FACTSHEET 5

Solar Mini Grids


Dreamstime / Inge Hogenbijl

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.

AUTHORS:
Amaia González-Garrido, Eduardo García, Elena Turienzo, David Valencia (TEC), María Yetano Roche (WI)

Contributors: Madeleine Raabe, Sophia Schneider (WI)

1 Introduction

Solar mini grids are key to delivering reliable, clean, 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 mini grids, sums up key business and financing models, and provides examples of successful deployment in the African context as well as in the SESA project specifically.

2 The technology

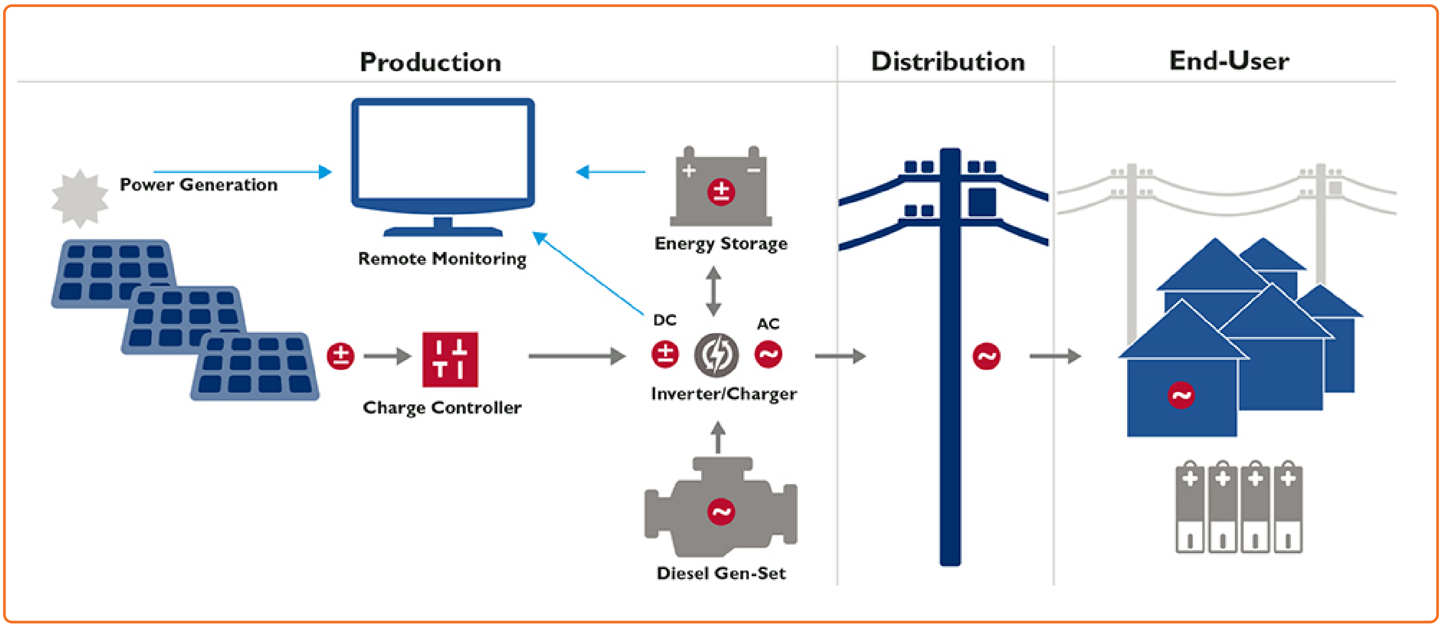
Solar mini grids are composed of a set of solar electricity generation and storage devices that are connected to a distribution network. The distribution network then supplies electricity to a group of customers. