needs of female customers with regards to their PUE products, in order to boost the participation of women farmers in the market (Power Africa, 2022).

2.5 Scaling-up

The agriculture, forestry and fishing sector accounts for 18.5% of total GDP in sub-Saharan Africa (World Bank, 2022). About 65% of land is still tilled, ploughed or weeded manually, resulting in low farm yields (World Bank, 2019). Solar-powered agricultural appliances have the **potential to drastically increase productivity and food production** while **reducing post-harvest losses.** Generally, the opportunities for solar-powered PUE vary across different African markets according to the maturity of the off-grid solar sector, the nature of the agricultural sector, and the strength of incumbent products (IFC, 2019). Table 2 illustrates the high market potential of replicating key solar PUE use cases in Sub-Saharan Africa.

Table 2. Estimated serviceable market potential for solar PUE technologies in sub-Saharan Africa (IFC, 2019)

	Total estimated serviceable market (number of farmers in 2018)	Projected increase of serviceable market until 2030	Number of projected serviceable farmers in 2030	Estimated market value in 2030 (USD)
Solar-powered water pumps	701,000	12.3%	2.83 million	1.633 billion
Cooling & Refrigeration	225,000	17.4%	1.55 million	1.32 billion
Agro-processing	54,000	13.9%	257,000	417 million

Some solar PUE products are particularly ready to scale. Solar water pumps are currently affordable even for use in small farming areas. They can increase yields for farms starting as small as 0.5 hectares (IFC, 2019). The expected 10-15% future reduction in prices of solar water pumps from 2018-2030 will drive the market growth further (IFC, 2019). The solar cooling and refrigeration market will continue to be dominated by small refrigerators in the short term, as walk-in cold rooms are still relatively expensive. Finally, agro-processing appliances are expected to remain outside the affordable price range for most smallholders in the short term, though prices in this market are likely to decrease within the next decade (IFC, 2019).

To **realise the potential in the PUE sector**, **policy action**, **market development**, **innovative partnerships as well as better conditions between energy and agriculture sectors are required**. Despite the importance of PUE to rural productivity and overall economic development, productive use appliances are often not included in national policies. Figure 11 illustrates key areas of intervention for the development sector and government actors to support the solar PUE market.

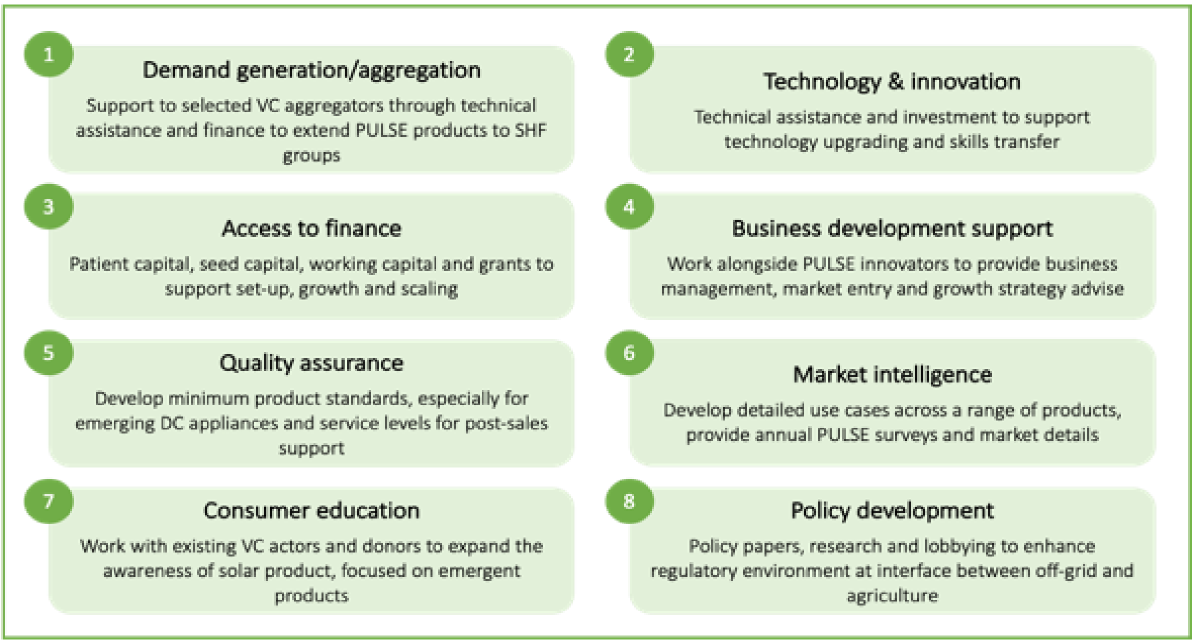

Figure 11. Areas of intervention for development sector and government actors to support solar PUE (own illustration, based on IFC (2019))

2.6 Productive Use of Energy in SESA

SESA partners in various countries are working on productive use of energy solutions. Their activities are briefly outlined below.

2.6.1 PUE solar solutions in Kisumu & Homabay counties, Kenya

The social enterprise and SESA partner **WeTu** in Kenya, founded by the Siemens Stiftung, works on innovative solutions for e-mobility, safe drinking water and solar lighting and charging and **productive use case appliances for job creation, environmental protection and increased productivity in the living lab areas.**

The main objective in the SESA living lab Kenya is to develop a modular demonstration project to provide sustainable energy access solutions that are relevant for validation and replication in both urbanized and rural contexts in Africa, creating opportunities to generate sustainable off-grid electricity, with sector linkages such as fishing, water pumping, water purification, e-mobility and waste management and combining energy solutions with local Info Spots for access to information, on energy, climate change and digital skills. The proposed modular demonstration case aims to address the three main innovation focus areas in energy transitions, namely access, productive use, and a circular economy.

Solar PUE solutions in Katito and Kisegi include fisher lantern charging systems and water pumping and purification systems.

2.6.2 PUE solar solutions in Ga North and Atwima Nwaibiagya, Ghana

The demonstration action in Ghana will focus on waste-to-energy solutions and solar energy for **productive use** in communities at Ga North and Atwima Nwaibiagya municipal assemblies. In collaboration with the selected local SME(s), waste-to-energy solutions and solar energy innovations will be developed for productive use and applications. Main SESA partner is AAMUSTED University. Exact locations will be decided in collaboration with the SME(s) that will be selected through the Siemens Foundation seed funding call for local innovators.

In collaboration with the selected local SME(s), **waste-to-energy solutions and solar energy innovations will be developed for productive use and applications**. In addition, InfoSpots will be installed as part of the demonstration actions. To deliver a complete value chain, the solutions will include business models, capacity building on construction and maintenance, and other activities. The demonstration activities are expected to contribute to the provision of clean and reliable energy for cooking, as well as to improving the availability of electricity for **productive uses such as lighting for night-time learning activities, energy provision for appliances, water pumping and illumination to provide security at night.** Free information access through the Infospots will promote energy knowledge acquisition and improve digital literacy.

2.6.3 PUE solar solutions in Alicedale and KwaNonzwakazi, South Africa

In the South African validation demonstration project, the activities are located in the Eastern Cape township of Alicedale and the semi-rural area KwaNonzwakazi on the outskirts of Alicedale. The main SESA partners are uYilo and Nelson Mandela University. The main beneficiaries of the activities will be the local community of KwaNonzwakazi. Although the area has access to electricity, the supply is unreliable and there are prolonged blackouts. Access to reliable, affordable transport is a challenge as a majority of the population cannot afford to pay costs for transport. Furthermore, there is a lack of access ICT infrastructure, cost of access and cost of devices.

The demonstration innovation will include electric vehicle batteries and stationary storage applications, the demonstration will include the provision of Infospots for internet access. The off-grid community energy hubs will support a range of local community activities. The demonstration site will aim to test, validate and replicate a containerized off-grid renewable energy system consisting of energy storage, together with a small fleet of micro-utility electric vehicles. The demonstration will extend the productive use of renewable energy for the community, and also offer sustainable charging of a small fleet of micro utility vehicles.

The demonstration site in South Africa also incorporates the extension of **productive use** of energy activities for the communities. In the course of a needs assessment, the **training needs** of the community in the area of productive use of energy were identified.

2.6.4 PUE solar solutions in Donkerbos & Otjisa, Namibia

The SESA living lab replication site in Namibia will employ an open-ended solution approach to co-design technologies and business models with the two communities Donkerbos and Otjisa. The SESA partner in Namibia is the Namibia University of Science and Technology.

The living lab aims at installing solar PV minigrids to replace annual firewood and paraffin use for cooking and heating and **productive use such as lighting.**

2.6.5 PUE solar solutions in Rwanda

The SESA living lab replication site in Rwanda aims at using solar power for PUE such as **solar irrigation systems** to ensure food security through the enhancement of growing crops. Working with solar irrigation systems will also reduce the reliance on seasonal rainfall and improve crops yields. The main SESA partner in Rwanda is the University of Rwanda.

2.6.6 PUE solar solutions in Tanzania

The SESA living lab replication site in Tanzania aims at implementing a variety of solar power for PUE solutions. Among the planned activities are **solar water pumps for irrigation systems,** the implementation of a **solar pottery wheel technology for 10 pottery producers and the provision of cooling facilities to increase life-lasting of food products and reduce post-harvest losses**. Within SESA, the main partner in Tanzania is the Energy and Livelihoods for Communities (E-LICO) Foundation.

2.7 Examples of application in the African context

SokoFresh (Kenya)

The idea: Provision of off-grid, mobile cold-storage as a service and a digital market linkage platform to Kenyan smallholder farmers.

The power source:

- Solar PV

The business model:

- Pay-as-you-store: the farmers/traders pay for storage on kg/day basis

The impact:

- Reduction of post-harvest losses
- Increase of income due to higher amounts of harvest sale

For further information visit:

- https://sokofresh.co.ke/
- https://energy-base.org/news/sokofresh-first-mile-cold-storage-as-a-service/

ColdHubs (Nigeria)

The idea: Provision of 24/7 off-grid storage and preservation of perishable foods via a "plug and play" modular, solar-powered walk-in cold room.

The power source:

- Solar P installed on the roof-top of the cold room and the energy is stored in high capacity batteries

The business model:

- Pay-as-you-store subscription model: farmers pay a daily flat for each crate of food they store. The reusable crates are provided by ColdHubs and perfectly fit into the shelves.

The impact:

- Extension of shelf life of perishable food from 2 to 21 days, resulting in a reduction of post-harvest loss by 80%
- Increase of annual income by 25% due to larger amount of harvest to sell

For further information visit:
- https://www.coldhubs.com/

SunCulture's RainMaker (Kenya)

The idea: Development of off-grid solar technologies to provide farmers and households with reliable access to water, irrigation, lighting, and mobile charging, possibly with a single system. The most sold products combine solar water pumping technology with high-efficiency drip irrigation.

The power source:
- Solar PV panels
- The energy is stored in 444 Wh 29.6 V 15 Ah Lithium batteries with max output power of 500 W

The business model:
- Upfront sale or pay-as-you-go
- The product packages include a consultation, installation services, training, and ongoing customer support in case of issues

The impact:
- Increase of yield by up to 300%
- The switch from rain-fed agriculture to irrigation can lead to a 10x increase in a smallholder farmer's income

For further information visit:
- https://sunculture.com/
- https://eepafrica.org/wp-content/uploads/2019/11/IBM_SunCulture.pdf

Koolboks (Nigeria, Kenya, Ghana, France)

The idea: Koolboks developed an affordable off-grid refrigeration solution that is able to cool for up to four days, even in the absence of power and limited sunlight. Energy is stored in the form of ice and not only in batteries. The unit can be used as a refrigerator or freezer or also function as a source of lighting.

The power source:
- During the day when sunlight is available, ice is created in compartments. At night, energy switches internally to the ice so that the temperature will be maintained until the sun is available again.
- The ice batteries are complemented with integrated Lithium-ion batteries

The business model:

- PAYG in the form of lease to own: Small weekly or monthly payments to eventually own the system

The impact:

- This technology has brought down the cost of owning an off-grid solar refrigerator by almost 40%, decreasing the barrier of financing such a system.

For further information visit:

- https://www.koolboks.com

Agsol (Kenya, among others)

The idea: Agsol designs and manufactures precision-engineered solar-powered mills for off-grid farming communities. The social enterprise was formed in 2016 and established itself in Kenya in mid 2018 to target the East African market and specifically maize and cereals milling, which are the most important staples in the region.

The power source:

- The MicroMill can be powered from solar, mini-grid, grid or e-bike
- The solar format comes with the latest Li-ion LFP battery technology

The business model:

- Customers can purchase the solar mills under a digital finance PAYG model in less than two years

The impact:

- Income generation through offering payment for milling services
- Time is freed (the machine can process food 50 times faster than a human can)

For further information visit:

- https://agsol.com/

Additionally: Bodawerk is an example for productive use of electric vehicles in the agricultural sector (See e-mobility factsheet).

2.8 Climate-proofing

In the agricultural sector, climate adaptive solutions are required at every phase of the value chain (Dolan, 2021). Solar PUE solutions can enhance agricultural resilience, if applied correctly. Solar water pumps, for example, offer an affordable and effective irrigation solution when surface water resources or shallow groundwater are available (Gadeberg, 2020). The use of solar water pumps also helps farmers become more resilient to natural disasters, especially droughts and other changes in rainfall patterns (Efficiency for Access, 2019). However, there is a risk of negative impacts, for example, as a result of excessive water pumping (Johnstone, 2021).

On the other hand, the technologies that enable sustainable PUE solutions include, not only the mentioned energy use appliances, but also the power sources (in this case, solar PV panels), energy storage devices (batteries), and Information and Communication technologies (ICT). They can also be vulnerable to a changing climate, and have to be designed to be resilient to projected climate conditions in their location. Some general guidelines for climate proofing of these solutions could be found in the Climate Proofing Factsheet.

2.9 Relevant tools and capacity building materials

PREO Knowledge Hub
The Powering Renewable Energy Opportunities (PREO) Knowledge Hub is an open-access library collecting information related to productive use of energy. The published resources aim to close critical knowledge gaps in sub-Saharan Africa's PUE market, helping to uptake PUE, stimulate economies and create jobs. The knowledge hub is clustered in various subject areas like case studies, mini-grids, agri-processing, cold-storage and many more and its content is updated regularly.
https://www.preo.org/category/knowledge-hub/

Report 2021: Productive Uses of Energy in Ethiopia
The 240-page study aims to create a shared understanding of and a common language to assess opportunities for productive use. In particular, it identifies opportunities to electrify agricultural productive uses today, how they can be developed through feasible business models, and the strategies and initiatives that stakeholders can use to overcome barriers to deployment.
https://rmi.org/insight/productive-uses-of-energy-in-ethiopia/

Power Africa's off-grid productive use of energy (PUE) catalogues (2020)
The Power Africa's off-grid productive use of energy (PUE) catalogues aims to increase awareness and uptake of off-grid PUE appliances that are available in the sub-Saharan African market for agriculture, fishing, livestock, and poultry. It provides stakeholders such as manufacturers, suppliers or policymakers with insights into PUE products and innovations. The catalogues include product technical specifications, manufacturer information, distribution channels, local distributor details, product payment methods, quality standards and links to related sources. Catalogues are available for the following countries: Cameroon, Côte d'Ivoire, Ethiopia, Ghana, Kenya, Niger, Rwanda, Senegal, Tanzania and Uganda.
https://www.usaid.gov/powerafrica/beyondthegrid/off-grid-solar-market-assessments#PUEcatalogs

Rapid Product Assessment: A New Approach to Testing Productive Use Appliances (2022)
In cooperation with Kijani Testing, VeraSol developed the Rapid Product Assessment framework. This framework offers a cost-effective and time-saving way to quality verification for nascent PUE technologies. The framework should help to access reliable data and information about the performance, durability, and safety of PUE to enable market stakeholders to make informed decisions and identify high-quality, energy-efficient technologies. Egg incubators were selected as a first trial product for the Rapid Product Assessment approach.
https://efficiencyforaccess.org/publications/rapid-product-assessment-a-new-approach-to-testing-productive-use-appliances

Productive Use of Energy (PRODUSE) user manual
The manual provides step-by-step guidance for designing and implementing productive use of energy activities in electrification programmes. It comprises six modules, each describing practical tasks to be conducted in every project phase, as well as references and links to other publicity available tools. The manual will be updated regularly. http://www.produse.org/

A2EI Productive Use Report & Productive Use Assessment Tool (2020)
The report by A2EI evaluates solar-powered agricultural technologies for productive-use applications. A business modeling approach was used to identify opportunities for solar energy to be used productively in agricultural contexts. A2EI also developed the productive use assessment tool which supports the design of business models that incorporate productive use in the agricultural sector, for example oil pressing, maize shelling or spice grinding. Based on evidence collected in Tanzania, the spreadsheet tool contains technological, business and energy assumptions. The tool can calculate revenue, operational costs, and gross profit margin on a per-hour basis based on the assumptions in each model. Due to its simple structure, the spreadsheet allows the values and calculations to be changed easily according to the operating environment.
https://a2ei.org/resources/uploads/2020/09/A2EI_Productive_Use_Report_Agricultural_Technologies.pdf

Energypedia Productive Use Portal
The productive use portal provides an overview of the articles related to productive energy use on energypedia. The articles are divided in various categories, including e.g. climate change & productive use (PU), energy technologies and PU, or promotion, financing & business models for PU. The portal is updated regularly (last edit December 2021).
https://energypedia.info/wiki/Portal:Productive_Use

Productive Uses of Energy Hub Mozambique
The PUE Hub Mozambique, developed by Energypedia, gathers information on productive uses of energy such as irrigation, drying, cooling and other applications for Micro, Small & Medium Enterprises in Mozambique. It discusses the market potential and the opportunity for private sector involvement in the PUE area. Information is updated regularly (last edit June 2022).
https://energypedia.info/wiki/Mozambique_Productive_Uses_of_Energy_Hub

Solar Pumping Toolkit
The Global Solar and Water Initiative developed the Solar Pumping Toolkit which is accessible at Energypedia. The toolkit is made up of four chapters related to solar pumping, including Guidance, Design, Installation and Monitoring. The toolkit is updated regularly (last edit June, 2020).
https://energypedia.info/wiki/Solar_Pumping_Toolkit_-_The_Global_Solar_%26_Water_Initiative

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3 Second-life Lithium-ion batteries

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3.1 Introduction

During the next decades, the strong uptake of electric vehicles (EVs) will result in the availability of **batteries** that can no longer be used in EVs but are still useful for **stationary applications**. Extending the lifetime of EV batteries has significant economic and environmental benefits and is an important piece of Africa's energy transition. This factsheet reviews the potential for use of **Lithium-ion (Li-ion) second-life batteries (SLBs)** in the context of sustainable energy solutions currently emerging in the African context. It sums up key technologies, business models and impacts, and presents examples of SLB use across the continent.

Please note that this factsheet is closely linked to the catalogue's electronic waste, circularity and e-mobility factsheets.

3.2 The technology

Li-ion batteries are currently the most commonly used type of battery in EVs. They have one of the highest energy densities of any battery technology today, can deliver large amounts of current for high-power applications, and have comparatively low maintenance requirements.

Li-ion batteries are designed for approximately a decade of useful life in an EV. At the end of the first life of an EV battery, manufacturers and users have three options: they can **dispose** of it, **recycle** the valuable metals, or **reuse** it (Figure 12). This factsheet focuses on the reuse option (please see e-waste and circularity for details on disposal and recycling routes).

Stationary energy storage is key for the functioning of off-grid solar photovoltaic (PV) applications such as mini-grids and standalone systems. Li-ion batteries are well suited for storing energy from off-grid solar because the batteries can be charged quickly and are lighter, more compact and can hold higher amounts of energy than other battery types (The Earth Awards, 2019).

Reusing Li-ion batteries, however, requires a **reconditioning process** (Figure 13). The first step is to test the battery's health. Batteries deemed fit for a second life are dismantled to extract the battery cells. These undergo a series of further tests and are then reassembled in the new application. It is important to achieve a balance in the health of battery cells within the new system (Pyper, 2020).

3.3 Business and financing models

Business models for the use of SLBs in solar off-grid applications are recently emerging, and they vary depending on the type of application and local context. The cost of new batteries, the lack of standards, and the reliability of supply of SLBs are some of the factors that affect the viability of SLBs business models in the African context. These are discussed here in turn.

3.3.1 Cost

The advantage of using SLBs is their **lower costs compared to purchasing a new Li-ion battery**. Estimates of the total cost of a SLB range from $40–160/kWh, while a new EV battery pack cost around USD 157/kWh at the end of 2019 (Clean Technica, 2020). Therefore, using SLBs can increase the affordability of solar off-grid systems, such as a mini-grid or rooftop PV installation. However, as the cost of new batteries continues to decrease in the future, the cost difference between used and new batteries will narrow (McKinsey, 2019). Hence, a growing number of startups are working on ways to lower the cost of the battery reconditioning process. For example, the **reconditioning process can be shorter if the battery health has been continually monitored** during the life of the EV.

Figure 12. Second life for former EV batteries in stationary energy storage (Falk et al., 2020)

Figure 13. Overview of the battery repurposing value chain (Angliviel et al., 2021)

3.3.2 Need for standards

A challenge for SLB businesses is the complexity of reconditioning batteries that vary widely in size, chemistry and format. Currently, batteries are designed to meet the needs of a given EV vehicle model, rather than a stationary application. McKinsey (2019) estimates that up to 250 new EV models will exist by 2025, featuring batteries from more than 15 manufacturers. EV manufacturers such as Nissan and Renault have recently started to design their vehicles with second-life applications in mind. Moreover, a number of initiatives are underway to increase standardisation of batteries as well as to streamline the disclosure of the state-of-health of a battery that has reached the end of its first life. In 2019, the first international standard for evaluating and repurposing batteries was created in the United States, but this is still lacking in Europe and Africa (Bustamante et al., 2020).

An immature regulatory regime is also an obstacle. Most African countries **lack regulations specific to SLBs** or delineations of responsibility between the producer and the consumer. This creates uncertainties for manufacturers, second-life-battery businesses and eventually also for customers (McKinsey, 2019).

3.3.3 Reliability of supply

SLB businesses need a reliable supply of used EV batteries. Businesses can either engage directly with a supplier, for example an EV manufacturer (See REVOV example below) or a battery company. There is also the possibility to establish a collection system. Collection systems can be facilitated with Information and Communication technologies (ICT) and Internet-of-Things (IoT) elements, for example through the **monitoring of battery health** and **monetary incentives to take back batteries** (For more on take-back schemes, See e-waste and circularity factsheets).

3.4 Socio-economic and sustainability impacts

Using SLBs **reduces the need for harmful mining**, avoids the environmental impacts of improper battery disposal, and can create employment. These impact areas are treated here in turn.

Lithium extraction through evaporation ponds uses large quantities of water and this can lead to water shortages that damage ecosystems and threaten the livelihoods of local communities (Figures 14 and 15). It is estimated that over 2 million liters of water are needed to produce one ton of lithium (UNCTAD, 2020). Moreover, lithium mining can lead to soil degradation and a loss of plant diversity (Agusdinata et al., 2018). The mining of cobalt used in Li-ion batteries is also associated with strong health, environmental and human rights impacts. An increased use of SLBs can reduce the impacts of mining for lithium, cobalt and other raw materials needed in Li-Ion batteries.

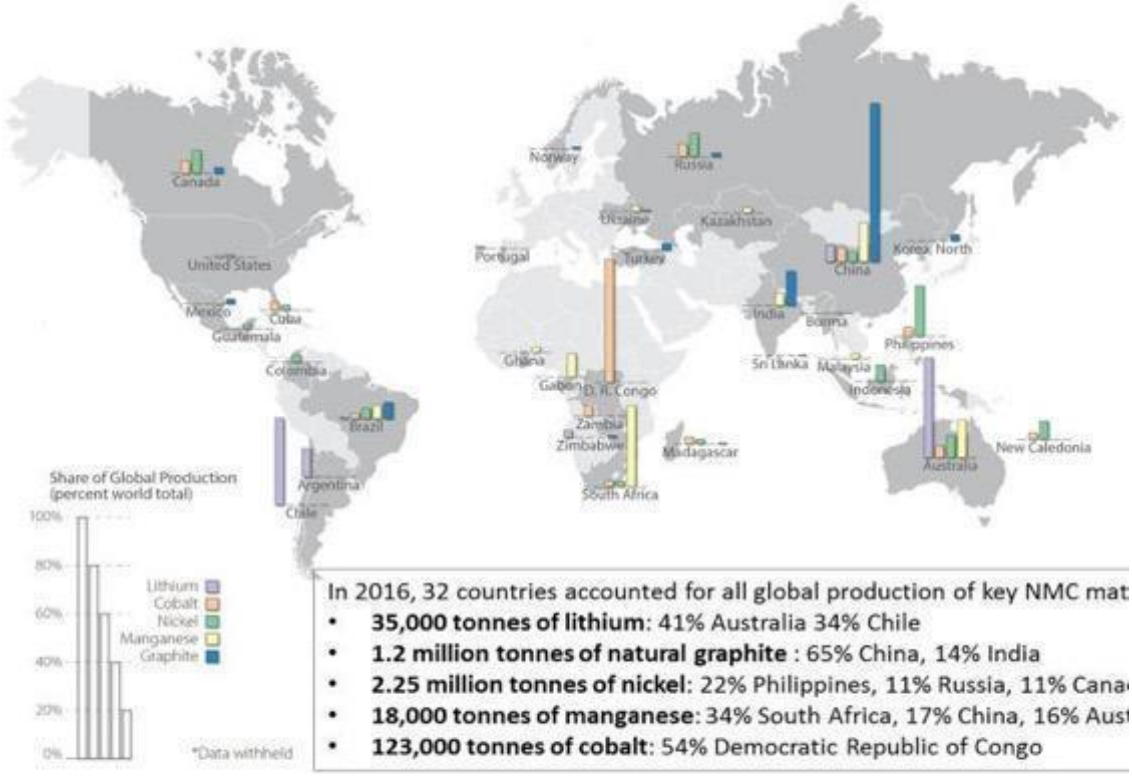

Figure 14. Production of key Li-ion battery materials, including Lithium and Cobalt (Mayyas et al., 2019)

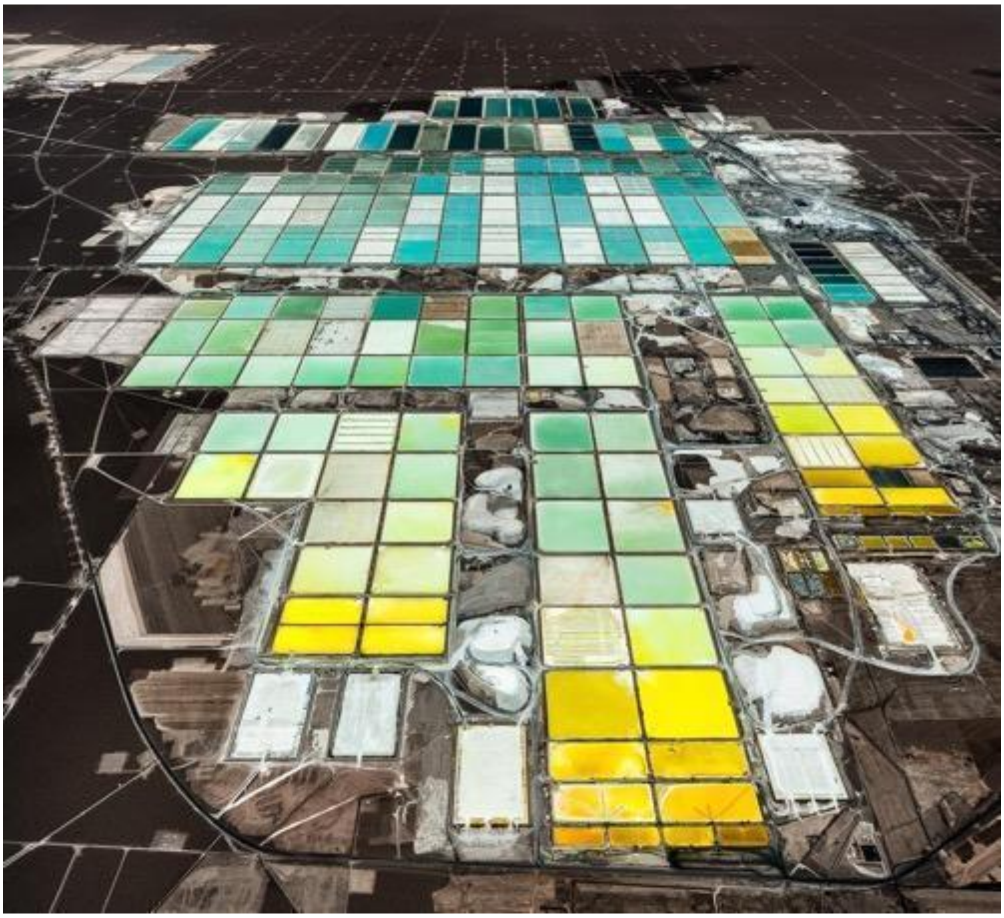

Figure 15. Lithium fields in the Salar de Atacama salt flats in northern Chile (Hegen, 2021)

The impacts of improper disposal of Li-Ion batteries are relatively less severe than those of other batteries such as lead-acid batteries. However, leaks of heavy metals such as cobalt, nickel, manganese from Li-ion batteries can lead to significant contamination of soil and groundwater (Jacoby, 2019). Moreover, improper disposal can lead to fires that release toxic gases (Mrozik et al., 2021).

The adoption of circular economy approaches with efficient SLB collection systems and recycling and repurposing processes can create new employment opportunities. For establishing a local industry for SLB repurposing, skills, infrastructure and the necessary capital are needed (Charles et al., 2019). Furthermore, creating local value chains for SLB repurposing can reduce the dependence on battery imports (Godfrey et al., 2021).

3.5 Scaling-up

There is significant potential for scaling up the use of SLBs in the solar off-grid sector. It is estimated that demand for EV batteries will increase from 15-30 GWh in 2015 to 300-1,000 GWh by 2030 (Falk et al., 2020). This in turn will lead to an increase in SLBs availability.

Battery manufacturers, second-life battery companies and automotive manufacturers can contribute significantly to the scale up of SLBs. For example, vehicle manufacturers can design their batteries already having in mind their second-life application and they can help streamline circular economy approaches (McKinsey, 2019). Policies play an important role in the uptake of SLBs as well, due to the fact that standards and regulations need to be established for the reduction of barriers to a widespread use of SLBs in Africa (Clean Technica, 2020).

3.6 Second-life battery solutions in SESA

SESA partners in various countries are working on second-life Li-ion battery solutions. Their activities are briefly outlined below.

3.6.1 SLB use Kisegi and Katito, Kenya

The demonstration implementation activities will be carried out at two project sites, Kisegi, a rural village in Homa Bay county, and Katito a peri-urban community in Kisumu County with the social enterprise WeTu being the key stakeholder for SESA on site. The main objective of the Kenyan living lab is to provide sustainable energy access solutions relevant for validation and replication in both urbanized and rural contexts in Africa. Both demonstration sites include solar charging hubs that incorporate PV modules, central Li-ion battery storage, and balance-of-system (BoS) to increase energy accessibility for a range of electrical needs within the local community. The solar charging hubs will charge and power the many use cases as well as the battery storage system.

3.6.2 SLB use Marrakech, Morocco

The demonstration implementation activities will be carried out in an urban location in Marrakech and a low socioeconomic rural region currently without access to grid electricity. The main SESA partner in Morocco is **Green Energy Park**.

The rural demonstration action consists of the installation of 10 mini grids using photovoltaic panels, with **second life batteries as energy storage technology**, in a dozen houses located in isolated villages whose population are vulnerable and with little or no means to connect to the national network. Thus, the overall objective of this demonstrator is to provide electricity to vulnerable populations that will enable social and business activities. The demonstration action also aims at the **investigation and diagnosis of repurposing and recycling of SLB from EVs.**

This demonstrator will serve as a model and will be used for replication in Morocco and Africa. The choice of the validation sites to host the project's activities follow the same vision of the Moroccan electrification program and aim to boost the economic development in rural areas, by promoting the creation and modernization of income-generating activities through the energy transition and the integration of off-grid solar energy systems.

3.6.3 SLB use Alicedale and KwaNonzwakazi, South Africa

In the South African validation demonstration project, the activities are located in the Eastern Cape township of Alicedale and the semi-rural area KwaNonzwakazi on the outskirts of Alicedale. The validation demonstration will **test, validate and evaluate** the performance of a c**ontainerised off-grid solar energy system** comprising PV panels in combination with **second life EV batteries for energy stationary storage** for community energy access as well as to charge a small fleet of micro utility EVs. The energy hub will be extended by information spots (Infospots) for the provision of internet services and providing free access to information on energy usage, maintenance and business opportunities. The main SESA partners in South Africa are **uYilo** and **Nelson Mandela University**.

The aim of the project is to investigate the performance of these batteries, the technical and financial viability of such systems, as well as the scalability and replicability of this use case. The demonstration will also identify the commercial case for local authorities to invest in these solutions and study the **repurposing potential** of retired EV batteries for energy storage and as a means to **create new jobs.**

The main beneficiaries of the activities will be the local community of KwaNonzwakazi. The demonstration will extend the productive use of renewable energy for the community, and also offer sustainable charging of a small fleet of micro utility vehicles.

The SESA validation site in South Africa will show the value and repurposing potential of electric vehicle batteries for stationary storage applications.

3.7 Examples of application in the African context

Inno-Neat, Mombasa, Kenya

The idea: Analyses, recycles and repurposes used lithium-ion battery cells into Solar Ready battery packs for use in solar applications targeting low income communities

Areas of expertise and innovation:

- Recycling, cell testing, refurbishing, battery packs

The business model:

- Circular economy approach by battery collection and selling stationary storage batteries at a reduced prices

The impact:

- Creation of an environmentally friendly solution that will provide low cost alternatives of renewable energy to off-grid communities
- Selling product at a reduced price to low income communities

For further information visit:

- https://energy.innoneat.co.ke/index.html#/about

REVOV, Johannesburg/Cape Town, South Africa

The idea: REVOV 2ndLiFe batteries are cost-effective lithium iron phosphate (LiFePO4) batteries. The batteries can be used for charging off the grid, to supply backup power or reduce costs (charge at non-peak tariffs and consume at peak hours).

Areas of expertise and innovation:

- repurposing of li-ion battery cells that were used in EVs

The business model:

- Revov imports batteries from BYD (largest manufacturer of electric vehicles and accessories in the world), tests and refurbishes them, placing them into more usable enclosures for the verticals it serves
- Distributes them through its channel partners

The impact:

- environmental impact through adoption of renewable energy solutions in South Africa by introducing affordable Li-ion batteries
- preventing waste,
- reduction of the need to produce new batteries
- inclusion through targeting rural and low-income population by providing batteries for charging off the grid, supply backup power and reduce costs

For further information visit:

- https://revov.co.za/2ndlife/
- https://www.dataweek.co.za/15613r

3.8 Climate-proofing

Even though the implemented measures depend on the location and context, some general guidelines can be provided focusing on climate proofing of SLBs.

- **High ambient temperature** is the most important factor that **influences battery aging** and can cause its **premature failure** (Riello Elettronica, 2022). Li-ion batteries 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 counts as much for SLBs as for batteries in first life applications.
- **Power sources used to charge SLBs** used in stationary storage are also **vulnerable to climate conditions** (Stankeviciute, 2019). For charging the SLBs, low-carbon electricity can be obtained in two ways, through solar PV mini-grids or the grid. Current factsheet considers the use of SLBs for storing solar energy in off-grid solar PV applications.The main climate threats to solar PV mini-grids could be related to extreme wind and storm events, changes in radiation and ambient temperature, and phenomena that could cause physical damage to the infrastructure such as floods, landslides, and forest fires.

3.9 Relevant tools and capacity building materials

Dealing with the End-of-Life Problem of Electric Vehicle Batteries - Insights and Recommendations for Kenya
A comprehensive national system for e-mobility requires to think about batteries after the end of use for EVs. This is relevant for electric mobility and battery life considerations. Smart reuse and recycling systems need to be put in place as they can help to prolong the life cycle of such used batteries and provide significant business opportunities. This short paper gives an overview of the topic and ties it to the Kenyan context.
https://changing-transport.org/wp-content/uploads/202107_GIZTraCS_DealingwithEoLLiBs-1.pdf

Battery Second-Use Repurposing Cost Calculator
The National Renewable Energy Laboratory of the U.S. Department of Energy developed a cost calculation system for the determination of repurposing costs for the second use of plug-in electric vehicle batteries. The tool accounts for factors on module property, transportation, module handling and testing time as well as on costs, staff and required revenues.
https://www.nrel.gov/transportation/b2u-calculator.html

Repurposing of Lithium-Ion Batteries - Technology & Market Insights
This study identifies the key drivers and barriers for adoption of Second Life Batteries (SLB). The challenges highlighted in this report include handling the diversity of electric vehicle (EV) battery packs in the market, costly battery transportation, development of grading and disassembly processes, difficulty in accessing historical data of used batteries, and the lack of unified standards for used battery repurposing. Examination of 33 case studies for SLB implementations in various applications, such as reuse by EV OEMs, energy storage systems (ESS) for grid stabilization, back-up power systems, smart grids, home ESS, EV chargers, and portable power.
https://www.batteryconsortium.sg/sites/default/files/2021-04/REPURPOSING%20OF%20LITHIUM-ION%20BATTERIES.pdf

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4 E-waste from solar off-grid solutions

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4.1 Introduction

Electronic waste (e-waste) is the fastest-growing waste stream in the world and has severe impacts on human health and the environment (UNITAR, 2020). At the same time, e-waste is also a source of scarce and valuable materials. Off-grid solar (OGS) products currently make up only a small proportion of the global e-waste stream. In 2020, around 10,000 tons of e-waste resulting from OGS products were produced globally (EEP Africa, 2020), compared to over 50 million tonnes of total e-waste (GOGLA, 2020). However, as the OGS industry continues to grow, managing its e-waste is becoming increasingly important.

This factsheet focuses on solutions for the **collection, handling, recycling and disposal** of e-waste components resulting from OGS (off-grid solar) products, particularly in the African context. It focuses on solutions for the end-of-life (EoL) stage of OGS products, when options of extending the product life such as reuse and repair have been exhausted (see Figure 16). However, it is important to remember that the prevention of e-waste during the design, manufacture and use stages of the product plays a key role in reducing e-waste. For details on these solutions, please consult the factsheet "Circularity and sustainable energy".

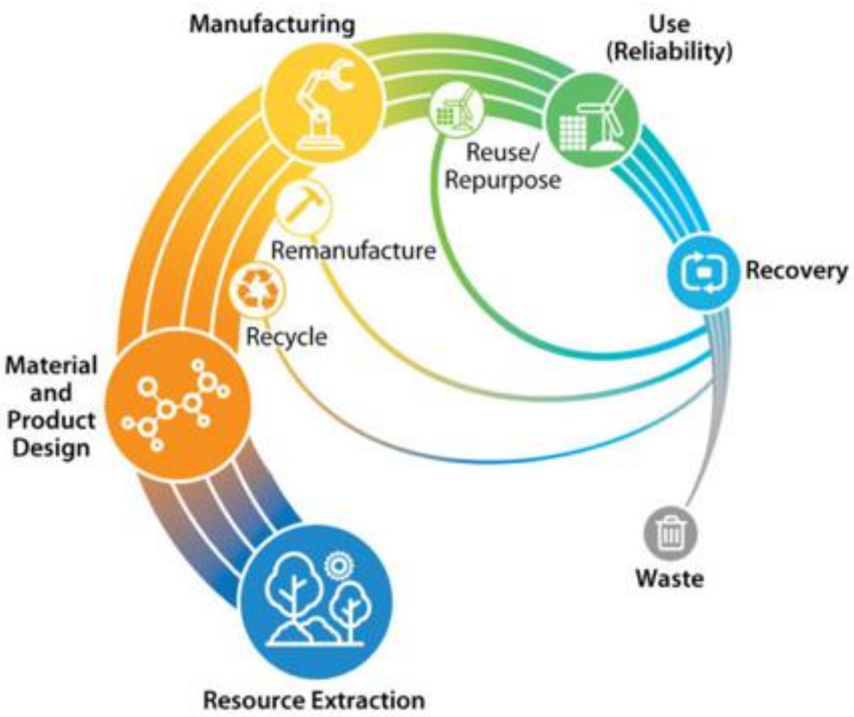

Figure 16. Circularity in sustainable energy solutions (NREL, 2022)

4.2 The technology

The main components of OGS e-waste are: photovoltaic (PV) solar modules, batteries (which can be lithium-based, lead acid, or other), electronic controls, cables, metal components and end-use appliances (e.g., light bulbs, televisions, monitors) (Figure 17) (GOGLA, 2019a, Solar-Electric, 2022). Each of the components requires a specific treatment technology due to the different materials they are made of.

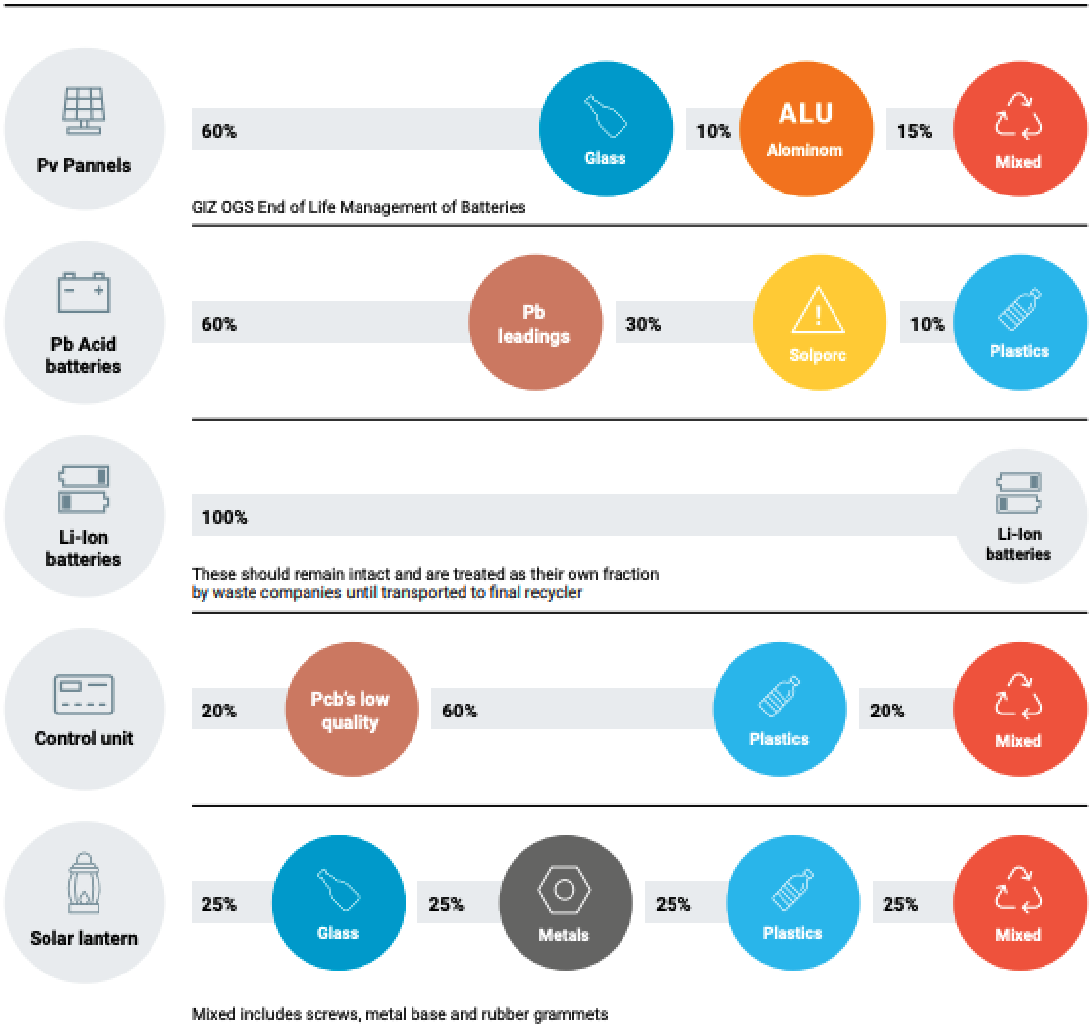

Figure 17. The waste components of off-grid solar products (Gibson & Demir, 2022)

Different technologies come into play in the **different steps of e-waste treatment**: collection, recycling and disposal of OGS products.

4.2.1 Collection

At the end of the life of an OGS product, or when a repair is needed, the product needs to be collected. This is very important in order to avoid that products are abandoned and that e-waste is disposed of improperly. Information and communications (ICT) and Internet of Things (IoT) technologies are increasingly used to support collection operations. Remote performance monitoring, such as tracking battery performance, helps to understand which products are due for repairs or replacements (Efficiency for Access, 2021). Commonly, OGS companies have established **operations to take-back products** when they are defective during the guarantee period (Cross & Murray, 2018). It is important that the technologies supporting take-back schemes continue to operate beyond the expiration of the product warranty, as the majority of products reach EoL after the warranty period (GOGLA, 2020).

For more information on different business models for collection (such as take-back schemes or third-party collection), see the business and financing models section below.

4.2.2 Recycling

After e-waste is collected, it is dismantled and separated smaller parts and fractions (see Figure 18). Dismantling means the mechanical or manual dis-assembly of products while the separation into fractions refers to the grouping of waste according to materials it is composed of (GOGLA, 2019a).

The subsequent handling, transport and recycling of the fractions then depends on the characteristic of each fraction and the level of risk they pose. Some fractions have more complex recycling needs than others. For example, Li-ion battery recycling requires mechanical shredding, while plastics require careful sorting as not all types of plastics are recycled at the same melting point (GOGLA, 2019a). Fractions that contain hazardous or toxic substances are recycled separately. For further details on recycling of different waste fractions of OGS components see GOGLA toolkit "Technical introduction to recycling of off-grid products".

Insufficient infrastructure, **lack of profitability** due to high cost of recycling, and the **lack of policies and legislation pose challenges to effective recycling** of e-waste from solar products. Most regulations for supporting e-waste recycling in Africa are still in draft form and governments lack support of implementation (EEP Africa, 2020) (see Scaling up section).

Figure 18. Manual dismantling of e-waste (Sustainable Recycling Industries, 2022

4.2.3 Disposal

Disposing of e-waste in appropriate engineered landfills can be less harmful to the environment than incineration or uncontrolled disposal. The landfilling process involves excavating soil and burying the e-waste, using a liner of plastic or clay to isolate. However, landfilling e-waste can still lead to the leaching of toxic materials into the soil and groundwater. Therefore, the **ultimate goal** is that all OGS components can be **fully diverted from landfill through reuse and recycling** (Jariwala & Soni, 2021). For more details, see section on socio-economic and sustainability impacts below.

4.3 Business and financing models

Most off-grid solar companies in Africa are not yet in the position to bear the full cost of managing the e-waste they produce. The cost of solar e-waste solutions poses a challenge in what is already a high-risk market. Moreover, there is a lack of necessary widespread collection infrastructure of e-waste that is needed for effective collection. (Hansen et al., 2022). A series of business models are being used to address the affordability and infrastructure problems. It is essential that these are complemented via a supporting enabling environment, e.g., through regulation (see "scaling-up" section).

4.3.1 Types of solar e-waste businesses

It is important to note that there are different types of businesses in the solar e-waste market. Some are solar companies that incorporate e-waste treatment (or some of the steps) into their core business. An example is ENGIE Energy Access, which developed a comprehensive buy-back scheme to get access to broken OGS components and lead acid batteries from the informal sector (Blair et al., 2021) (see more under Examples section). Other businesses focus on e-waste treatment in general, and solar e-waste is only one of many e-waste streams they deal with. This is the example of Nigerian Hinckley Associates (see Examples section).

4.3.2 Consumer- vs producer-financed models

While many African countries are yet to develop policies to manage e-waste, business models of solar e-waste companies will be influenced by the policy tools chosen by the government. Two major policy approaches can be applied. In the consumer-financing approach, the consumer carries the costs of the e-waste that is produced. When purchasing a product, the consumer pays a fee (sometimes known as an "advanced recycling fee") that is used to cover the collection and processing of the e-waste. Occasionally, the fee is refunded to the consumer when the device is correctly disposed of (Ichikowitz & Hattingh, 2020).

The second main approach is the one where the producer finances the costs. Under Extended Producer Responsibility (EPR) policies, the manufacturer (or the importer) of the product pays for the e-waste treatment and bears the responsibility for managing the end-of-life of its products (GOGLA, 2019c). A key goal of EPR policies is to incentivize producers to consider environmental aspects during the design phase and ultimately reduce the volume of e-waste (IRENA & IEA-PVPS, 2016).

In reality, in the EPR model, the costs for recycling are often transmitted into the price the consumer pays for the product (Ichikowitz & Hattingh, 2020). The passing on of the costs of e-waste treatment to solar product customers can create an obstacle for low-income households and dampen investment in the businesses (GOGLA, 2019c).

4.3.3 Public-private partnerships

In public-private partnerships (PPPs) a mutually beneficial alliance between government and the private sector is forged to tackle e-waste. Through a long-term contractual agreement, a specific service is provided to the public and private entities share some of the risks involved (Awuku et al., 2021). An example for a PPP in e-waste is the Rwandan company Enviroserve (see Examples section).

Hybrid PPPs are a further solution to finance e-waste management. They entail arrangements between non-conventional stakeholders, e.g., the informal sector, NGOs, academic institutions and private companies (Ndzibah et al., 2022). An example of a hybrid PPP is the Kenyan company WEEE Centre (see Examples section).

4.3.4 Take-back models

In the absence of a widespread collection infrastructure, solar businesses use different approaches for effective take-back of their used solar products. Companies may set up collection points, partner with third parties and engage with informal collectors. Moreover, they will provide customers with incentives such as receiving a new product at a discounted rate ("trade-in"). Such schemes need to be accompanied by effective customer education campaigns and labelling. On the other hand, companies benefit from the implementation of take-back schemes by an additional customer touchpoint, which allows them to retain customers or acquire new ones and strengthen their brand recognition (Blair et al., 2021).

4.4 Socio-economic and sustainability impacts

E-waste from solar solutions contains toxic and hazardous substances such as lead and mercury. If disposed of or recycled improperly, it poses **severe risks to ecosystems, human health and livelihoods** (CDC, 2021). This section reviews the impacts of e-waste in the African context, and highlights the benefits of appropriate e-waste management. It is important to remember that e-waste from solar products still represents only a small proportion of the general e-waste stream. Therefore, existing knowledge of the impacts of e-waste in Africa is not specific to e-waste from solar products, but to e-waste in general.

Most e-waste recycling in Africa is carried out in the **informal sector** with the purpose of extracting valuable materials such as copper and aluminum. The valuable materials in e-waste are extracted by heating and burning, immersion in acids, and other methods (Lebbie et al, 2022). Workers in the e-waste sector often rely on inefficient tools and inadequate safety clothing that can increase their exposure and health risks (Maphosa & Maphosa, 2020).

Moreover, e-waste burning and dismantling activities are frequently undertaken at informal e-waste treatment sites, often in or near homes. As a result, toxic pollutants concentrate in the water, air, soil, dust, fish, vegetable, dairy products, eggs and human breast milk and affect those living in the surrounding areas, even if they are not directly involved in the recycling. For example, Agbogbloshie in Ghana is the largest e-waste treatment site in Africa, and one of the largest in the world. It is estimated that about 40,000 people live and work within the environs of this site (Figure 19).

Children and pregnant women are particularly at risk from the exposure to toxic chemicals from e-waste (WHO, 2021). Children absorb more pollutants relative to their size, and are less able to metabolise them, and are impacted most strongly due to their rapid rate of growth and development. They absorb more pollutants relative to their size and are less able to metabolize. Exposure to lead from e-waste recycling activities has been associated with neurological impacts in newborns, changes in lung function, DNA damage, impaired thyroid function and increased risk of some chronic diseases later in life, such as cancer and cardiovascular disease.

Figure 19. Manual Burning of waste in one of the world's biggest e-waste recycling sites, Agbogbloshie (Accra, Ghana). (Ejolt, 2022)

Despite the lack of safety and poor working conditions, **e-waste collection and treatment represent a major income source for many households and communities involved** (Maes & Preston-Whyte, 2022). In West Africa, for instance, workers can make significantly more money in e-waste management than in some other industries. In Ghana alone, between 120,00 and 200,000 people depend fully or partially on informal e-waste recycling, collection or repairs for their livelihood (WHO, 2021). In fact, appropriate recycling of solar e-waste poses a great opportunity for the creation of businesses and decent jobs. However, safe recycling facilities remain rare and regulations to improve safety and working conditions are lacking or not enforced (Asante et al., 2019).

Recovering valuable metals through appropriate and safe solar e-waste recycling brings economic and environmental benefits. It is estimated that recycling or repurposing solar PV appliances can unlock an estimated stock of 78 million tonnes of raw materials (including valuable components) by 2050 (IRENA & IEA-PVPS, 2016). This can lower the need for extraction of new materials as well as reduce the costs of new products.

4.5 Scaling-up

The health and economic benefits of scaling-up recycling of OGS products in Africa are significant. As the market for OGS products increases, so will the volume of e-waste related to this sector (Figure 20).

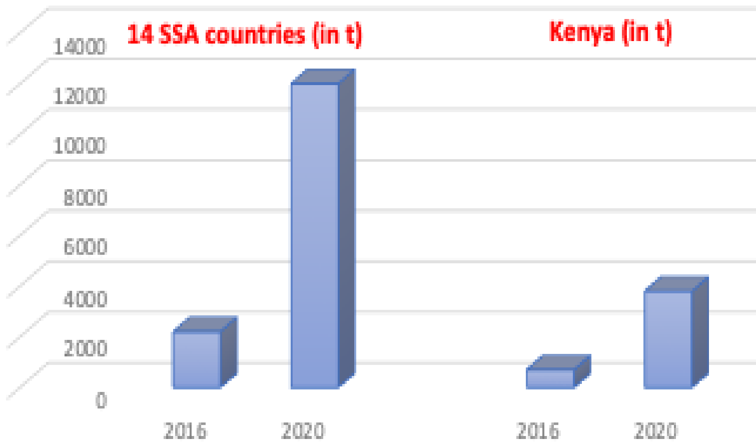

Figure 20. Recent development of waste from OGS products in 14 Sub-Saharan countries and in Kenya described in Maes & Preston-Whyte, 2022

To scale up safe and environmentally sound e-waste treatment in African economies, an **effective enabling environment and policy framework** are urgently needed. **Policy is the foundation of a thriving e-waste market** because it can allocate the cost fairly among producers and enable profit for recycling businesses (GOGLA, 2019d). Moreover, enforcement needs to be strengthened significantly (Maes & Preston-Whyte, 2022).

The treatment of solar e-waste in Africa needs to be understood in the context of the scale of domestic and imported e-waste (Figure 21). Domestic generation of e-waste in Africa only amounts to 50%-85% of the whole volume, the rest originates from **imports from the Americas, Europe, and China** (Maes & Preston-Whyte, 2022). Most of the imports are illegal, despite the existence of treaties that forbid the import of any hazardous waste such as the Bamako Convention (1998).

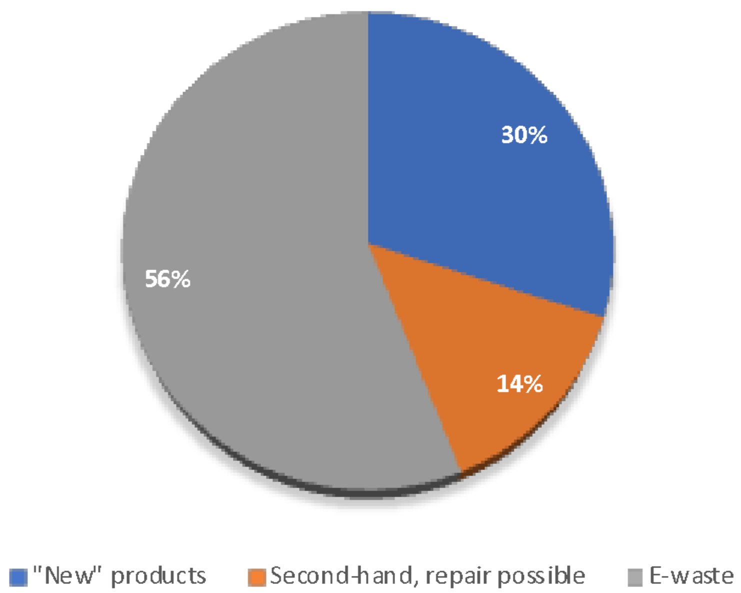

Figure 21. Type of imported electronics to Ghana, 2019, described in Maes & Preston-Whyte, 2022

4.6 E-waste from solar off-grid solutions in SESA

SESA partners in various countries are considering the treatment of e-waste from solar off-grid solutions. Their activities are briefly outlined below.

4.6.1 SLB use and e-waste management Kisegi, Katito and Homabay county, Kenya

The demonstration implementation activities will be carried out at two project sites, Kisegi, a rural village in Homa Bay county, and Katito a peri-urban community in Kisumu County with the social enterprise WeTu being the key stakeholder for SESA on site. The main objective of the Kenyan living lab is to provide sustainable energy access solutions relevant for validation and replication in both urbanized and rural contexts in Africa. Both demonstration sites include solar charging hubs that incorporate PV modules, central Li-ion battery storage, and balance-of-system (BoS) to increase energy accessibility for a range of electrical needs within the local community. The solar charging hubs will charge and power the many use cases as well as the battery storage system.

The company takes a community integrated approach to e-waste management by sensitising and incentivising community members and stakeholders to return and hand-in e-waste. They are establishing seven WeTu hubs as e-waste collection centers and developing an e-waste pre-processing/dismantling plant at the WeTu Hub in Homabay.

The solution includes the goal that devices that are out of use shall be seen as valuable resources with potential to be repaired or recycled and reused to its full extent. To live up to this goal, WeTu is searching for suitable business partners for the different downstream parts such as plastics, metals, glass, and its specific e-waste components.

4.7 Examples of application in the African context

Hinckley Associates, Lagos, Nigeria

The idea: The company is the first registered e-waste recycler in Nigeria, providing end-of-life solutions for electronic equipment, preventing environmental pollution and human harm caused by hazardous e-waste.

Areas of expertise and innovation:

- Hinckley Recycling is forging the way for the formal e-waste sector in the country, balancing bureaucratic challenges with competition from a massive, well-organized informal collector coalition, with an emphasis on batteries used in off-grid solar
- Collection and recycling of e-waste
- Re-use and redeployment
- Value return services

The business model:

- Hybrid PPP, working together with Hewlett Packard (HP) and other manufacturers across Africa as well as the informal sector

The impact:

- environmental impact through recycling of e-waste
- strengthening the formal e-waste sector by conforming to strict environmental recycling and working closely with the government

For further information visit:

- https://hinckley.com.ng/
- https://medium.com/efficiency-for-access/hinckley-recycling-takes-on-nigerias-informal-recycling-industry-d8f8880e9b2c

Engie Energy Access, Kampala, Uganda

The idea: Engie Energy Access is mainly a pioneer of the PAYGo solar model in Sub-Saharan Africa with a waste management system included

Areas of expertise and innovation:

- Solar Home Systems (SHS), mini-grids and an innovative, inhouse-developed software suite Paygee for the business model, focus on e-waste collection and informal sector

The business model:

- Pay-As-You-Go (PAYGo) business for SHS and run last-mile distribution for any product worldwide
- Company developed a comprehensive buy-back scheme to retrieve broken off-grid solar components (of any brand), along with off-grid solar lead acid batteries from the informal sector.

The impact:

- Job creation in the company
- Set-up of e-waste infrastructure through collection points
- Training and awareness raising

For further information visit:

- https://engie-energyaccess.com/
- https://www.clasp.ngo/research/all/innovations-in-off-grid-solar-e-waste-management/

Enviroserve Rwanda Green Park, Kigali, Rwanda

The idea: Enviroserve Rwanda Green Park is a private company dedicated to electronic and electrical waste recycling, green growth, and the circular economy.

Areas of expertise and innovation:

- Enviroserve is pioneering e-waste management in East Africa and operates the region's only state-of-the-art e-waste dismantling and recycling facility
- After collecting e-waste materials from different institutions, Enviroserve Rwanda separates materials that can be refurbished and recycled, while others are disposed of in an eco-friendly manner

The business model:

- PPP between EnviroServe in partnership with the Rwandan Government
- Equipment that can be repaired and refurbished, they are fixed and sold at heavily discounted prices or donated to local schools.
- Items beyond repair are dismantled to recover valuable components

The impact:
- job creation in the company (600 green jobs created so far)
- protection of the environment, health and mitigation of CO_2 emissions through collection, dismantling of (solar) e-waste

For further information visit:
- https://enviroserve.rw/
- https://www.builtinafrica.io/videos/enviroserve-rwanda

WEEE Centre, Nairobi, Kenya

The idea: WEEE Centre is an e-waste recycling company based in Nairobi, Kenya, that provides e-waste collection, dismantling and automated processing services in Nairobi and several other major cities in Kenya. It sources e-waste from the private & public sector and raises awareness through collection campaigns aimed at individual households.

Areas of expertise and innovation:
- WEEE Centre works in the areas awareness creation, e-waste disposal, e-waste processing, secure data destruction and training

The business model:
- Hybrid PPP as WEEE Centre partners with SMEs across Kenya, international NGOs and the Kenyan government
- Uses a dispersed incentive and collection model
- In order to create a financially viable business, WEEE Centre is extracting valuable materials from some of the collected e-waste to be sold or reused in the production of other electronics

The impact:
- Securing a green and safe environment through safe disposal of e-waste
- Performance of training and awareness creation on safe and circular e-waste management
- Job creation through the training of youth on repair, maintenance of electronics and e-waste collection

For further information visit:
- https://weeecentre.com/services/
- https://medium.com/efficiency-for-access/weee-centre-creates-an-economically-viable-e-waste-management-model-c9ee1ed4b5af

4.8 Climate-proofing

The treatment of solar e-waste needs to be climate proofed for a number of reasons:

- In general, phenomena that could cause physical damage to the facilities such as floods, landslides, storms and forest fires should be carefully considered not only in the selection of the implementation site, but also in the design of the infrastructure.
- Management of e-waste contains many hazardous materials so the process of e-waste recycling involves significant risks to the environment and human safety, for example in case of fire (Kazancoglu et al., 2022).
- Handling of EoL batteries poses significant explosion and/or fire risks during transportation, storage and handling, most of all if batteries are exposed to extreme temperatures. This should be considered in the design of transportation routes and means, storage conditions and processes design.
- E-waste infrastructure can be harmed because of extreme wind, storms, air sand, extreme temperatures, floods, landslides, and forest fires. The occurrence, frequency and intensity of these extreme climatic conditions needs to be considered in the design and setting up of an EoL infrastructure.

4.9 Relevant tools and capacity building materials

E-waste toolkit from GOGLA

The e-waste from OGS products toolkit designed by GOGLA is aimed at helping address the main challenges in setting up sustainable recycling chains. As the sector grows, companies and investors are increasingly focusing on resource efficiency and lifecycle of products – from design and manufacturing to EoL. The toolkit is a work in progress and content will be added regularly as modules are developed. The toolkit consists of the following training modules: 1. Technical introduction to recycling of off-grid solar products, 2. Design for reduction of e-waste, 3. Financials of e-waste management, 4. E-waste policy and regulation, 5. E-waste and the consumer, 6. Take-back and Collection
https://www.gogla.org/e-waste

Circularity Toolkit: E-Waste Blueprints

Building on the GOGLA E-waste Toolkit, which captured knowledge and best-practice through a series of six modules, the Blueprints provide OGS companies with practical tools to encourage implementation and improve e-waste management practices across the industry. Wherever possible, we have sought to ensure that the E-Waste Blueprint documents are applicable to a broad cross-section of OGS companies, regardless of company stage, product type or country of operations.
https://www.gogla.org/resources/circularity-toolkit-e-waste-blueprints

E-waste toolkit from EEP Africa

The e-waste toolkit from EEP Africa has compiled a set of resources to support companies overcome many of the barriers to e-waste management and recycling in East and Southern Africa. The toolkit provides best practices for project developers and consumers for off-grid solar e-waste management, resources on local legislation, and recommendations for recycling services.
https://eepafrica.org/resources/e-waste-toolkit/

E-waste Training Manual from GIZ

The e-waste training manual from GIZ is about safe handling of e-waste. The publication assembles compact information about e-waste in theory, it covers practical dismantling of

different types of equipment, output fractions after manual dismantling, the management of a small-scale recycling facility, and the organizing of training.
https://www.giz.de/de/downloads/giz2019-e-waste-management.pdf

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5 Solar Power and the Water-Energy-Food Nexus

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5.1 Introduction

Promoting the transition to clean and affordable energy for all in Africa requires understanding the relationship between energy, water, and food resources. Climate change is resulting in **increased water stress** and shorter growing seasons in agricultural systems across Africa, an increase in aridity, and water-related extreme climate events such as droughts (IPCC, 2022). This is exacerbated by an increase in the share of population facing food insecurity, which affects nearly one in four people in 2021 (FAO et al., 2022).

The **Water-Energy-Food (WEF) Nexus** concept offers an integrated framework which enables to **reduce trade-offs** and **increase synergies** in securing goals of energy, water and food security (Terrapon-Pfaff et al., 2018; Srigiri and Dombrowsky, 2021). Electricity from decentralised solar is a cost-effective solution to meeting energy needs and also plays a central role in achieving the goals of the WEF Nexus. This factsheet presents how different solar power solutions can effectively address the WEF Nexus, and gives examples of how this is already happening in the African context.

5.2 The technology

WEF Nexus challenges not only introduce risk factors, but also create opportunities for innovative solutions. Some of the key solar-powered technologies that can boost water and food security include solar water pumps and irrigation systems, agrivoltaics, and water filtering and purification systems. Internet and communication technologies (ICT) and Internet-of-Things (IoT) can also support the efficient use of water in agriculture. (For further examples of WEF Nexus solutions, including food storage and processing, see also the factsheet on solar power for productive use.

5.2.1 Solar-Powered Water Pumps and Irrigation Systems

Solar-powered irrigation systems (SPIS) consist of PV panels on a mounting structure that are connected to a controller unit for water pumping purposes. The controller unit is responsible for running an electric pump. The pumped water can be either directed to a water storage reservoir or to an irrigation system. Before it flows into the irrigation system, the water can be filtered or mixed with fertiliser (Figure 22).

In order for SPIS to adequately address the WEF Nexus, it is crucial that they are coupled with sustainable irrigation practices. This requires solid knowledge of the farming practices, the water demand of different crops, and the water availability patterns (Energypedia, 2020). These factors strongly impact the type of SPIS that can be used in a specific field or farm.

Figure 22. Solar Powered Pump (Sub Sahara Farmers Journal, 2022)

For more information on SPIS, see also the factsheet on solar power for productive use of energy (PUE).

5.2.2 Solar Agrivoltaics

Solar agrivoltaic systems are an excellent example of the use of solar technologies in the context of the WEF Nexus. An agrivoltaic system is the practice of growing crops underneath solar panels. The mounted PV panels provide shade and reduce water evaporation, therefore leading to lower irrigation requirements (Figure 23). Using a sprinkler irrigation system allows for the cleaning of the PV panels and, at the same time, the use of the water for the crops. Additionally, the PV arrays can be used as rainwater channels and irrigation runoff (Ersoy et al., 2021). Lastly, the electricity generated can be used for multiple purposes on site such as powering the water pumping and irrigation, cold storage or processing.

Agrivoltaic systems have the potential to increase agricultural productivity and generate clean energy while reducing competition for agricultural land. Falling costs of photovoltaic systems are making agrivoltaic systems more viable economically, with particular potential in arid and semi-arid regions (Fraunhofer ISE 2020). In the African context, agrivoltaic systems are being currently piloted in Mali, Gambia, and Kenya (see Examples section).

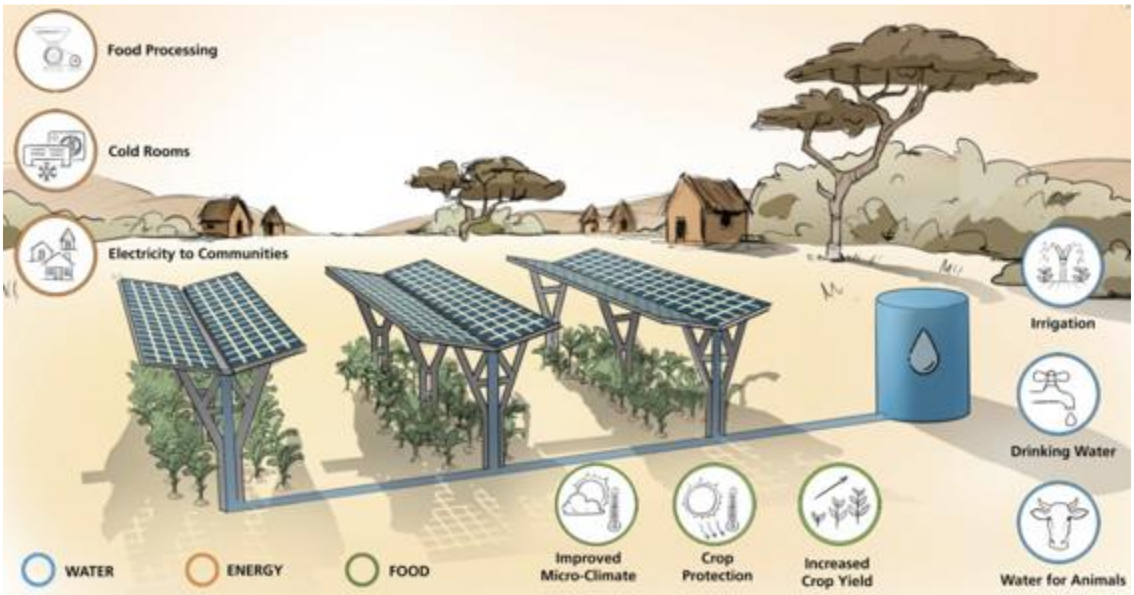

Figure 23. Schematic diagram of a Solar Agrivoltaics system (Fraunhofer ISE 2020)

5.2.3 Solar Water Treatment Systems

Generating safe drinking water for households or livestock, or treating saline groundwater so that it is suitable for irrigation, is another area where solar technologies can help address the WEF Nexus. Small-scale and mobile solar water treatment systems can be advantageous in remote and rural areas that are not connected to the electricity grid.

Solar power can drive electrochemical water treatment processes such as electrocoagulation and reverse osmosis, where the electricity powers pumps that push water through semiporous membranes. Water treatment technologies can also use solar energy for heating, or solar ultraviolet light, such as the rain water harvesting and filtering systems piloted in South Africa (EPCM, 2022).

Hydropanels are an innovative solar-powered water treatment technology. They take in ambient air via fans and collect water vapor from it, which they transfer onto a material that can absorb moisture. The hydropanel then converts the vapor collected into safe liquid water, which is then mineralised by adding magnesium and calcium (Kart, 2022).

Lastly, desalinating sea or saline borehole water holds potential in areas where groundwater is saline. While water desalination usually takes place in large-scale facilities, there are also examples of solar-powered decentralised desalination units in Africa (Nzuki and Elliott, 2022).

Figure 24. OffGridBox unit delivering clean water in Rwanda (OffGridBox, 2022)

5.2.4 ICT and IoT in the WEF Nexus

Remote monitoring or Internet of Things (IoT) platforms are increasingly available for the management of the water cycle in agriculture. For water efficient management of SPIS, for example, soil sensors and small weather stations can analyse data and provide users with rain forecasts and best irrigation timing advice on their mobile devices, or they can automatically disable a farmer's pump and notify them if their well runs dry (GOGLA, 2019). For water treatment facilities, communication technologies and data analysis can enhance the effective use of water, fertilisers and nutrients (Watermed 4.0, 2022). Watermed 4.0 in Miliana, Algeria, is an example of research for the efficient use and management of conventional and non-conventional water resources through smart technologies, especially in arid and semi-arid areas. The objective of Watermed 4.0 is to develop and apply a decision support system for managing the water cycle for agriculture, based on IoT (see Examples section).

5.3 Business and financing models

A business model that considers all three sectors (energy, water, and food) at the same time has, potentially, a higher return than one that considers them individually. Based on an analysis of 20 rural electrification projects in Sub-Saharan Africa (SSA), projects that provided electricity together with other WEF Nexus-related services were found to be more financially sustainable than those providing only electricity (Aresti et al., 2019, p. 20). However, despite the potential for attracting different streams of investment, truly integrated WEF Nexus-oriented business models in Africa remain a niche (Dalton et al., 2019). Financing geared towards entrepreneurs in this space is still rare (see, for example, the financing from the WE4F Grand Challenge (WE4F, 2022)). A number of programmes are supporting African entrepreneurs in building the WEF Nexus into their business models (ENI CBC Med, 2021).

5.3.1 Consumer financing and affordability

Like other business models for solar solutions, nexus-oriented models need to address the challenge of **affordability**, in particular, when they are geared towards smallholder farmers. Solar systems are more affordable than conventional diesel-powered systems over their whole lifetime. For example, when replacing diesel-powered irrigation systems, solar water pumps lead to fuel cost savings, and are overall 35% cheaper than the diesel system. However, the solar system has a comparatively **higher upfront cost**.

Different approaches to overcome the affordability challenge include **joint ownership models**, the **service-provider model**, or the incentive to multiple use of the system. Different **consumer-financing models,** such as **pay-as-you-go (PAYGO)** and **micro-finance**, can also be used to facilitate the initial investment in a solar system. For example, the Senegalese company Bonergie offers several consumer-financing models to overcome the affordability challenge, among them the “Asset Protection Mode” module integrated into the pump, which allows customers to pay a self-selected amount (see Examples section). For more details on financing models, consult the factsheet on productive use of energy in agriculture.

5.3.2 Partnerships and synergies

On top of the affordability challenge, solar energy business models that embrace the link between water, energy and food systems have a higher level of complexity: they require a strong understanding of the links between different resources and value chains. For example, solar water pump businesses require agronomic and irrigation expertise. For this reason, energy businesses that apply a WEF Nexus approach, often partner with other businesses. For example, solar pump providers partner with irrigation equipment providers and other businesses that provide complementary services, including financing solutions (Efficiency for Access, 2019).

Indeed, energy businesses that apply a WEF Nexus approach always need to partner, engage with and/or share data with other businesses or public organisations in the agricultural and water sectors, and broker agreements and compromises, sometimes between competing interests. For example, in agrivoltaic systems, the business model needs to encompass the farm owner and operator (and the landowner, if different) as well as the PV system owner and operator (Fraunhofer ISE 2020). In jointly owned solar water pumps, there needs to be an agreement among the owners on the sharing of the water resource, not just the pump (Gebrezgabher et al., 2021; IRENA and FAO, 2021).

Finally, nexus-oriented business models in the agricultural sector share many features with productive use business models: they revolve around the development of local skills and local businesses, the building access to markets, and a strong engagement with the communities involved.

It is important to remember that business models are always context-specific and need to be based on a strong understanding of local needs. In the case of nexus-oriented businesses, it is key to identify the impacts, trade-offs, investment opportunities and business synergies.

5.4 Socio-economic and sustainability impacts

Solar energy solutions implemented under a WEF Nexus approach can deliver a range of health, economic, environmental and inclusion-related benefits.

Solar-powered irrigation is one of the best studied solutions in terms of impacts on livelihoods of smallholder farmers. Providing access to modern irrigation can have a significant **impact on agricultural yields.** In fact, some case studies show an increase in yields of as much as two to three times (Efficiency for Access, 2019). The impact of irrigation is higher when accompanied by other support such as access to markets. When replacing diesel-powered irrigation systems, SPISs lead to fuel cost savings, by making the solar water pump system 35% cheaper than the diesel system.

Impacts of SPISs on livelihoods go beyond increases in yield or income. When coupled with drip irrigation, (an irrigation technique in which water flows into drip pipes and exits through emitters located at different distances), SPISs are proven to significantly **increase nutritional intake**, particularly during the dry season (Burney et al., 2010). An **increase of the quality and availability** of food and a **decrease in food imports** was also observed in Ghana (RES4Africa, 2019).

Nevertheless, **SPISs are a perfect example of the risks of solar solutions when the WEF Nexus is not taken into account.** Experience in India and Morocco has shown that SPIPs tend to carry a risk of groundwater depletion if not properly designed (Beaton et al., 2019; Gupta, 2019). To reduce this risk, there need to be incentives for the farmers to **irrigate efficiently**. Potential solutions to mitigate the risk of overextraction are making water-table data available to solar water pump companies and smallholder farmers, smart metering on pumps that track water usage and allow to pre-set pump operation times, encouraging pump sharing, and rigorous water accounting to regulate groundwater use (Efficiency for Access, 2019).

Other solar solutions that consider the WEF Nexus approach can also lead to positive socio-economic and sustainability impacts. For example, solar water treatment systems can lead to significant improvements in health and reduce the time required to collect water (WeTu, 2022). Agrivoltaic systems have the potential to **reduce competition for agricultural land** while increasing agricultural productivity and generating clean energy. This is particularly important for improving resilience to climate change.

Figure 25. Rows of crops under solar irrigation system (Bonergy, InfraCo, 2022)

5.5 Scaling-up

Delivering access to energy, while ensuring the security of water and food resources, is at the heart of development goals in Africa. This is of particular importance in rural regions, which rely predominantly on agriculture. There are currently 500 million rural dwellers in SSA, and these are set to become more than 900 million by 2050. More than two-thirds of rural dwellers in SSA currently have no access to electricity (crucial for crop irrigation, processing, and storage) and the majority of cropland is rainfed only, resulting in reduced and unstable yields (Falchetta et al., 2022; Mumssen, 2022).

In order to scale up the deployment of solar solutions that embrace a WEF Nexus approach, a variety of levers are needed, including **government policy, business and financing models**, **technology** and **product adaptation**, and partnerships among various stakeholders.

High-level political support for and ownership of the WEF Nexus is the first step to integrating it into public policy and planning. This needs to be coupled with a continuous dialogue among different institutions and stakeholders, and a build-up of institutional capacity and knowledge that can support decisions (Jembere, 2021). For example, efforts are currently underway to institutionalise the WEF Nexus in the Southern Africa region. This includes integrating the concept into national economic plans, as well as into the specific energy, water, agriculture, rural development, nutrition, industry and climate strategies.

Solar-water pumps are, once again, a key example of how policy efforts can support the scale-up of the WEF Nexus approach. In India, a mapping of policies promoting off-grid solar pumps indicated a potential to increase their effectiveness by taking into account the WEF Nexus. In particular, they found solar pump programmes could lead to savings from subsidy expenditure on electricity and diesel (Beaton et al., 2019).

Finally, **mobilising large investments** for nexus-focused solar solutions is **key to scale up**. Sometimes, this may not only be a case of increasing existing financial resources, but also of redirecting them so that they take into account the links across the energy, water and food sectors. Financing institutions and governments can provide funds, blended finance, soft loans, and other incentives to private developers that apply the principles of the WEF Nexus in their projects and business plans. Subsidies for the agricultural sector and for solar power are a particular area where nexus-oriented financing opportunities can be leveraged.

5.6 The WEF Nexus in SESA

SESA partners in various countries are considering the WEF Nexus in their Living Labs. Their activities are briefly outlined below.

5.6.1 Solar water pumping, water purification and small-scale irrigation in Kisumu & Homabay counties, Kenya

The social enterprise WeTu in Kenya, founded by the Siemens Stiftung, works on innovative solutions for the pumping and purification of drinking water and solar powered small-scale irrigation.

The solution for pumping drinking water innovates through "Solar Spring Membrane Solutions", selling filtered water from Lake Victoria combined with rainwater. The purification system is suitable for the treatment of contaminated surface water from wells, rivers, lakes and rainwater. For small scale irrigation, the solution innovates through the mechanisation and improvement of agriculture through the use of dependable renewable energy to power irrigation and irrigation systems. Also, another innovative aspect is the use of climate-friendly energy sources with drip irrigation and other irrigation technologies to reduce water and energy use and increase the harvest.

Within the Katito living lab in SESA, WeTu uses energy generated by solar power to pump water from a 50 meters deep borehole to be stored in large storage tanks. From the water tanks, water is filtered through reverse osmosis and pumped into elevated water storage tanks. The obtained clean drinking water can be purchased by locals through a water ATM (Figure 26).

Figure 26. Water ATMs run by WeTu. Own images (2022)

5.6.2 Solar-powered pump system in Ga North and Atwima Nwabiagya, Ghana

Within SESA, the municipalities of Ga North and Atwima Nwabiagya in Ghana will apply solar-powered water pumping systems.Water pumping in remote areas involves raising water from a well or spring and storing it in a tank for irrigation, cattle watering or village water supply.

5.6.3 Solar-powered irrigation systems in Rwanda

The SESA living lab replication site in Rwanda aims at using solar power for PUE such as **solar irrigation systems** to ensure food security through the enhancement of growing crops. Working with solar irrigation systems will also reduce the reliance on seasonal rainfall and improve crops yields. The main SESA partner in Rwanda is the University of Rwanda.

Solar-powered water pumps for irrigation in Tanzania

The SESA living lab replication site in Tanzania aims at implementing a variety of solar power for PUE solutions. Among the planned activities are **solar water pumps for irrigation systems, and the provision of cooling facilities to increase life-lasting of food products and reduce post-harvest losses**. Within SESA, the main partner in Tanzania is the Energy and Livelihoods for Communities (E-LICO) Foundation.

5.7 Examples of application in the African context

Bonergie, Dakar, Senegal

The idea: Bonergie is a solar company in Senegal. They offer solar products that are suitable for productive use to their customers and thus help generate income. One of their products is SPIS.

The power source:

- Solar PV
- Irrigation equipment

The business model:

- Bonergie offers a flexible payment plan, where farmers typically pay between 20 and 30 percent down and are offered the possibility to pay monthly instalments to pay the balance within 18 months
- Possibility for “Asset Protection Mode” module integrated into the pump, which allows customers to pay a self-selected amount on a variable basis, whenever income is generated. Bonergie sends a code to the customer for the number of days paid. When the code expires, the pump stops working

The impact:

- Increasing irrigation efficiency & protecting groundwater resources from over extraction
- Diversification of crop harvest throughout the year
- Increasing incomes through the diversification of crop harvest, less energy costs in the long-term, expansion of seasonal growing cycles

For further information visit:

- https://bonergie.com/en/
- https://infracoafrica.com/project/bonergie-irrigation-i_ii/

Watermed 4.0, Miliana, Algeria

The idea: Develop and apply an integrated decision support system based on the Internet-of-Things, for managing the whole water cycle in agriculture, monitoring water resources and water demands including the measure of economic, energy, social and governance factors that influence the water use efficiency.

The power source:

- Solar PV

The business model:

- Pilot research project (universities and research institutions involved)

The impact:

- Increase of quantity, quality and safety of non-conventional water use for agriculture and food processing
- Increasing the efficiency of water smart management systems with regard to energy and water smart infrastructures
- Enhancement of agriculture export potential
- Decreasing probability of migration flows

For further information visit:

- https://www.watermed-project.eu/

Water Kiosk water treatment, Kenya

The idea: The company installs, operates and maintains solar water desalination systems delivering high quality hygiene drinking, irrigation, fish farm and sanitation water from any kind of high saline and polluted water resources for off-grid communities around Africa.

The power source:

- Solar PV

The business model:

- Payments are done when water is collected from Kiosk

The impact:

- Increased incomes and access to sustainable employment
- Empowerment of women
- Minimising the effort and dangers in traveling to collect drinking water
- CO_2 reduction
- Affordable drinking water for communities
- Community WIFI
- Potential for additional value-added business around the Water Kiosk's infrastructure

For further information visit:

- https://waterkiosk.africa/

5.8 Climate-proofing

Projections suggest increasing demands for **freshwater, energy and food** as a consequence of future development in terms (amongst others) of demographic changes, economic development and international trade (EC, 2021). At the same time, climate change adds additional stress. According to the IPCC (2022), future warming will shorten growing seasons and increasing water stress across Africa, and a wide range of rainfall extremes are expected, having severe socioeconomic and environmental consequences. This will require planning under deep uncertainty (IPCC, 2022).

The implementation of WEF Nexus approach is a climate change adaptation measure itself, enhancing resilience to climate change in agricultural and energy systems. For instance, solar powered water pumps, coupled with efficient water management, have the potential to expand seasonal growing cycles and mitigate periods of low or irregular rainfall. This can make farmers more resilient to droughts or changing rainfall patterns (Efficiency for Access, 2019). For more information, see also Factsheet on Productive use of Solar Energy.

5.9 Relevant tools and capacity building materials

WEF Nexus Discovery Map
The WEF Nexus Discovery Map is a combination of a data visualization tool and a filterable research depository developed by the Penn State WEF Nexus strategic initiative program. It supports projects of sustainable development by locating areas of need, growth, partnership and action. Therefore, different maps and filters can be selected: i.e., project locations or country-wide WEF indices (water, energy and food supply). Projects can be added.
https://www.water-energy-food.org//resources/tool-wef-nexus-discovery-map

Toolbox on Solar Powered Irrigation Systems (SPIS)
The Toolbox on SPIS, a legacy project embraced by the Water and Energy for Food (WE4F) programme, offers essential information and tools for the implementation of SPIS. The aim is to minimise risks related to system efficiency, financial viability, and unsustainable use of water resources. It provides software tools like calculation sheets, checklists and guidelines, e-learnings and tutorial videos for all stakeholders who advise SPIS end-users, financiers, or policymakers. Besides basic information, the toolbox contains content about promotion and initiation, water management and governance, markets, investing, financing, design, set up, irrigation and maintenance. The toolbox can be also downloaded in the app store.
https://energypedia.info/wiki/Toolbox_on_SPIS

World Bank: Solar Pumping Handbook
The World Bank produced a package on solar pumping information including a handbook of solar pumping basic knowledge addressing end-users. Besides basic information about solar pumps and their major system components it offers a guidance for choosing the right system and gives advice for essential questions like the location of the system or the water consumption of crops and livestock.
https://documents.worldbank.org/en/publication/documents-reports/documentdetail/880931517231654485/solar-pumping-the-basics

Water and Energy for Food (WE4F) Portal
The Water and Energy for Food (WE4F) Portal gathers information about clean energy, water- and energy-efficient technologies to enhance agricultural production and value. The portal provides

information on sustainable energy and water use among the value chain of agriculture, including knowledge about policies, financing and business models.
https://energypedia.info/wiki/Portal:Water_and_Energy_for_Food

Solar Pumping Toolkit
The Solar Pumping Toolkit by the Global Solar and Water Initiative is divided into four chapters which offer information about guidance and assessment, technical design and tender, installation and operation and maintenance, monitoring and evaluation.
https://energypedia.info/wiki/Solar_Pumping_Toolkit_-_The_Global_Solar_%26_Water_Initiative

Interactive map "Potential for Solar Photovoltaic Based Irrigation"
The International Water Management Institute (IWMI) created an online interactive tool to assess land in SSA, suitable for photovoltaic based irrigation. A map with various filterable criteria identifies suitable regions, based on the quality of solar radiation. The parameters to modify include regions, water source (ground or surface water) and pump capacity (from 0-250 m).
http://sip.africa.iwmi.org/

WEF Nexus in Africa Initiative
The Water-Energy-Food Initiative is a network of academic, public, and private sector institutions addressing significant scientific, social, environmental, and engineering challenges at the WEF Nexus. The purpose is to provide technical knowledge for local solutions through public-private partnerships. In addition to relevant publications the website provides information on webinars.
https://wefnexus.org/

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6 Circularity and Sustainable Energy

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6.1 Introduction

Today's predominantly linear economy works by using resources to manufacture products which are later disposed of at the end of their useful life. A circular economy can be defined as a sustainable economic system where the loop linking waste and raw materials is closed, and where economic growth is decoupled from resource use. Achieving circularity in businesses and economies is a necessary step to sustainability, as well as a source of economic opportunities.

Applying circular approaches to sustainable energy solutions aims to eliminate waste throughout the lifecycle of the energy technologies (Figure 27). This includes, for example, improving the design of products so that they last longer, or maximising the recycling potential of the products when they reach the end of their life.

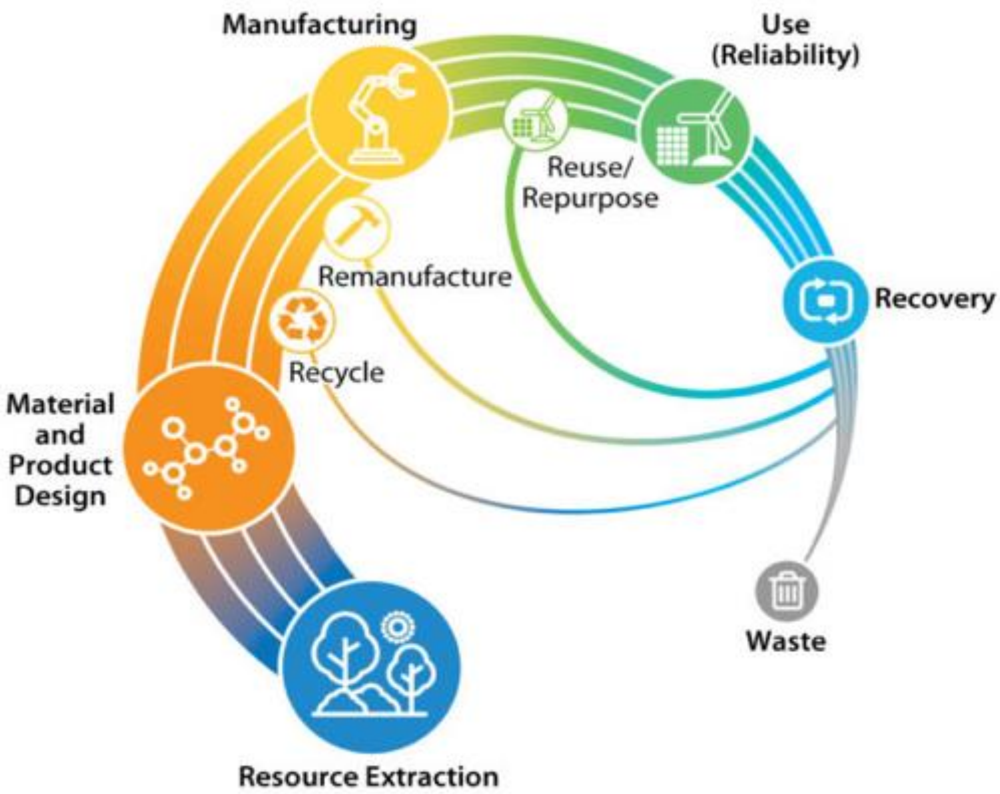

Figure 27. Circularity in sustainable energy solutions (NREL, 2022)

This factsheet focuses on how the different approaches to circularity can be integrated into different sustainable energy solutions (such as sustainable e-mobility or solar off-grid solutions) in the African context. It also presents the potential socio-economic impacts of circularity and the potential for scaling up the approaches, and gives examples of the application of circularity principles in sustainable energy in the African context and within the SESA project.

It is important to note that Circular Economy (CE) approaches focus on the entire lifecycle of a product and not only on the end-of-life (EoL) stage. For more details on the EoL stage (in particular for solar off-grid systems), please consult the factsheet "E-waste from solar off-grid solutions". A further solution in the catalogue that is related to circularity concepts is the "Second life of Lithium-ion batteries" factsheet.

6.2 The technology

The technological innovations that most contribute to circularity in sustainable energy are those that **prevent** the production of waste in the first place. A mini-grid, electric vehicle or solar home system that strives for circularity is one that seeks to prevent waste production during all phases of the product's life: manufacture, distribution, storage and use**.**

The most effective innovations to prevent waste are those that are integrated **into product design.** Designing products that are **durable** and **easier to maintain and repair** is central to extending the use phase and therefore to preventing waste production. Durable and repairable products that stay in the loop for a longer period of time also bring significant side benefits to users (see "Impacts" section). There are different examples of innovations that have been implemented by off-grid solar companies to increase the reparability of their products (Efficiency for Access, 2020). For example, Solarly solar home systems (Solarly, 2022) are designed so that the batteries and fuses are accessible for ease of repair, as opposed to other designs where the whole system needs to be replaced in case of failure.

The appropriate operation of products also helps to extend their life. For example, the life of batteries can be extended significantly by avoiding frequent rapid charging, strong acceleration, mechanical shocks and extreme temperatures (Mosshammer, 2022)**.**

Similarly, innovations that make it **easier for the product to be reused, refurbished and recycled** are also preventing waste creation. For example, Lithium-ion batteries in electric vehicles are increasingly designed to make it easier for them to be used as storage units in off-grid solar applications during their second life (see factsheet on 2nd life batteries). There are also multiple ways to improve the recyclability of a product (e.g., using recyclable materials, limiting the number of material types and composites, or increasing modularity) (Circular Economy Practitioner Guide, 2022).

Making products less material-intensive or introducing **recycled materials** into the design of products is a further avenue towards circularity. Ecolife in Uganda is an example of how this can be integrated into the design of PUE (productive use of energy) appliances. They manufacture cold storage rooms that use locally available agricultural waste, plastic bottles and other recycled materials as isolation material (Efficiency for Access, 2020).

Strategies for waste prevention during the **manufacturing and distribution** include, for example, the use of local materials and suppliers (to reduce the waste, water and carbon footprint of transport), or the minimising of packaging and the use of sustainable logistics infrastructure.

Finally, ICT and Internet of Things (IoT) technologies are key to achieving circularity, as they allow remote monitoring of vehicles, batteries and other components of sustainable energy solutions. This facilitates repair and maintenance services, therefore contributing to extending the life of the product. Moreover, it allows to learn from product-in-use data, which can inform innovations and improvements in design (Ingemarsdotter et al., 2019) (see Business models Section)

Figure 28. Refurbishment of a control box in the workshop at the BBOXX distribution centre. Kisumu, Kenya (Walcott, 2019)

6.3 Business and financing models

Business models that support circularity increase the lifetime of sustainable energy products, integrate circular economy approaches and are potentially a source of savings and benefits for businesses, as they can lower maintenance costs, improve efficiency and lead to new revenue streams (e.g., through sale of parts or recovered materials). However, circular economy approaches can also pose challenges. For example, companies may be concerned that, by increasing repairability (and thus extending lifetime) they will sell less products and experience a loss in revenue, or that using more expensive materials or increasing the investment in product design will lead to substantial costs. Many manufacturers may be reluctant to design systems for repair and disassembly because of fears that this will make it easier to copy components or bypass smart payment mechanisms (Efficiency for Access, 2020).

There may also be trade-offs between different circularity approaches. For example, solar home system businesses may perceive a trade-off between increasing durability and repairability: if a product is easier to open, it may lose the protection required to keep out dust and rain (Efficiency for Access, 2020). Some businesses may be concerned that increasing the repairability also affects their ability to honor warranties (as warranties require that the product is untampered with).

New business models are emerging in the sustainable energy space with the aim of tackling these challenges and closing the loop of the product life cycle. This factsheet focuses on business models addressing the design and use phase. For information about models dealing with e-waste (e.g., public-private partnerships, take-back models), please take a look at the factsheet on e-waste from OGS.

In the **Productive Service System (PSS) model,** customers can purchase a service for a limited time while the provider maintains ownership of the product. The provider remains incentivised to maintain the product and enhance its durability (Jensen, 2022). The benefits for product owners are continuous customer contact and insights into how their products are used. The companies can potentially gain access to new remanufacturing and refurbishment markets (Jensen, 2022). IoT facilitates these models. An example for a PSS approach is battery swapping in e-mobility solutions (see sustainable e-mobility factsheet).

Business models focused on **peer-to-peer trading** seek to use existing assets or infrastructures, enabling a more efficient use of resources. Electricity trading, for example, allows households with solar panels to sell unused energy to their neighbours instead of wasting it (Efficiency for Access, 2021).

Applying a **decentralised repairs** approach can help reduce the costs to businesses by outsourcing repairs. Three variants of this model can be distinguished (Efficiency for Access, 2020):

- Training product distributors for repair (and making spare parts and repair tools available).
- Leveraging third party repair technicians in the informal economy
- Empowering end-users - making provisions for providing spare parts and repair guides publicly to the customers to repair the products themselves or by a third party.

Local assembling or manufacturing of products, and using some degree of locally manufactured components can improve the availability of spare parts and appropriate repair tools, and bring about substantial co-benefits of local skilling and job creation.

6.4 Socio-economic and sustainability impacts

Africa's demographic and economic growth is leading to an increase in waste generation, with devastating health and environmental impacts. The African Union projects that by 2050, the volume of waste will triple from current levels. Notably, more than 90% of Africa's waste is disposed of at uncontrolled dumpsites and landfills, often followed by open burning (Dugbazah et al., 2021). The generation of e-waste is also increasing particularly rapidly, driven by international trade and domestic consumption. When disposed of or recycled improperly, e-waste poses severe risks to ecosystems, human health and livelihoods. Resource extraction can lead to environmental impacts (such as water shortages, in the case of Lithium extraction) and threaten the livelihoods of local communities.

While sustainable energy solutions can bring about a range of social, economic, and environmental benefits, there is a risk that they exacerbate the problems linked to waste generation and resource extraction in Africa. Applying circular economy approaches to sustainable energy can help prevent waste and reduce material demand (and therefore of the impacts of material extraction). Indirectly, circularity helps to harness the value of materials and can create new local industries and income generation activities.

In many African countries, circular economy activities such as waste collection, repair or remanufacturing already provide many jobs. These jobs are predominantly in the informal sector, where they lack legal and health protection as well as social security coverage (Gower & Schröder, 2016). Nonetheless, in many informal economies, the repair of products provides a basic income to local livelihoods and households. An increased support for the repairability of products can lead to a corresponding increase in local employment related to repair (Efficiency for Access Coalition & University of Edinburgh, 2020). Additionally, circular economy interventions can create new job opportunities in higher-value supply chains, and improve the quality of employment (World

Economic Forum, 2021). Repair and refurbishing of products also present an opportunity to constantly upskill technicians (Efficiency for Access Coalition & University of Edinburgh, 2020).

Figure 29. Dismantling of computers at WEEE Centre in Nairobi, Kenya (TNO, 2022)

6.5 Scaling-up

Circularity approaches with the sustainable energy sector in Africa have only recently started emerging and still have an immense potential for scale up. To drive a widespread application of circularity concepts in African sustainable energy businesses, an effective enabling environment and policy framework are urgently needed. Policy can allocate the cost of waste generation fairly among producers and enable profit for businesses that promote durability, repairability and recycling. Some of the strategies for scale up include:

6.5.1 Extended Producer Responsibility (EPR)

Extended Producer Responsibility (EPR) policies shift the responsibility for waste management towards the producer and away from municipalities. They thus provide incentives for producers to improve the design and manufacturing of their products and ensure recycling for recovery of materials. Some of the challenges with EPR implementation in Africa include the sharing of responsibility between importers and manufacturers (Africa Clean Energy, 2019), as well as the difficulty in enforcing the policies.

6.5.2 Eco-design

Eco-design policies can help integrating circularity into all stages of the product development, (EEA, 2001). For example, it can stipulate the use of less material or a modular design of components which facilitates their reuse or the use of interchangeable components across products.

6.5.3 Role of government and industry

The industry can help consumers and businesses shift towards a circular economy through collection campaigns and joint collection schemes. Besides this, technical advice and access to good quality spare parts are necessary. Currently, there is still a supply shortage of spare parts due to the high import costs and the small order sizes of local repairers. Policymakers can counter this with favourable import tax regimes for solar components while the spare part supply can be supported by local original equipment manufacturers (OEMs) by building regional supply networks and sharing information (Blair et al., 2021).

6.6 Circularity solutions in SESA

SESA partners in various countries are working on circular economy approaches in their Living Labs. Their activities are briefly outlined below.

6.6.1 Circularity in solar off-grid Kisumu and Homabay counties, Kenya

The social enterprise WeTu in Kenya, founded by the Siemens Stiftung, works on innovative solutions for the reuse and recycling of electronic and electrical waste in the Lake Victoria Region, in Kenya, therefore working on a circular economy approach.

The company takes a community integrated approach to e-waste management by sensitising and incentivising community members and stakeholders to return and hand-in e-waste. They are establishing seven WeTu hubs as e-waste collection centres and developing an e-waste pre-processing/dismantling plant at the WeTu Hub in Homabay.

The solution includes the goal of devices that are out of use to be seen as valuable resources with potential to be repaired or recycled and reused to its full extent. To live up to this goal, WeTu is searching for suitable business partners for the different downstream parts such as plastics, metals, glass, and its specific e-waste components.

Within SESA, WeTu addresses the three main innovation focus areas in energy transitions, namely access, productive use, and a circular economy.

6.6.2 Circularity through clean cooking solutions in Malawi and Ghana

Within SESA, the Malawi demo site works on the adaptation and validation of the Make it Green BioCooker to a small-scale, commercial product. The MiG BioCooker utilizes traditional wood-based fuel to provide heat for cooking and produces biochar as a byproduct. The biochar thus obtained, is used as an affordable water purification system and as an enrichment of soil for agriculture. The use of biochar for agriculture has been seen as an efficient means of carbon sequestration (Make it Green, 2022). The main objective of developing this cooking stove is to obtain several values to be used in a **circular business model.**

The main objective of the validation site is to co-produce the bio cooker and strengthen the applicability and replicability of the technologies as well as the basic business concepts. The expected impact includes reduced cost of cooking, income from biochar, decreased health problems, especially for women and children, the access to clean water, the generation of fertilizers from biochar and the opportunity to use a variety of biomass feedstock.

In the Ghana living lab validation site, the demonstration implementation activities are located in the Ga North Municipal district, which is an urban settlement, and Atwima Nwabiagya Municipal Assembly, which is a rural community. The innovation tested is biogas cooking systems to improve the knowledge, skills, trust and capacity of stakeholders in the design, construction, operation and maintenance of this clean, cheap, efficient cooking technology. Fuel will be sourced from waste feedstocks. In addition to making cooking more energy efficient, **a circular economy is being embraced.**

6.7 Examples of application in the African context

Solibrium-Solar, Kakamega, Kenya

The idea: Provide access to affordable and reliable solar energy. Consider the entire life cycle of SHS through Resource Efficiency and Waste Management for OGS products (REWMOS).

Areas of expertise and innovation:

- Modular household solar kits, coupled to usable solar-based appliances
- Consider *entire life cycle* of SHS consisting of: *Production* with as little material input as possible and raw materials produced in powered-mix factories, a regional *transportation* of light products, a *use-phase* accompanied with regular maintenance and a component-based repair system to avoid waste, and an *end-of-life system* based on reusing or recycling the SHS.

The business model:

- Flexible and variable payment system (e.g., PAYGo)
- Work with micro-franchisees to grow entrepreneurs from the grassroots
- Take-back/buy-back system for faulty or broken products
- Repair and refurbish of products for resale
- Refurbish components for resale to informal sector

The impact:

- The work done by Solibrium contributes to at least 9 of the 17 United Nations Sustainable Development Goals

For further information visit:

- https://www.solibrium-solar.com/
- https://medium.com/efficiency-for-access/the-global-leap-awards-are-an-international-competition-to-identify-and-promote-the-worlds-best-d33623740612
- https://www.solibrium-solar.com/rewmos-2

Engie Energy Access, Kampala, Uganda

The idea: Engie Energy Access is a pioneer of the PAYGo solar model in Sub-Saharan Africa and integrates a waste management approach into its business model.

Areas of expertise and innovation:

- Solar Home Systems (SHS), mini-grids and an innovative, inhouse-developed software suite Paygee for the business model, focus on e-waste collection and informal sector

The business model:

- Pay-As-You-Go (PAYGo) business for SHS and run last-mile distribution for any product worldwide

- Company developed a comprehensive buy-back scheme to retrieve broken off-grid solar components (of any brand), along with off-grid solar lead acid batteries from the informal sector.

The impact:
- Job creation in the company
- Set-up of e-waste infrastructure through collection points
- Training and awareness raising

For further information visit:
- https://engie-energyaccess.com/
- https://www.clasp.ngo/research/all/innovations-in-off-grid-solar-e-waste-management/

Innovex, Kampala, Uganda

The idea: Accelerate Africa's socio economic transformation through the development of new technologies to remotely monitor and control solar PV systems and equipment. and supporting preventative maintenance and repair activities.

Areas of expertise and innovation:
- Competencies include embedded systems, connected devices, web and software development and wireless communication technologies.
- Home-grown IoT solution ´Remot´ offers after-sales service support and manages preventative maintenance and repair activities.

The business model:
- PAYGo for solar companies
- Setup of solar businesses on a loan, grant financing or external investment
- Mobile money integration for transparency and quick response to clients

The impact:
- Technological advance
- Transformation of off-grid energy access sector through the distribution of off-grid solar energy systems and equipment using digital tools

For further information visit:
- https://innovex.org
- https://disrupt-africa.com/2021/01/27/uganda-based-payg-solar-startup-innovex-raises-seed-funding/

6.8 Climate proofing

Although Africa is currently still a minor contributor to global emissions, the impacts of climate change on the region are comparatively higher than in other regions, and the resiliency of populations and economies is lower. Among other things, climate change poses major threats to African energy assets.

Circularity approaches are linked to the climate proofing of sustainable energy solutions in different ways:

- The need to develop more robust and climate-resilient solar infrastructure and products to withstand more extreme conditions (extreme wind, storms, air sand, extreme temperatures, floods, landslides, and forest fires). Moreover, ease of repair, refurbishment and replacing due to damages needs to be included in the product design (IEA, 2022).
- Modular infrastructures and ease of replacing is always desirable, not only when damages occur, but also when climate conditions change and make it less efficient the use of the installed infrastructure. This infrastructure could be replaced and used in locations where climate conditions are more suitable according to design specifications.
- Adapt the selection of batteries and ensure they are operated appropriately. Higher ambient temperature can cause premature battery failure (Riello UPS, 2022).
- Adapting buildings and energy-intensive appliances to new climatic conditions so that they require less energy consumption and less installed solar capacity.

6.9 Relevant tools and capacity building materials

Circular Economy: Learning Hub l Ellen MacArthur Foundation
The Ellen MacArthur Foundation has created a Circular Economy Learning Hub. The Hub contains many different capacity building elements to expand the understanding of the circular economy and to learn how the concept can be applied to different parts of the economy.
https://ellenmacarthurfoundation.org/explore

Circularity Toolkit: E-waste Blueprints l GOGLA
The E-waste Blueprints provide practical resources and tools, including an assessment framework, policy template and KPIs (Key Performance Indicators), that can be adapted to suit the individual needs and context of OGS companies. Through a plan with 3 steps (assess-plan-execute), such companies are encouraged to implement and improve e-waste management across their operations, according to their business, operational, geographical and resource context.
https://www.gogla.org/circularity/tools

Business Model Innovations Project l Efficiency for access
The business model innovation research focuses on three main pillars: environmental sustainability and circularity, consumer affordability and resilience to regional and global shocks. Based on various case studies, it provides information on a range of business model innovations in the off-grid appliance sector. The research project aims to enhance awareness among private and public sector actors of business model innovations for off-grid appliances and their applications for households, farmers, and businesses in areas of off-, weak- or mini- electricity grid connection.
https://efficiencyforaccess.org/publications/business-model-innovations-project

StEP Initiative - Partnerships between the informal and formal sector for sustainable e-waste management
In this circularity process, the informal sector plays an important role in the collection and management of e-waste. In this context, this paper presents approaches and case studies on current informal-formal partnership models in different countries around the world, among which the African continent stands out. The partnership concept presented in this paper aims to support the achievement of high recycling rates and legislative requirements, in the framework of extended producer responsibility (EPR) or other collection systems in low- and middle-income countries.

https://www.step-initiative.org/files/_documents/publications/Partnerships-between-the-informal-and-the-formal-sector-for-sustainable-e-waste-management.pdf

ACE Africa - Accelerating Circular Economy in Africa
The ACE Africa project aims to support the growth of circular economy businesses in Africa. Circular economy is a growing area of interest for achieving sustainability across multiple sectors, and it is clear that, in Africa, the private sector is leading the transition to a circular economy. The desired outcomes of the capacity building webinars are to support a number of businesses to mature, to contribute to improved innovation ecosystems for circular economy, and to provide guidance to local governments on how to improve or support innovative businesses that enhance circular development.
https://riseafrica.iclei.org/aceafrica/#circularity-is

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7 Solar Mini-grids

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7.1 Introduction

Solar minigrids 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. This factsheet introduces the technologies involved in solar minigrids, sums up key business and financing models, describes the impacts they bring about as well as the potential for their scale up, and provides examples of successful deployment in the African context as well as in the SESA project specifically.

Figure 30. Solar PV minigrid in Zambia (CrossBoundary Energy Access, 2020)

7.2 The technology

Solar minigrids (sometimes referred to as microgrids) are composed of a set of solar electricity generation devices and batteries that are connected to a distribution network. The distribution network then supplies electricity to a localized group of customers. A typical solar minigrid in Africa will have a size between 10 and 100 kW, though other sizes are possible. Importantly, minigrids can be operated and controlled independently from the main grid (Hirsch et al., 2018).

7.2.1 Key components

The key components of solar minigrids (see Figure 31) are:

- **Power generation**: while solar photovoltaic (PV) systems are the most common generation technology used in African mini-grids, other renewable energy resources such as micro-hydro turbines, biomass or small wind generation units can also be used to generate power. In hybrid solar/diesel mini-grids, some of the power is also provided by a back-up generator (in particular where mini-grids have high demand peaks which cannot be met with the PV system).

- **Storage**: this component absorbs the surplus power during off-peak hours and dispatches stored energy at times of high demand (Hossain Lipu et al., 2022). Storage can also act as a frequency control, smoothing the output from the PV system and improving power quality and grid stability (Ovaskainen et al., 2019). Storage technologies are typically batteries, though flywheel and pumped-hydro storage are other technology options. It is important to note that 2nd-life Lithium-ion batteries are an affordable source of storage devices in solar mini grids (more information in the factsheet "Second Life Li-ion batteries")
- **Distribution system**: composed by distribution lines (overhead or underground), poles, protections, and transformers if needed. The distribution system can use a variety of voltages (medium or low voltage levels), and either alternating current (AC), direct current (DC) configurations. Overhead lines are cheaper to build and therefore more common (USAID, 2018).
- **Energy management systems**: often coupled to digital tools, they control and monitor electrical loads. These include the charge controller that connects the solar panel to the battery or inverter/charger to prevent over-charging of the battery. Meters and monitoring equipment allow data collection that informs the operation decisions. Energy management systems often allow operators to control the minigrids remotely, to some extent.
- **Consumption loads:** depending on the context, there can be a combination of different users, such as households (powering appliances such as TVs and fans), public services (schools, hospitals, street lighting), businesses (powering productive use appliances such as water pumping, irrigation, cold storage, or mechanical food processing) or other applications (e.g., charging of batteries for electric vehicles). Managing different types of loads (e.g., anchor loads, flexible loads) is key to the operation and viability of the minigrid.

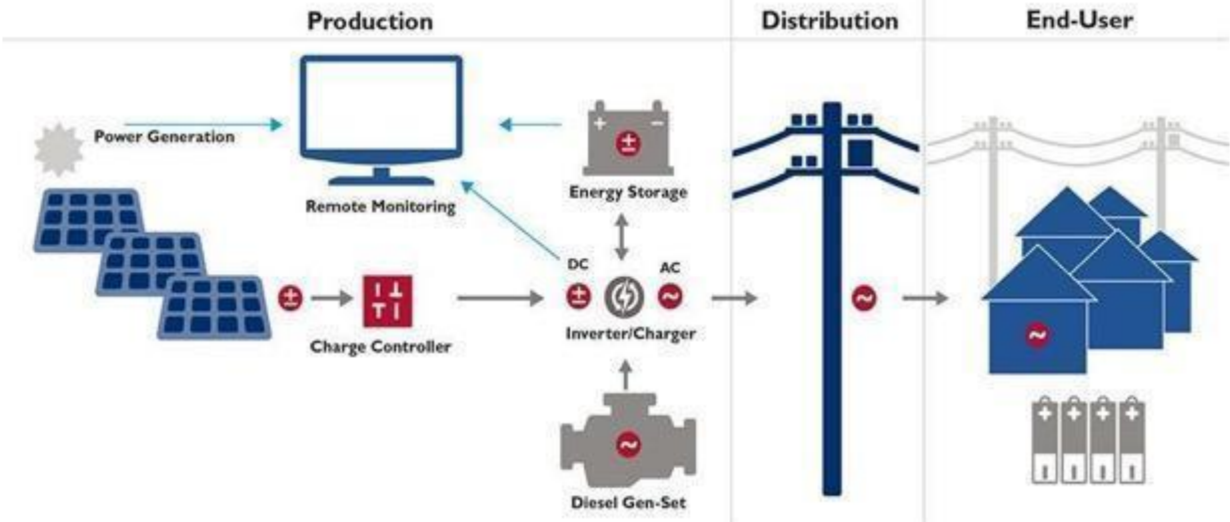

Figure 31. Components of a solar minigrid (USAID, 2018)

7.2.2 Minigrid design

The technical design of a minigrid requires careful consideration of the loads (or energy consumption by the end-users). Developers need to have a strong understanding of energy demand, including the maximum peak power required, when and how much energy is required for a time period. Developers need to make decisions based on a series of trade-offs regarding the power availability, cost, maintenance needs, and others. Design also needs to consider the applicable national and international standards and regulations (e.g., the IEC 62898 international standard for AC minigrids).

In the design stage, the PV system is designed according to the energy demand profiles. The installed capacity of the PV system is described in Wp (watt-peak) which corresponds to the nominal power at high sun irradiation levels (1000 W/m2). The real generation of PV panels is normally significantly lower than their peak value, and strongly depends on the sun irradiance received. To maximize the output, PV panels should be placed facing south in the northern hemisphere or facing north in the southern hemisphere. When equipped with a solar tracking system, PV panels can follow the path of the sun during the day, thereby increasing their output. Additionally, the optimal inclination should be selected where possible during the design stage.

Another key decision in the design process concerns the electrical configuration. Mini-grids can have three basic configurations: alternating current (AC), direct current (DC), or hybrid (both AC and DC) (Martin-Martínez et al., 2016). The generation technologies, system sizing and battery use are the primary factors in deciding which configuration to use. The DC configuration is common among solar isolated minigrids, as PV systems (DC output) can be connected directly to many DC appliances, avoiding the use of inverters.

However, the potential for connection to the external utility distribution grid (typically AC) is a key factor in the design process, which influences the configuration (USAID, 2020). If the communities or developers consider that an off-grid minigrid might eventually be connected to the national grid, it should be designed with this in mind, and the decision will lead to cost and regulatory implications.

A series of software tools exist to support the optimal design of minigrids (See Section “Tools and training material” below).

7.2.3 Towards smart minigrids

New technologies are emerging for the efficient management of minigrids. The integration of ICT and IoT are key to the technical and economic viability of the systems because they can manage power quality, improve maintenance services, respond to variability in energy production or consumption, facilitate payments, and enable energy trading among users (prosumers), among others. These technologies rely on communication between the different components and intelligent electronic devices. For example, the Advanced Metering Infrastructure (AMI) allows two-way communication between the smart meters (from the end-users) and the minigrid operator (ISGF, 2017). AMI enables real-time monitoring of consumption and billing, remote control, and demand response mechanisms. Smart minigrids need computing platforms that can handle large-scale data analytic tasks and support real-time operation of the minigrid.

7.3 Business and financing models

A business model defines the way in which a solar minigrid project or business is planned, implemented, and executed to meet its strategic objectives. Minigrid projects within the African context face challenges due to the low existing electricity demand and ability to pay of consumers, regulatory barriers, and higher financial risks, among others.

Fortunately, a range of financial and business models are being designed to overcome the existing barriers. It is important to remember that business models should be context specific and based on a strong understanding of the needs of the local communities and value chains. The exact ownership and financing model will vary significantly depending on the type of customer and the final use (households, hospitals, businesses, electro-mobility user, productive activities, or others). This section describes the types of potential minigrid ownership and presents the main business models classified according to whether they are oriented to financing or to operating the minigrid.

7.3.1 Ownership

The following ownership models can be identified in minigrids (Boche et al., 2022):

- **Gathered minigrids**: can be owned by a public entity (government utility ownership) or otherwise a private or third-party entity.
- **Federated minigrids**: belongs to multiple owners, i.e., 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 minigrid. Many business and financing models are covered under this category.
- **Networked minigrids**: The customers (e.g., a community association, or a cooperative) own and operate the minigrid. This customer-owned model places all financial and operating risk on the customer.

7.3.2 Financing

Minigrid assets and infrastructure require high upfront investment and steady and reliable returns over a long time period. The risk on market and regulatory frameworks, market mechanisms, revenues, costs, liabilities, and finance should be reduced for investors, energy suppliers, owners, and customers as much as possible (CrossBoundary Energy Access, 2020).

The **Anchor Business Community** (ABC) model is applied by for-profit companies, which leverage anchor customers (i.e., energy-intensive productive users such as agribusinesses) in rural areas with predictable demand to reduce the risk of the business via a long-term steady contract. This then allows the electrification of other customers (small consumers, households, or others) (Ramchandran et al., 2016).

The concept of **design, build, own or finance, operate, and maintain** is the business model in which the owner builds the project (and also finances it in some cases to alleviate the need to upfront capital) and then maintains the assets, by paying for new equipment and upgrades, which improve the efficiency and reliability of the minigrid, while capturing the entire revenue stream to recover their upfront capital, costs, and risks (Weston et al., 2018).

In federated minigrids, the financing responsibilities can be shared by different actors: i) the developer builds the minigrid, ii) the minigrid is transferred through a **Purchase and Sale Agreement** (PSA) to a company created specifically to hold the assets and then, iii) the Asset Company pays another company to operate and maintain the grid as stipulated in an **Operating Services Agreement** (OSA). The OSA stipulates operating fees, operation and maintenance costs, customer services and tariffs, and insurances. Additionally, a long-term agreement to purchase clean energy between the developer (and owner) and the consumer(s) is known as **Power Purchase Agreement** (PPA).

It is worth paying attention to the financing of energy use appliances, where the developer can offer short-term loans or sell it at a discount, where the customer pays the debt in instalments and finally owns the asset (i.e., solar panels, small fridge, farming, fishing, or agriculture appliances) (Mulupi, 2015).

In terms of raising the initial financing, concessional financing (such as subsidies, risk guarantees, grants or loans) are crucial, as are crowdfunding initiatives (IRENA, 2022).

7.3.3 Customer tariff setting

A key element of business model design is the mode of cost recovery from users. Effective cost recovery is essential to attracting financing and for building a sustainable and scalable minigrid. Fair and effective tariffs should be designed according to the kind of users, their consumption, and their ability to pay (Reber et al., 2018). The approach to tariff setting will depend on the regulations and on any subsidies applicable in the location. Tariffs can be differentiated for different customers, based on their energy use, their nature (e.g., households vs. businesses), their peak consumption. Tariffs can also be flat or vary by time of the day or season. Mini-grid tariff collection is usually pre-paid or based on the PAYG model, though they can also be post-paid (i.e., collected at the end of the month.

7.4 Socio-economic and sustainability impacts

Solar minigrids 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, solar minigrids are a more viable solution to electricity access than grid expansion and can potentially meet the needs of 65% of new connections in communities located more than 20 km from the grid infrastructure (see Figure 32).

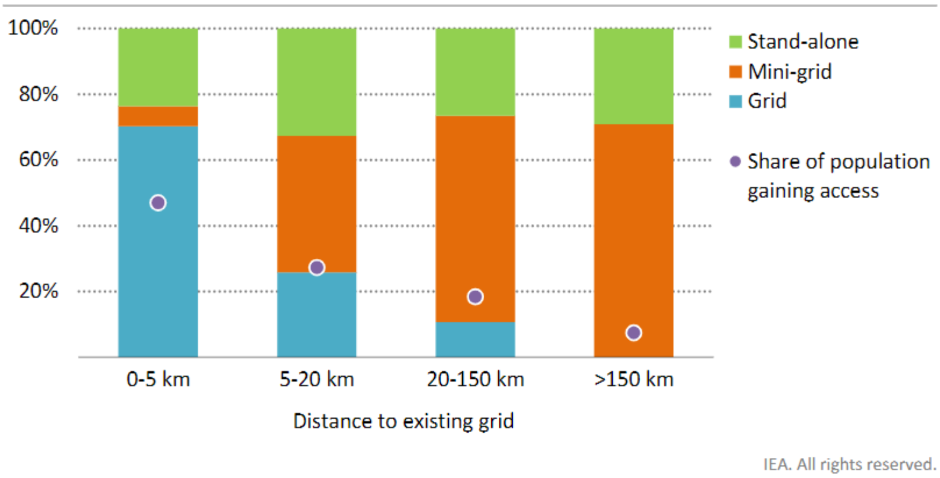

Figure 32. Share of new electricity connections by technology and distance in the SAS, 2022-2030 (IEA, 2022)

Examples around the world demonstrate that in order to realise and maximise the benefits of solar minigrids to the users, and to ensure the long-term viability of the minigrid, the users need to be involved at all stages of project development. 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. operation of local clinics). Solar minigrids have recently also become important in the promotion of electrified mobility (for more details, see Factsheet "Sustainable e-mobility").

Minigrids have the potential to create high-quality jobs (Figure 33). Capacity building, in particular targeted to youth and women, is crucial to deliver these employment benefits, as specific skills are needed to install, operate, and maintain minigrids (IRENA, 2019a). The creation of new value chains in minigrid component manufacture, distribution and maintenance is an additional source of employment (IRENA, 2022).

Figure 33. Left) A technician testing one of Standard Microgrid's mini-grids in Zambia (CrossBoundary Energy Access, 2020). Right) REG, the Rwandan electricity utility, technician on the job under WIRE initiative (WIRE, 2019).

Solar minigrids displace the use of expensive and polluting small and medium diesel and petrol generators, with the corresponding reduction in air pollution. Finally, they are also key to Africa's transition to a low carbon future. Although Africa is a minor contributor to global climate change (less than 4% of CO2 emissions) -40% of its emissions come from electricity and heat (IEA, 2022).

Solar minigrids, like other off-grid solar solutions, are composed of many electronic and hazardous components and are potentially a source of e-waste. A series of solutions can be deployed to increase the repairability of solar minigrids and improve the management of the waste produced (see factsheets on "Circularity in sustainable energy solutions" and "E-waste from solar off-grid solutions").

7.5 Scaling-up

The minigrid sector has great market growth potential with 590 million Africans still living without access to electricity. According to AMDA (African Minigrid Developer Association), the major challenges to replicability and scalability of minigrids are the regulatory environment and the lack of finance. Approval processes are slow with an average time of 58 weeks to get through regulatory compliance, with licensing taking most of this. This results in slow growth of licensed minigrids in the last few years. Simplifications in the regulation are urgently needed as well as shortening of licensing timelines or bulk licensing instead of licensing individual sites (AMDA, 2022).

On the other hand, the shortage of concessional funding (finance below market range) and subsidies hampers the scale up of the sector. Affordable long-term loans and low interest rates are needed to unlock commercial investments and to decrease investment risks in order to raise the viability of minigrid projects (ACE TAF, 2021).

Nevertheless, the sector is growing, as reflected by the steady increase in the number of minigrids installed. Other positive signs in the sector include the increasing revenues and decreasing operational costs (AMDA, 2022).

It can be pointed out that there are spillover effects and savings from having multiple minigrids in close proximity: cost sharing (personnel, management, maintenance, logistics, economies of scale), highly trained staff for multiple installations, rapid transfer of lessons learnt. Moreover, from the technical point of view, interconnected minigrids can create wider, more resilient power networks (Kamal-deen, 2022).

7.6 Solar mini-grids in SESA

SESA partners in various countries are working on circular economy approaches in their Living Labs. Their activities are briefly outlined below.

7.6.1 Solar hubs for multiple uses in Kisumu & Homabay, Kenya

Several mini grids, or "solar hubs", are proposed within the SESA Living Lab in Kenya. Each solar hub has a complete off-grid minigrid with a ground-mounted PV array, battery banks as energy storage, equipment to monitor energy production and sockets for several uses: 1) charging fisher lanterns, 2) electric two-wheelers, 3) small business, 4) local infospots for access to information, on energy and digital skills, 5) water pumping and purification systems, 6) irrigation system for agriculture, and 7) cooling systems and flake ice machine, among other energy uses.

The social enterprise WeTu in Kenya, founded by the Siemens Stiftung, works on innovative solutions for e-mobility, safe drinking water and solar lighting and charging. It owns and operates seven solar powered hubs in Kisumu country, close to Lake Victoria.

Within the SESA project, WeTu recently inaugurated the solar hub in Katito, Kisumu County. The installation incorporates a ground-mounted PV array, battery banks as storage and energy monitoring equipment. The energy generated by solar power is used to pump water from a 50 meters deep borehole to be stored in large storage tanks. From the water tanks, water is filtered through reverse osmosis and pumped into elevated water storage tanks. The obtained clean drinking water can be purchased by locals through a water ATM. Also, e-motorcycles (boda-boda) are converted on site and their batteries charged and monitored in the solar hub. Further activities, for example cooling systems to avoid post-harvest losses, are planned.

7.6.2 Solar mini grid for households, Morocco

Within the SESA project, the Moroccon living lab will develop and implement one off-grid solar mini grid to provide energy for 10 housing units in the rural demonstration site by December 2023. Second-life Li-Ion batteries will be used for energy storage. For monitoring the performance of the second-life batteries, a diagnosis facility will be installed. The overall objective of this demonstrator is to provide electricity to vulnerable populations that will enable social and business activities. The demonstrator will serve as a model and will be used for replication in other parts of Morocco. The main SESA partner in Morocco implementing the activities is Green Energy Park.

7.6.3 Solar mini grid for community access and e-mobility, South Africa

Within the SESA project, a containerized off-grid solar PV mini grid with second-life batteries is proposed in South Africa for community energy access and to charge a small fleet of micro electric vehicles. Additionally, infospots will be located powered by off-grid solar units to provide free access to information, including the use of energy and business opportunities. The main SESA partner in South Africa are uYilo and Nelson Mandela University.

7.6.4 Solar mini grid for educational and lighting uses, Ghana,

In Ghana the main purpose is to have an off-grid mini grid powered by solar electricity mainly for educational purposes, for lighting for learning activities and night-time security, for water pumping and purification systems and for infospots for community empowerment.

7.7 Examples of application in the African context

KUDURA mini grid solution (Kenya, Tanzania, Mozambique)

The idea: KUDURA is a minigrid solution developed by RVE.SOL that integrates multiple utility provision with the goal of catalyzing economic development in rural, off-grid areas.

The technology:

- KUDURA can be scaled to support anywhere from 1 home or business to 1200 individual rural customers.
- The mini grid is an integrated, scalable standalone renewable energy sub-system, containing a hybrid Solar Photovoltaic plant, a Biogas and organic fertilizer plant, a Water Purification plant and a Central Monitoring system.

The business model:

- KUDURA is a containerised hub that provides potable water and clean energy for lighting, cooking and productive energy use in rural, off-grid areas
- As inputs, raw water, agricultural waste, solar energy and animal manure are converted to potable water, electricity, biogas and organic fertilizer. The outputs are stored at the installation site within the community and distributed to meet consumer demand on a “pre-pay-for-service” basis.

The impact:

- Communities are empowered by owning and running the mini grid system.
- The reduction of the consumption of kerosene, diesel, charcoal and firewood leads to positive socio-economic and environmental impacts.

For further information visit:

- https://www.rvesol.com/kudura-2/

Gbamu Gbamu community minigrid (Nigeria)

The idea: The minigrid, developed by Rubitec, aims to strengthen agricultural processing in the rural farming community of Gbamu Gbamu. Additionally, the mobility company MAX is offering electric motorcycles, powered by the minigrid.

The technology:

- The generated capacity of 85kWp was installed in order to serve 600 households and small businesses

The business model:

- After the initial funding period for the pilot project through a grant from GIZ to cover distribution costs, funding was provided through the crowdfunding platform Bettervest
- A custom-built E2W model for certified local drivers including a battery swap charging model

The impact:
- Mostly large-scale businesses benefiting from the electrification
- The model delivers uninterrupted energy supply and decreases the use of gasoline

For further information visit:
- https://www.greentechmedia.com/articles/read/nigeria-solar-powered-minigrids
- https://sun-connect.org/wp-content/uploads/powering-small-format-electric-vehicles-with-minigrids-report.pdf

Solar PV mini-grid (Sitolo Village, Malawi)

The idea: The project was implemented to deliver electricity to the rural, off-grid village to enable the development of village activities including 250 households, several businesses and public services connected. This first project in Mchinji district is likely to become the base of a multi-site mini grid including nearby villages.

The technology:
- 80kWp/950kWh solar off-grid mini grid with a maximum peak power demand of 5kw and one diesel generator as a back-up.

The business model:
- The Sitolo mini grid infrastructure is built, owned and operated by the Community Energy Malawi Trading Ltd. (CEMT) which also acts as the liaison with government and regulatory bodies in relation to compliance. CEMT trained local staff who operate the vending unit.
- CEMT implemented a household tariff (USD 0.18), business tariff (USD 0.19) and social tariff (USD 0.09).

The impact:
- The plant is able to provide 263k kWh of energy per year reducing the equivalent of 178 tons of CO_2 emissions per year.
- Contribution to economic development by powering productive uses of energy.

For further information visit:
- https://ease.eee.strath.ac.uk/wp-content/uploads/2021/05/CEMT-Minigrid-Presentation.pdf
- https://clubinternational.ademe.fr/wp-content/uploads/ademe-enviroearth-en.pdf

Solar powered mini-grid (Id Mjahdi, Morocco)

The idea: The two companies Cleanergy, a solar power company, and Cluster Solaire, a Moroccan non-profit focused on renewables selected the Moroccan village Id Mjhadi to test a sustainable model for electrifying remote communities. Before the project, the community was lacking any kind of water and power infrastructure.

The technology:

- A power station with 32 solar pv panels generates 8.32 kw of electricity for distribution via a mini-grid to around 20 homes. The solar network has a battery that can supply up to five hours of electricity outside daylight hours.

The business model:

- The village now acts as a cooperative solar farm where the residents crush argan oil, sell it to the French businesses and maintain the solar network with the sales. Cleanergy trained men and women how to manage the mini grid.

The impact:

- Contribution to socio-economic development within the village.
- Being the 'first fully solar-powered village' in Africa, this mini grid serves as a best practice example to be replicated in other rural areas.

For further information visit:

- https://edition.cnn.com/2019/12/13/business/morocco-solar-village-intl/index.html
- https://cleantechnica.com/2019/12/20/id-mjahdi-is-africas-first-fully-solar-powered-village/

7.8 Climate-proofing

Some risk areas regarding the impacts of climate change of solar mini-grids include (European Commission, 2013; IAEA, 2019; Tecnalia, 2020; WBG, 2019):

- Uncertainty on the irradiance, temperature and precipitation in the long term, which would affect the design and viability of the project.
- Extreme wind, storms, flooding, landslides, forest fires, and extreme temperatures could cause physical damage to the infrastructure when exposed.
- High ambient temperature is the most important factor that influences battery aging and can cause its premature failure (Riello UPS, 2022).

Some of the measures that can be taken to increase the climate resilience of the system include:

- More robust design specifications to withstand more extreme conditions.
- Select solar modules with small temperature coefficient, i.e. whose efficiency is not greatly reduced with high temperatures.
- Selection of batteries to withstand high temperatures, and adapting their operation and maintenance procedures.
- Climate proofing can also be achieved by improving the efficiency of buildings, and energy-use appliances (see "Energy Efficiency" factsheet).

7.9 Relevant tools and capacity building materials

HOMER "Hybrid Renewable and Distributed Generation System Design" Software
HOMER software is designed to evaluate and compare cost effective and reliable hybrid microgrid and grid-connected systems that combine traditionally generated and renewable power, storage, and load management. HOMER explores the lowest-cost solutions, by optimizing the energy assets (sizing and operation) from utility-scale, distributed generation to standalone minigrids. Specifically, from the African context, the Homer Pro minigrid software is adequate for optimizing minigrid design in all sectors, from village power and island utilities to grid-connected campuses and military bases.
https://www.homerenergy.com/

GEOSIM software
GEOSIM is a powerful geospatial rural electrification planning tool software exploiting all the power of the Geographic Information System (GIS) capability, used to create highly interactive rural electrification planning scenarios. GEOSIM selects priority projects within the targeted territory and proposes least cost electrification solutions. A wide range of renewable options is studied allowing a maximal flexibility to users for effective plans.
https://www.ied-sa.com/en/products/planning/geosim-gb.html

Network Planner
Network Planner is a simulation tool to analyze least cost of electrification to energize off-grid communities, powered by machine learning and geo-spatial analysis algorithms. This tool enables to compare the most suitable option versus traditional minigrid networks.
https://staging.okrasolar.com/network-planner/

"Minigrid policy" toolkit by European Union Energy Initiative
This toolkit is composed by a set of Excel templates to support the calculation of cash-flows ("Financing tool"), to calculate technology-specific Feed-in Tariffs for mini-grids selling power into the main grid ("FIT-tool"), to calculate the indications on electricity generation costs for different types of generators, that can be applicable to a PPA or at joint ventures ("PPA tool"), to determine average tariff levels for covering the costs ("Retail tariff tool").
http://minigridpolicytoolkit.euei-pdf.org/support-tools

"Green Mini-grid help desk" by Energy 4 Impact and INENSUS
Green mini-grids in sub-Saharan Africa is a Help Desk, in which mini-grid developers and policymakers can find practical information on mini-grids quickly. This includes market reports, links to industry stakeholders, instruction guides, business models energy policy, technical system design, financial support schemes, operation and maintenance, among others.
https://greenminigrid.afdb.org/

PVGIS
PVGIS is a data platform hosted by the EU Joint Research Commission. PVGIS offers data on solar irradiation for Europe and Africa, as well as a large part of Asia and America. It provides solar radiation and temperature, as monthly averages, daily and hourly profiles for solar radiation and electricity generations (considering different PV technologies and configurations, e.g.., slope and azimuth angles, fixed or variable solar tracking). A report of the rough performance of grid-connected and off-grid systems is provided, including the consumption and generation profiles and the size of the energy storage system.
https://re.jrc.ec.europa.eu/pvg_tools/en/

IRENA Global Atlas for Renewable Energy
The Global Atlas for Renewable Energy is an initiative coordinated by IRENA, aimed at supporting to evaluate the national renewable energy potential of developing countries, including solar, wind, geothermal, bioenergy, hydropower, and marine technologies. For the selected location, the annual and monthly irradiation, average wind speed, soil temperature, suitability and crop resource is provided. Additionally, other general information is provided, such as the distance to the utility grid and the nearest substation, distance to the road, population, and land features.
https://globalatlas.irena.org/workspace

“Policies and regulations for renewable energy mini-grids” by IRENA
The report provides a list of measures to have in mind to accelerate mini-grid deployment such as: existing national policy on energy, rural electrification strategy, mini-grid policies, cost recovery and tariff regulation, land rights, environment protection, technical assistance and financial support. Among other. Eight case studies for off-grid minigrid, half located in Africa, are presented in the report: Nigeria, Rwanda, Sierra Leone, Tanzania.
https://www.irena.org/publications/2018/Oct/Policies-and-regulations-for-renewable-energy-mini-grids

“Renewable Readiness Assessment: Design to action” by IRENA
The Renewables Readiness Assessment is a comprehensive tool for assessing the suitability of conditions in different countries for the development and deployment of renewable energy. It is a guide for countries aspiring to scale up renewable energy. It outlines a process designed for IRENA Member States to help them assess the status and prospects of renewable energy deployment at the national level. In the follow-up to the process, IRENA is ready to act as an interlocutor between development partners and countries in need of support, and to directly assist the implementation of RRA findings. The RRA can also assist in attracting funds and leveraging support.
https://www.irena.org/rra

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8 Energy Efficiency

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8.1 Introduction

Energy efficiency means using less energy to perform a certain task. Energy efficiency can lead to savings in energy costs, increases in productivity, reduced environmental impacts, and improved access to electricity (Fowlie & Meeks, 2021). This factsheet aims at presenting different facets of energy efficiency technologies and business models in the context of the African energy transition. Also, the factsheet discusses the socio-economic impacts of energy efficiency and the potential for its scale up in the **African** region. Finally, it gives examples of energy efficiency solutions in Africa, as well as within the SESA project.

8.2 The technology

A variety of energy efficiency technologies and applications exist. Key examples for solar off-grid electricity systems and for buildings are presented here in turn.

8.2.1 Energy efficiency for off-grid solar solutions

Energy efficiency for solar off-grid solutions is key to making the solutions economically viable for the operators, and for lowering electricity costs to the users (Efficiency for Access, 2022). By using energy efficient supply systems (like more efficient PV panels or batteries) and energy use appliances (such as efficient lightbulbs), the overall size of the energy supply system can be reduced and with that the costs over the whole lifetime of the system. In other words, with energy efficient appliances, less solar energy supply needed.

Figure 34. Solar Home Systems are more affordable when coupled with energy efficient light bulbs and fans (Lumos, 2022)

When productive use (PUE) appliances (such as irrigation systems, cold storage or grain milling) are energy efficient, they lead to greater productivity, such as larger yields per unit of energy input. This is the case of Agsol, a manufacturer of solar-powered agricultural machinery, who improved the efficiency for its mill by 32%. This made the product more affordable for customers (for more details, see the "Solar power for agriculture" factsheet).

Energy efficiency in solar off-grid solutions needs to be planned from the design stage, in particular with the choice of efficient energy use appliances. A number of organisations are developing technology to make appliances efficient and suited for use with off-grid solar standalone systems or mini-grids: the Efficiency for Access Research and Development Fund (Efficiency for Access, 2018) and the Low Energy Inclusive Appliances (LEIA) Programme (Efficiency for Access, 2022b).

However, energy efficiency is also a key consideration during the construction or installation stages (e.g., the choice of positioning of the PV panel) and during the use phase (e.g., maintenance of the components). The use of ICT and IoT, such as smart meters and remote monitoring, can also support energy efficiency during the use phase.

8.2.2 Energy efficiency in building design

Building design is crucial to increasing energy efficiency and realising energy savings while increasing affordability of the building and providing a comfortable space. Simple methods, such as the orientation of a building, the use of eaves to shade walls from the sun, or the choice of materials with high thermal mass (which can mediate extremes of hot and cold temperatures), can greatly improve energy efficiency. In addition, many bioclimatic design approaches exist that can reduce the need of energy for cooling and ventilation (Figure 35). Very often these methods are found in traditional building designs and construction methods (Guedes & Cantuaria, 2019).

Figure 35. The Eastgate Centre, Harare, built in 1996 and one of the first large-scale buildings in the world designed to be ventilated and cooled by entirely natural means (Livin Spaces, 2018)

8.3 Business and financing models

Already a large number of businesses in Africa are focussing on developing energy efficient appliances, services and business models. Like other business models for solar solutions, they need to address the challenge of affordability, in particular, when they are geared towards off-grid, low-income households.

Energy-as-a-service (EaaS**)** business models allow customers to pay for energy services without the necessity to make upfront capital investments. EaaS business models can be structured differently, but they share the main objective of removing the upfront investment costs for the consumer, which are the main barrier towards accessing energy efficient appliances and technologies. Other features can be added to EaaS business models, such as the offering of operation and maintenance services (EACREEE, 2020).

An example of a business model geared directly at energy efficiency is **Energy Performance Contracting (EPC)**, which allows funding energy efficiency upgrades from the future savings made through energy efficiency. Under an EPC agreement, an Energy Service Company (ESCO) implements a project to deliver energy efficiency, and uses the stream of income from the cost savings to repay the costs of the project, including the costs of the investment.

The company EnSo, operating in Kenya, developed the innovative **ESCO-in-a-boxTM** business model. ESCO-in-a-box is an 'operating system' for energy services, aimed at unlocking the wide range of financial, environmental, and social benefits provided by energy efficiency upgrades for SMEs that traditionally lack the time and resources to implement projects (for more details see Examples section).

8.4 Socio-economic and sustainability impacts

The direct benefits of energy efficiency are the reduction of energy consumption and therefore of expenditure on energy. This can in turn boost productivity and affordability of mobility, lighting, heating and cooling, and other services. The subsequent savings free up resources for households, businesses and governments (IEA, 2022a), and makes economies less dependent on energy imports. The indirect impacts of energy efficiency are therefore broad, and promote economic and social development, health and wellbeing and energy access – among other strategic goals. Considering the multiple benefits of energy efficiency (Figure 366) is crucial to achieving political buy-in for it and for leveraging support for the investments required.

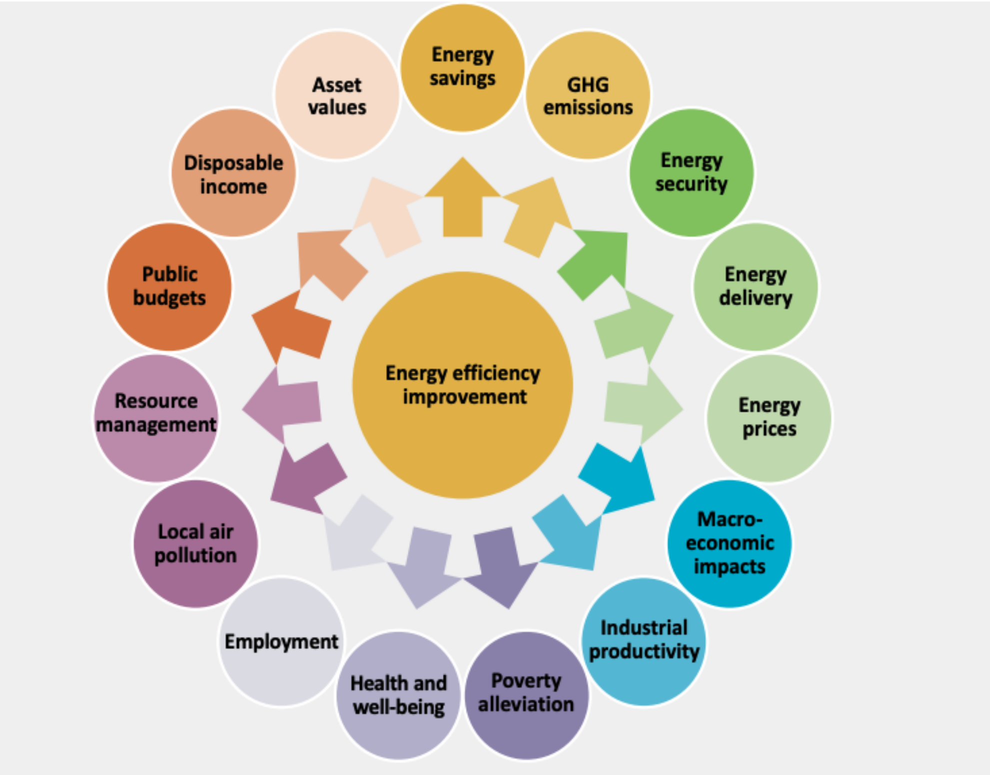

Figure 36. The multiple benefits of energy efficiency (IEA 2015)

Energy efficiency has the potential to deliver sustainable high-quality employment in Africa. The Africa Energy Outlook projects that 1.3 million jobs will be created by 2030 in the clean energy sector, of which 20% are related to energy efficiency (IEA, 2022b). Areas of particularly high potential for job creation include the retrofitting of buildings to increase their efficiency, the application of energy efficiency measures in industry, and the manufacturing of efficient appliances. Most of the jobs will require specialized training and education (IEA, 2022b).

8.5 Scaling-up

Energy efficiency policies and programmes exist across Africa but will require significant acceleration in order to keep up with growing energy demand. This will require a combination of regulation, information and incentives. Regulation, for instance, is crucial to exclude worst-performing equipment from the market by introducing **stringent minimum energy performance standards** (MEPS) and **mandatory comparative labels** (IEA, 2022c) (See tools section for more details). For the effective implementation of policies, it needs to be ensured that resources are in place to put the policies into action. An example in the African context is the ECOWAS Regional Centre for Renewable Energy and Energy Efficiency (ECREEE), in charge of developing and harmonising standards in West Africa (IEA, 2022c). There is also a need for public-private partnerships for the implementation of the policies.

Regulation is also necessary to put a stop to the dumping of inefficient second-hand appliances from the global north on the African market (see also e-waste factsheet). Restrictions on the import of inefficient appliances from the global north are not only beneficial for increasing energy efficiency, they also have the potential to encourage local manufacturing (IEA, 2022b).

8.6 Energy efficiency in SESA

SESA partners in various countries are taking into account energy efficiency when planning their Living Labs. Specific actions taken by the Living Labs in this regard will be included in subsequent updates of the factsheet.

8.7 Examples of application in the African context

EnSo Impact, "Esco-in-a-boxTM" Kenya

The idea: EnSo aims to deliver environmental and social impact by supporting the ESCO industry in Kenya to improve the rate of implementation of energy efficiency projects.

Areas of expertise and innovation:

- Growing a viable ESCO industry in Kenya to improve the rate of implementation of energy efficiency projects
- ESCO-in-a-box is an 'operating system' for energy services, incorporating all the systems, processes, and contract templates needed to deliver energy efficiency projects to SMEs, based on internationally established good practice.

The business model:

- ESCO-in-a-box offers a new business model that aims to unlock the wide range of financial, environmental, and social benefits provided by energy efficiency upgrades for SMEs that traditionally lack the time and resources to implement projects.
- Project aim is to conduct a feasibility study that will adapt and apply the ESCO-in-a-box model for the Kenyan context, including a focus on specific sectors, development of a preliminary business case, and scope of work for a potential follow-on pilot project.

The impact:

- Support for businesses
- Job creation
- Energy savings
- Capacity building for SMEs

For further information visit:

- https://enso-impact.co.uk/projects/esco-in-a-box/

Powerhive, Nairobi, Kenya

The idea: Powerhive partners with utilities and independent power producers to provide access to productive, affordable, reliable and efficient mini-grid electricity. The company developed an energy efficient storage solution for electric vehicles to make micro-grids economically viable, called "Jerr-e-can".

Areas of expertise and innovation:

- Make EVs more viable with mini-grids
- Powering of EV by a "Jerr-e-can", a swappable, energy efficient battery

The business model:
- Pay-as-you-go purchase of electricity using mobile money payment
- Payments trigger automatic electricity production for households and businesses for a period of time, based on amount of electricity purchased

The impact:
- Access to reliable, affordable, clean energy for off-grid communities

For further information visit:
- https://powerhive.com/
- https://www.cigionline.org/static/documents/documents/Paper%20no.130.pdf
- https://storage.googleapis.com/e4a-website-assets/Powerhive-Project-Spotlight-Report.pdf

8.8 Climate-proofing

Some of the key links between energy efficiency and climate proofing are:
- Energy efficiency can **reduce vulnerability** to climate change, especially in rural populations (IPCC, 2022a).
- Solar photovoltaic systems can potentially suffer efficiency reductions in case of large temperature increases or significant heat waves. Climate proofing PV system requires selecting more resilient modules.
- Energy infrastructure has a high-risk exposure through extreme wind and storm events and phenomena that could cause physical damage to the infrastructure such as floods, landslides and forest fires. Energy efficiency reduces the need for energy infrastructure because energy efficient buildings and appliances require less energy consumption.

8.9 Relevant tools and capacity building materials

“The value of urgent action on energy efficiency” Policy Toolkit
To support stronger action on efficiency the IEA has designed a policy toolkit for governments, launched at the IEA’s 7th Annual Global Conference on Energy Efficiency in June 2022. The toolkit provides a practical approach to accelerate action on energy efficiency by guiding governments in the design of effective policy measures, the support of policy decisions and the delivery of policy actions.
https://www.iea.org/reports/the-value-of-urgent-action-on-energy-efficiency/policy-toolkit

Energy efficiency in Cold Water Supply Systems Tool
Replacement of old and inefficient cold-water ground pumps in municipal cold-water systems are recognised as the “low hanging fruits” to highly increase energy efficiency with a very short and attractive 2-5 years payback period. This developed online tool requires only minimal, limited data on cold-water consumption in municipalities and presents potential energy savings, CO2 savings, investment volume and a simple payback period. What makes a difference from other tools is that this tool identifies the potential investment volume and payback. Having investment volume, energy, CO2 savings and payback period, the decision makers can make a decision relevant to the project implementation.
https://c2e2.unepccc.org/kms_object/energy-efficiency-in-cold-water-supply-systems-tool/

Energy Efficiency Indicators: Fundamentals on Statistics
Energy efficiency is high on the political agenda as governments seek to reduce wasteful energy consumption, strengthen energy security and cut greenhouse gas emissions. However, the lack of data for developing proper indicators to measure energy efficiency often prevents countries from transforming declarations into actions. The main objectives of this manual are to identify the main sectoral indicators and the data needed to develop these indicators; and to make surveying, metering and modelling practices existing all around the world available to all.
https://www.iea.org/reports/energy-efficiency-indicators-fundamentals-on-statistics

ECOWAS Energy Efficiency Technical Assistance Facility
The ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE) and Clean Energy Solutions Center (CESC) of the National Renewable Energy Laboratory (NREL) of the United States of America have joined efforts to promote an Energy Audit Market in the ECOWAS Region. The initiative was designed to create and operationalize a technical assistance facility for Micro, Small and Medium Enterprises (MSMEs) whose business model includes provision of energy audit services. The overall objective of this CESC- ECREEE collaboration in West Africa is to promote energy audit as a valid and reliable market tool to enable Energy Efficiency.
http://www.ecreee.org/page/ecowas-energy-efficiency-technical-assistance-facility

Impact Assessment Framework
The framework merges evidence on the impacts of four high-performing appliances: fans, refrigerators, solar water pumps, and TVs, and provides a set of formulas that have a common language and structure to help quantify these impacts. The Framework and formulas will help facilitate the financing, planning, measuring, and reporting of these impacts. Efficiency for Access is publishing a number of outputs based on this study, to help identify the impacts of high-performing appliances further.
https://efficiencyforaccess.org/publications/impact-assessment-framework

CLASP tools: Efficient appliances for people and the planet
The CLASP website offers dynamic tools to support evidence-based decisions. In the CLASP database tools can be found that provide essential data and information on appliance energy performance and quality. The selection includes the analysis of impacts of efficiency policy options, a comparison tool for off-grid energy solution appliances, a search engine in the form of a policy resource hub as well as an overview for policymakers and practitioners on policy compliance and an open-source testing tool to measure the power and performance of computers.
https://www.clasp.ngo/tools/

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9 Clean Cooking

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9.1 Introduction

Around 940 million people in sub-Saharan Africa lack access to clean cooking facilities, relying instead on solid biomass, kerosene or charcoal as their primary cooking fuel. This is particularly pronounced in rural regions (Figure 38). The gathering and use of biomass for cooking, particularly in rural areas, dramatically damages health and impairs productivity. Only in sub-Saharan Africa, almost 490,000 premature deaths per year are linked to household air pollution from the lack of access to clean cooking facilities (IEA, 2022). Unsustainable use of forest resources for cooking energy also contributes to deforestation. Therefore, clean cooking fuels and technologies are critical to Africa's energy transition. This factsheet reviews the potential of clean cooking solutions, including key technological aspects, business models and impacts, as well as examples of the use of the solutions across the continent and within the SESA project.

Figure 37. Cooking with an improved biomass cookstove in Kenya (Climate Impact Partners, 2022)

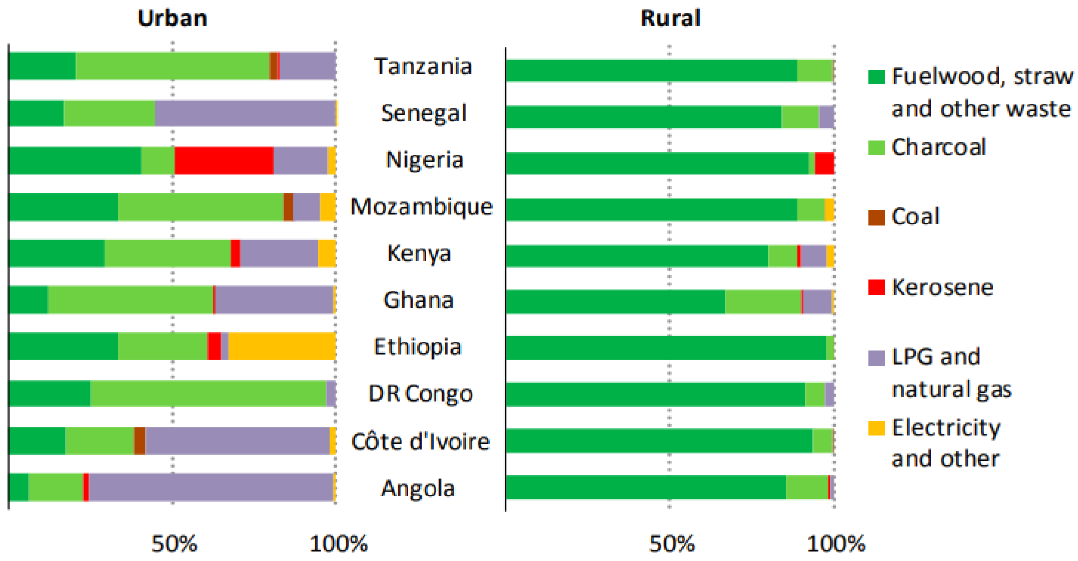

Figure 38. Main fuels used by households for cooking in selected Sub-Saharan African countries, 2018 (IEA, 2019)

9.2 The technology

Clean cooking technologies come in various shapes and sizes, and may use different fuels and different approaches to reducing polluting emissions. The World Health Organization (WHO) defines clean cooking technologies as those that are safe for the health of users at the point of use. In other words, cooking fuels and cooking devices that attain the fine particulate matter (PM2.5) and carbon monoxide (CO) levels recommended in the WHO global air quality guidelines (2021) (WHO, 2022). Only a few technologies meet the cleanest standards, such as electricity, biogas, liquefied petroleum gas (LPG), and alcohol fuels including ethanol. However, there also are different transitional technologies that oftentimes are easier to access and afford compared to the cleanest ones. These include improved cookstoves which burn biomass more efficiently and provide some health benefits over open "3-stone" fires or inefficient stoves (WHO, 2022). Figure 39 below shows the variety of cooking fuels, classified in polluting and clean fuels, whereas Figure 40 delves into how different technologies are classified under the Multi-Tier Framework (MTF).

It is important to note that ICT and IoT technologies play an important role in clean cooking solutions. They enable businesses to track real-time usage data on fuel consumption and to offer consumers feasible PAYGO solutions. This can help to overcome customer affordability barriers (CCA, 2022).

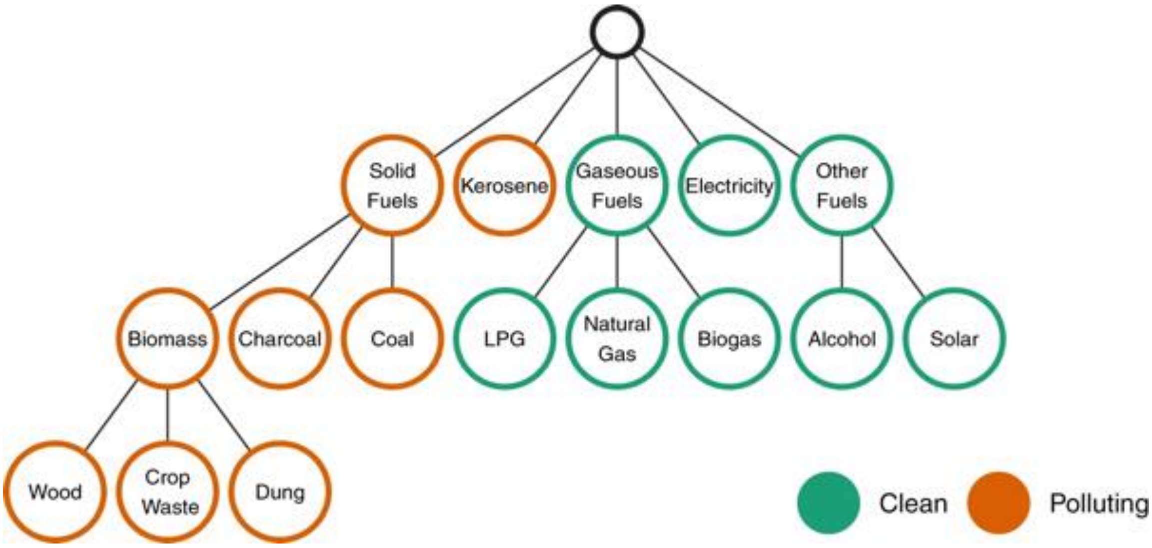

Figure 39. Cooking fuel categorization (Stoner et al., 2021)

Figure 40. Basic framework for classifying degree of access to modern cooking fuels and appliances (Energydata, 2022)

9.3 Business and financing models

The clean cooking sector in sub-Saharan Africa is characterised by various challenges such as underdeveloped markets with a small number of sizable players, a lack of ability and willingness of customers to pay as well as poor access to finance for businesses and consumers (MECS, 2021). A key barrier for low-income households to replace traditional fuels with clean cooking solutions oftentimes is often not only the cost, but the cost structure. For example, in the case of LPG, fuel costs can often be lower than solid biomass but the financial outlay required to pay upfront for pre-set units of gas (e.g., 6 kg-15 kg cylinders) is prohibitive for many households (Shupler et al., 2021). Price fluctuations and supply unreliability can also act as a barrier. However, business and financing models are developing to counter these barriers.

Consumer financing models are key for the viability of clean cooking companies. In consumer financing, supplier offer payment plans, potentially with Pay-as-you-Go (PAYGO) technology, to align customer's ability to pay with the business' revenue needs. Businesses also often partner with financial institutions to implement consumer financing (CCA, 2022). The PAYG model can be used for both financing or leasing clean cookstoves as well as purchasing the fuel. Low-income consumers can lease the product through periodic payments. Once they have made enough payments on the product, they can reach an unlock price that allows them to own the device outright (Junio, 2021). PAYG for fuels enables consumers to only purchase the amount of fuel that they need (e.g., LPG gas from a cylinder that). Businesses that apply this model in the LPG sector are, for example, KOPAGAS and PayGo Energy (see Examples section).

Figure 41. PAYG-enabled LPG cookstove (CCA, 2021b)

Another key area in business models relates to the companies' approach to the value chain. Businesses can either manufacture and distribute cooking appliances, or only the fuels, or both. Integrated clean cooking models that provide the appliance and fuel currently dominate the sector with 45% of companies accounting for 71% of overall capital raised in the clean cooking sector (CCA, 2022).

9.4 Socio-economic and sustainability impacts

The use of traditional cookstoves with solid fuels like wood and charcoal is predominant in sub-Saharan Africa and has severe impacts on health, ecosystems, climate and livelihoods:

- As stated above, almost 490,000 premature deaths per year are linked to household air pollution from the lack of access to clean cooking in sub-Saharan Africa (IEA, 2022)
- Up to 34 % of wood fuel harvested is unsustainable, contributing to forest degradation and deforestation (Global Alliance for Clean Cookstoves, o. J.)

- Although Africa is responsible for a minimal share of global greenhouse gas emissions, cooking with biomass contributes greatly to global black carbon emissions, which is a significant contributor to climate change (Global Alliance for Clean Cookstoves, o. J.).
- Significant time is spent collecting fuel, especially in locations where firewood value chains do not exist.

While the most climate-friendly cooking fuels are those relying on renewable energy (e.g., solar-powered electricity, biogas), the use of fossil fuels in clean cooking solutions can have a lower climate footprint than traditional biomass fuels, depending on how the biomass is sourced and how much the collection of biomass leads to deforestation and land degradation. For example, LPG has a lower climate impact than biomass, even when a large fraction of the biomass is renewable (Kypridemos et al., 2020).

Women and children stand to benefit drastically from a transition to clean cooking. Apart from avoiding the health risks described above, some of the gender-specific benefits of clean cooking are time savings and safety. Household fuel collectors (who are often women and children) can spend up to 10 hours a week gathering fuel and might be limited in attending school or generating an income to do that work (CCA, 2021a). In conflict settings, fuel wood collection involves an increased vulnerability to physical attack when leaving the communities or refugee camps (CCA, 2021a).

Strengthening the clean cooking sector also has economic benefits in terms of creation of new value chains (for fuels, stoves, cylinders, etc), increased opportunities for local manufacturers and distribution companies, new employment and skills. Electric cooking solutions can also increase the economic viability of solar mini-grids, by increasing the array of energy services are offered to customers (MECS, 2021).

9.5 Scaling-up

There is an urgent need to scale up the use of clean cooking solutions in sub-Saharan Africa. The number of people who rely on wood and charcoal for cooking is currently 950 million worldwide, and it is projected grow to 1.67 billion by 2050 (United Nations, 2022). Affordability, accessibility of liquid petroleum gas (LPG), lack of electricity access, tradition, perceptions, and a lack of suitable cooking appliances all act as barriers to scaling up the use of clean cooking solutions (MECS, 2022). Programmes and projects to replace traditional but unsustainable fuels are likely to succeed only if they are able to take account of the different barriers to adoption in their design.

Grants, loans and financing incentives such as tax exemptions or import duty waivers (for imported stoves) have a critical role to play in de-risking businesses and developing the market. Beyond project-specific financing, financial instruments can be used to support the growth of clean cooking companies (CCA, 2022). Incentivising local manufacturing of clean cookstoves and of local fuel value chains, and improving the enabling environment for businesses via policy changes (e.g., removal of subsidies on dirty fuels, adoption and enforcement of technical standards), all have a role to play. Figure 42 shows the top policy areas that were prioritised by 37 clean cooking companies surveyed by the Clean Cooking Alliance in 2020.

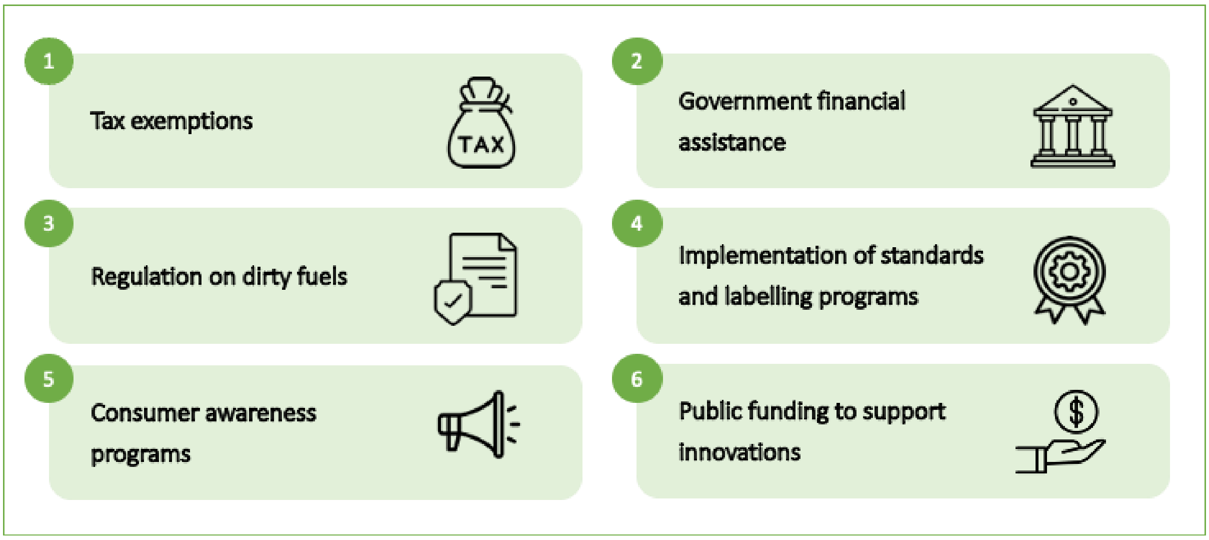

Figure 42. Top priority policies for surveyed clean cooking companies (own illustration, based on CCA, 2022)

It is important to also consider the barriers that impede widespread adoption of clean cooking technologies and fuels. A challenge to scale up clean cooking at the required level are under-developed markets, reflected by the relatively small number of sizable players in each segment of the market (MECS, 2021). This is accompanied by a lack of country-level data on the market (e.g., consumption patterns, competing fuel prices), technologies (e.g., unit economics), companies (e.g., business models, distribution strategies, payment plans), and customers (cooking behaviours in different cultural settings) as well as the lack of standardised impact metrics.
Perceptions and customs can also be part of the barriers to adoption. Firewood may be preferred due to its deep cultural meaning (Tamire et al., 2018), or households perceive other benefits of open-fire cooking, like keeping mosquitos away or the provision of light (Energypedia, 2018).

9.6 Clean cooking solutions in SESA

SESA partners in various countries are working on clean cooking solutions. Most of the Living Labs will test PAYG business models which will be based on surveys on current fuel use, perceptions, etc. Moreover, the SESA Call for Entrepreneurs will identify potential businesses in the clean cooking ecosystem in Ghana, Malawi and Rwanda and thus will contribute to the growth of the sector beyond the Living Labs locations.

9.6.1 BioCooker in Malawi

Within SESA, **the Malawi validation site** works on the adaptation and validation of the **Make it Green BioCooker** to a small-scale, commercial product. The MiG BioCooker utilizes sustainably-sourced traditional wood-based fuel to provide heat for cooking and **produces biochar as a byproduct**. The biochar thus obtained is used as an affordable water purification system and as an enrichment of soil for agriculture. The use of biochar for agriculture has been seen as an efficient means of carbon sequestration (Make it Green, 2022).

The main objective of the validation site is to **co-produce the bio cooker and strengthen the applicability and replicability of the technologies as well as the basic business concepts.** The expected impact includes reduced cost of cooking, income from biochar, decreased health problems, especially for women and children, the access to clean water, the generation of fertilizers from biochar and the opportunity to use a variety of biomass feedstock.

9.6.2 Biogas for cooking in Ghana

In the **Ghana validation site**, the activities are located in the Ga North Municipal district, which is an urban settlement, and Atwima Nwabiagya Municipal Assembly, which is a rural community. The potential innovation tested is clean cooking systems.

9.6.3 Clean cooking solution in Rwanda

The **Rwandan replication site** is considering testing **clean cooking solutions**. The main SESA partner in Rwanda is the **University of Rwanda**.

9.7 Examples of application in the African context

Solar-Biomass Hybrid Stove by Mozambique Renewables Limited (Mozambique)

The idea: To develop clean cooking solutions that displace charcoal with agricultural residues to bring energy and light into rural areas in Sub-Saharan Africa.

The power source:

- Crop residues, Pellets / Briquettes
- Solar-Biomass Hybrid Stove

The business model:

- Carbon credits are secured against the displacement of charcoal & wood through the use of the clean stove.
- The stove can be given to families in rural areas free of charge and paid for by companies that need to offset their emissions.

The impact:

- Cost savings: The cookstove will burn processed agricultural waste at a cost that is at least 50% cheaper than the equivalent cook with charcoal.
- Emissions reduction: Each stove displaces 7.5 tonnes of carbon annually when displacing charcoal with our fuel made from agricultural residues.
- Electricity provision: The stove also provides a solar panel, a 100 lumen LED lamp and a USB Charger thus providing the minimum requirements for a modern life off-grid.

For further information visit:

- https://www.mo-re.uk/

KOPAGAS (Tanzania)

The idea: Through smart meters and PAYG technology, KOPAGAS distributes LPG to last-mile Tanzania regions. Until 2025, KOPAGAS aims to switch 1 million people in Tanzania from charcoal to LPG.

The power source:

- LPG

- A smart meter solution that enables PAYG

The business model:
- PAYG with a mobile money account.

The impact:
- Increased accessibility and affordability of clean cooking technologies due to the elimination of high up-front costs and a large distribution network for LPG in Tanzania.

For further information visit:
- https://www.kopagas.com/

PayGo Energy (Kenya)

The idea: PayGo Energy is a venture-backed technology company based in Nairobi, Kenya. The company develops and brings proven technologies to the LPG industry to expand access to clean cooking for millions of households in the developing world.

The power source:
- LPG

The business model:
- With the PayGo Cylinder Smart Meter (CSM), customers can purchase gas in any amount from a cylinder in their home, using mobile money. The CSM tracks consumption at the household level and notifies the customer when the cylinder is approaching empty.

The impact:
- Enables clean affordable cooking
- Leads to improved health conditions

For further information visit:
- https://www.paygoenergy.co/

9.8 Climate-proofing

Even though the implemented measures will depend on the location and context, some general guidelines can be provided focusing on climate proofing of clean cooking solutions. The different fuels that are used for improved or clean cooking are differently affected by the impacts of climate change. For example:

- The availability of fuelwood might be reduced due to droughts and fires as an impact of climate change.
- LPG supply and storage infrastructure can be physically damaged by climate change-induced floods, landslides, storms, or sea level rise.
- Biofuel supply chains can be interrupted or altered by climate variability.
- Solar-powered electricity generation for clean cooking (for example via solar PV mini grids) can also be physically damaged or its efficiency reduced due to changes in radiation and ambient temperature

9.9 Relevant tools and capacity building materials

Clean Cooking Catalog

The Clean Cooking Catalog is a global database of cookstoves, fuels, fuel products, and performance data and includes information on features, specifications, emissions, efficiency and safety based on laboratory and field-testing. The catalog helps to drive the development of international clean cookstove standards, and provides monitoring and evaluation information. It was launched in 2013 by the Clean Cooking Alliance but is continuously updated.
http://catalog.cleancookstoves.org/

Improved Cooking Energy Portal (Energypedia)

The improved cooking energy portal collects and structures all information on clean cooking energy that is available on energypedia. The portal covers various sections, including a.o.: cooking fuels, cooking energy technologies, impacts or case studies. The portal is continuously updated (last edit June 2022).
https://energypedia.info/wiki/Portal:Improved_Cooking

Global Market Assessment for electric cooking (GMA) Factsheets (2021)

Modern Energy Cooking Services (MECS) developed country factsheets on the market assessment for electric cooking, covering many African countries. Each factsheet provides background information, key statistics, policies & projects and opportunities and challenges about the electric cooking sector as well as an assessment on the viability to scale up.
https://mecs.org.uk/resources/factsheets/

Clean cooking planning tool

The World Bank's Energy Sector Management Assistance Program (ESMAP) has developed a scenario-based, integrated Clean Cooking Planning Tool (CCPT) that helps decision makers and planners to explore and identify transition pathways for achieving universal access to clean cooking solutions. It adopts the World Bank's established Multi-Tier Framework (MTF) to classify cooking energy services.
https://energydata.info/cleancooking/planningtool/

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10 Climate Proofing Sustainable Energy Solutions

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10.1 Introduction

The transition to clean and affordable energy for all in Africa will take place while the continent is adapting to the impacts of climate change. Sustainable energy solutions, such as solar mini-grids or sustainable e-mobility fleets, are cost-effective and can bring about social and economic benefits while reducing emissions. But even if they are vital to fighting against climate change, they are also vulnerable to risks resulting from it. If the solutions are not designed to withstand the new climatic conditions and variability, they will not reach their full potential. Climate-proofing sustainable energy solutions is therefore vital to the success of the energy transition in Africa. Additionally, climate-proofing has the potential to create economic opportunities and ensure energy security.

Climate-proofing is a process that identifies risks to an asset as a result of climate change and variability, and ensures that those risks are reduced through long-lasting and environmentally sound, economically viable, and socially acceptable adaptation measures. It involves the integration of possible risks caused by climate change into policies, project planning and design (EC and EEA, 2022).

This factsheet introduces key facts regarding the **climate proofing of sustainable energy solutions in the African context, focusing on the solutions that are deployed within the SESA project**. The structure of the factsheet is as follows: first, it introduces the key impacts of climate change in Africa, followed by an analysis of the specific risks relevant to the sustainable energy solutions that are being tested within SESA. It then provides general guidelines for climate-proofing implementation, as well as examples of application in the African context. Lastly, the factsheet lists tools and capacity building materials on the topic.

10.2 Climate change impacts in Africa

The African continent is one of the lowest contributors to greenhouse gas (GHG) emissions and has the lowest emissions per capita in comparison to all other regions. Though one-fifth of the world's population live in Africa, the continent accounts for less than 4% of global energy-related carbon dioxide (CO_2) emissions (IEA, 2022). Nevertheless, the increase in warming is advancing faster in Africa than in the rest of the world, and Africans are disproportionately affected by climate change. Socioeconomic, political and environmental factors are exacerbating the exposure and vulnerability to climate change in Africa. As a consequence of observed anthropogenic climate change, Africa is experiencing widespread loss and damage, including loss of lives, water shortages, biodiversity loss, reduced food production, and reduced economic growth, among others (IPCC, 2022; IEA, 2022).

Key impacts of climate change in Africa – both impacts that are currently observed and those projected for the future- are summed up in Table 3.

As well as the impacts listed below, climate change poses **risks to infrastructure and value chains, including energy, mobility**, **telecommunications**, and **water**. Damages can be directly produced by extreme weather events, but also indirectly as a consequence of displacement or economic impacts. There are also interdependencies among different types of infrastructure, for example, between energy and water, or energy and mobility. If one infrastructural asset is negatively affected by a climate hazard, this can lead to a cascade of impacts through the system. Therefore, **resilient physical infrastructure and business models** are required in a context of increasing climate variability and change. When critical infrastructure and energy assets are climate-proofed, loss of lives, interruptions in critical services and physical damages can be reduced (UN Habitat, 2021). It is urgent to foster climate-proofing of infrastructure in Africa, including for emerging sustainable energy solutions such as solar minigrids or e-mobility assets. The following section focuses on the risks resulting from climate change on the sustainable energy solutions that are tested within the SESA project, and also highlights the potential for climate-proofing them.

Table 3. Observed and projected impacts of climate change in Africa, compilation of (IPCC, 2022; IEA, 2022)

Observed impacts
● Increase in average temperatures is faster than in any other world region ● Increase in annual heat wave frequency, intensity and duration ● Sea level rise faster than the global average, accompanied by coastal flooding and erosion ● Higher frequency of heavy precipitation events accompanied by floods, and extreme weather events such as cyclones ● More frequent multi-year droughts (e.g., 2015-2017 Cape Town drought was three times more likely due to climate change) ● Human displacement as a consequence of disasters such as floods, or of decreased liveability of areas of human settlement. Around 1.2 million people were displaced due to climate change-related natural disasters in the East and Horn of Africa in 2020, representing nearly 10% of global displacements. ● Significant increase in food insecurity due to climate variability: compounded by conflicts and exacerbated by the impacts of COVID-19 pandemic. Agricultural productivity has observed over one-third growth reduction since 1961 due to increased water stress and shortened growing season. ● Economic impacts: the IPCC (2022) states that African countries' Gross Domestic Product (GDP) per capita may be on average 13.6% lower since 1991 than if human-caused global warming had not occurred. ● Human health impacts are varied, including those from exposure to non-optimal temperatures and extreme weather events together with increased transmission of infectious diseases poses an important threat to be accounted for (IPCC, 2022).
Projected impacts
● Mean temperature and temperature extremes increase over the whole continent ● Increase in drought frequency: reduced mean annual rainfall projected over southwestern, southern Africa and coastal north Africa. By 2050, climate change can expose 951 million people in Sub-Saharan Africa to water stress. ● More severe and frequent coastal flooding in low-lying areas

- Around 85 million people could be displaced due to climate change impacts by 2050
- Health: malaria vector hotspots and prevalence are projected to increase in east and southern Africa and the Sahel under even moderate emissions scenario by the 2030s, exposing an additional 50.6-62.1 million people to malaria risk
- High temperatures and high humidity exceed the threshold for human and livestock tolerance over larger parts of Africa and with greater frequency
- Increased average temperatures and lower rainfall will further reduce economic output and growth in Africa

10.3 Climate-proofing sustainable energy solutions

Within the SESA project, sustainable energy solutions are tested within living lab locations throughout the African continent (Kenya, Morocco, Ghana, Malawi, Namibia, Tanzania, Rwanda, South Africa and Nigeria). Table 4 describes the potential climate change-related risks that the three key sustainable energy solutions tested in SESA can encounter, and provides an overview of how to respond to the risks through climate-proofing during the design and operation phases.

Table 4. Risks to sustainable energy solutions resulting from climate change and possibilities for climate-proofing the solutions (own illustration, based on IPCC 2022; IEA, 2022; Riello Elettronica, 2022; IAEA, 2019; ADB, 2013 & 2011; Johnstone, 2021

Solutions	Risks from climate change	Possibilities for climate-proofing
E-mobility fleets and infrastructure	• Damage to e-mobility charging infrastructure • Vehicle battery premature failure and more frequent replacement needs due to high temperature • Damage of roads/bridges/pavements, reducing their safety and security and/or reducing access to mobility	• Design of resilient re-charging infrastructure • Choice of batteries that are suitable to the expected temperature ranges • Vehicle operation and storage that avoids exposure to extreme heat
Solar PV mini grids	• Reduced efficiency of PV panels through excessive heat • Battery premature failure and more frequent replacement needs due to high temperature • Reduced efficiency of whole system due to changes in radiation and ambient temperature • Physical damage due to flooding, wind, landslides, fires. • Disruption or reduction of the ICT services vital to minigrid viability, due to damage of telecommunications networks	• Choice of PV panels that are suitable for expected temperature variability, i.e. with small temperature coefficient, where efficiency is not greatly reduced under high temperatures • Choice of batteries (including 2nd life Lithim-ion batteries) that are adapted to the expected temperature ranges • Design of robust minigrids with components that can withstand and are more resilient to climate extremes. • Choice of location that takes into account climate risks in the location • Design of modular infrastructure that integrates ease of repair and replacement in case of damage (circularity principles) • Design of ICT and IoT components that are resilient and adaptable
Clean cooking	• Availability of clean cooking fuels (e.g., LPG, biogas, fuelwood for efficient	• Design of robust fuel supply infrastructure that considers climate variability and risk

	stoves) may be reduced to the impacts of climate change on fuel production and distribution infrastructure	
PUE appliances	● Damage to PUE appliances and therefore to their productivity benefits	● Design and operation of appliances that considers climate variability and risks
E-waste of solar off-grid solutions	● Physical damage to e-waste collection or treatment infrastructure due to climate extremes	● Design of robust collection and treatment facilities and supply chains
2nd life Li-Ion batteries	● Exposure to high temperatures can damage battery and shorten its life	● Appropriate management of the battery during the first and second life to minimise temperature exposure

Moreover, climate proofing of sustainable energy solutions can be ensured through the application of the following principles (for further details, refer to corresponding factsheets):

- **Water-Food-Energy Nexus:** when the WEF nexus approach is applied in the design of sustainable energy solutions, it can enhance resilience to climate change by reducing water stress and strengthening food security. This is the case of solar agrivoltaics (Figure 44), or of solar-powered irrigation systems that are carefully tailored to the crop type and designed to save water via remote sensing and advice on optimal, water saving use of the pump based on usage data.
- **Energy efficiency:** when energy-intensive appliances are energy intensive, they consume less energy, thus require smaller infrastructure (e.g., smaller installed capacity of PV modules in a solar minigrid).
- **Circularity:** energy solutions that are designed to be easy to maintain and repair (e.g., modular) are more resilient to the impacts of climate change that create partial damages or outages.

Figure 43. Agrivoltaic systems provide shade to the crops while generating energy (Adhiambo, 2022)

Many of the risks from climate change to sustainable energy solutions are common: physical infrastructure can be damaged by extreme events such as floods, or extreme heat. Additionally, all energy solutions reliant on solar PV and storage technologies face the risk of reduced efficiency or shorter lifespans due to exposure to extreme temperatures.

10.4 Implementing climate-proofing

The first step in climate-proofing process is the assessment of the climate risk in the specific project or business model. **Climate risk assessments** should be integrated into each project development steps: planning and strategies, feasibility studies, technical design, and operation and maintenance. A climate risk assessment starts by defining the scope, i.e., project context, boundaries and interactions. The assessment must then establish the most appropriate timescale over which climate change risks are being assessed, taking into account the intended lifespan of the analysed project. It is advisable to use more than one time horizon, and to keep in mind that, the longer the timespan, the greater the uncertainty. As part of the assessment, potential climate hazards are identified, and detailed climate data is collected for the considered area of study. The climate risk assessment is then developed by mapping vulnerabilities of the analysed project to identified climate hazards, its exposure and the probability of those hazards to materialize.

The result of this assessment is used to guide planning and design processes, feeding these stages with essential information to make better decisions with regard to project location, technology selection and technical specifications (such as materials selection or sizing).

The following are key considerations in the implementation of climate-proofing for sustainable energy solutions (EUFIWACC, 2016; EC, 2021):

- Climate proofing is more effective and less costly when it starts at an early stage, i.e., in project planning and design.
- Integrating climate-proofing into the financing and business models of sustainable energy solutions is crucial, as the process can increase the complexity of design and therefore the

upfront costs and financing needs. However, not considering or delaying the consideration of climate proofing of energy solutions can lead to high costs in the long term.

- Before starting the analysis, it is important to allocate sufficient resources, create the most appropriate working team, and ensure compliance with applicable legislation, rules and regulations.
- Robust data on climate change impacts for a specific location can be challenging to find, but some sources are suggested in the "Relevant tools" section below.

10.5 Scaling up climate-proofing

Climate-proofing sustainable energy solutions is very important to make the solutions long-lasting, environmentally sound, economically viable, and socially acceptable, so they are able to respond to current and future climate change-related threats. Therefore, it is important to scale up climate-proofing of sustainable energy solutions in the design phase, the operational phase and the end-of-life phase. Two important influencing factors for scale up are the **availability of reliable climate change impact projections and risk assessments** and the availability of financing.

Easy-to-use climate information and risk management services is not only needed for policy makers to mainstream climate-proofing into policies. It is also crucial for the private sector and businesses operating in the renewable energy sector.

Financing for climate proofing of energy solutions is still only in its infancy and lagging behind already scarce climate adaptation funding. In 2019, USD 7.8 billion was provided by advanced economies for climate adaptation in African countries (IEA, 2022). However, it is estimated that the real cost is around USD 30-50 billion annually by 2030. Loans, grants and debt relief mechanisms, as well as blended finance (combination of public and private financing) are typical approaches for climate adaptation financing, which can be tapped into by businesses aiming to climate proof energy solutions.

10.6 Examples of application in the African context

Coping with Drought and Climate Change, Kalu Woreda, Ethiopia

The idea: Project aims to improve the livelihood strategies and resilience of farmers. Through enhanced farming practices, alternative livelihood strategies, and use of early warning information in agricultural systems, rural communities will be able to adapt to water scarcity and drought. The objective is to develop and pilot a range of coping mechanisms for the reduction of vulnerability of farmers (particularly women and children) in Kalu Woreda district.

The financing model:

- Special Climate Change Fund (SCCF) project of UNDP

The impact:

- Reduction in vulnerability to climate change of the population in pilot sites
- Households adopt alternative livelihood strategies by the project
- Pilot sites disseminate weather/drought information
- Households receive and use weather forecast information
- Farmers/ agro pastoralists outside the target area adopt/replicate best practices

For further information visit:

- https://www.thegef.org/sites/default/files/documents/Ethiopia_1.pdf
- https://www.adaptation-undp.org/CCA-Africa

Watermed4.0, Agrivoltaics system (Miliana, Algeria)

The idea: Climate-proofing Water-Energy-Food- Nexus solutions through the optimization of irrigation, water distribution, and consumption based on a holistic analysis that collects information from all aspects of the system including even the natural water cycle and the cumulated knowledge related to growing particular plants. Ensuring higher yields and crop sizes in water scarce regions.

The business model:

- Pilot research project (universities and research institutions involved)

The impact:

- Agrophotovoltaic applications ensure a reduction of irrigation needs through shadowing, while at the same time generating energy
- Enhancement of technology development, societal engagement, governance and transferring knowledge by the new possibilities of digitalisation and cyber-computing
- Adaption to users and supply chains through an open platform
- Prevention of over-and under-irrigation
- Potential to pump and desalinise water from different sources
- Export potential
- Decreasing probability of migration flows

For further information visit:
https://www.watermed-project.eu/

Saving lives and protecting agriculture-based livelihoods in Malawi: Scaling up the use of modernized climate information and early warning systems, Malawi

The idea: Main objective is the reduction of vulnerability to climate change impacts from extreme weather events caused by climate change by scaling up the use of modernized early warning systems and climate information. The project supports the Government of Malawi to save lives and enhance livelihoods at risk from climate-related disasters.

The financing model:

- UNDP supported and Green Climate Fonds funded

The impact:

- Building the capacity of local beneficiaries (farmers and fishers) as well as responsible government agencies and stakeholders to adapt to the changing climate
- Reduction of vulnerability to climate change impacts on lives and livelihoods, particularly of women, from extreme weather events
- Expansion of networks that generate climate-related data to save lives and safeguard livelihoods from extreme climate events
- Development and dissemination of products and platforms for climate-related information/services for vulnerable communities and livelihoods
- Strengthening communities' capacities for use of early warning systems/ climate information

For further information visit:
https://www.adaptation-undp.org/CCA-Africa

10.7 Relevant tools and capacity building material

This chapter compiles some of the tools and viewers available for climate change analysis and risk assessment:

Climate-Proofing Toolkit: For Basic Urban Infrastructure with a Focus on Water and Sanitation

The overall goal of the toolkit is to ensure that climate-related risks and impacts are factored in the design, construction, location and operation of current and future basic urban infrastructure. The toolkit outlines current capacity gaps and proposes specific actions for climate-resilient infrastructure (planning, designing, building and operating) that anticipates, prepares for and adapts to changing climate conditions.
https://unhabitat.org/climate-proofing-toolkit-for-basic-urban-infrastructure-with-a-focus-on-water-and-sanitation#:~:text=The%20Climate%20Proofing%20Toolkit%20is,current%20and%20future%20basic%20urban

IPCC AR6 WG1 interactive atlas

The Interactive Atlas regional information supports the assessment done in the IPCC AR6, allowing for flexible temporal and spatial analyses of trends and changes in key climate variables.
https://interactive-atlas.ipcc.ch
https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Atlas.pdf

Climate Change Knowledge Portal (CCKP)

This online tool provides access to comprehensive global, regional, and country data related to climate change and development. It offers global data on historical and future climate, vulnerabilities, and impacts. Country reports are also provided that summarize most relevant data and information on climate change, disaster risk reduction, and adaptation actions and policies at the country level.
https://climateknowledgeportal.worldbank.org/

UNDP Climate Change Country Profiles

Country-level climate data summaries that address the climate change information gap for developing countries by making use of existing climate data to generate a series of 52 country-level studies of climate observations and the multi-model projections.
https://www.undp.org/publications/undp-climate-change-country-profiles

ThinkHazard! tool

This web-based tool assists with project planning and design, providing non-specialists with information on potential impacts of disasters on new development projects. It provides qualitative information about hazards present in a project area (at country, provincial or district level), including river, coastal and urban flooding; extreme heat; wildfire; earthquake; drought; cyclone; tsunami; volcano; and landslide. As a result, it is obtained the level of awareness recommended of each hazard when planning the project together with recommendations and guidance on how to reduce that risks and links to additional resources (country risk assessments, best practice guidance, additional websites). It also highlights how each hazard may change in the future as a result of climate change.

https://thinkhazard.org/en/

Vouwgrond / Climagon

Vouwgrond / Climagon is an easy-to-use viewer of climate behaviour created for educational use and to provoke thoughts about climates.
https://climate.vouwgrond.nl/

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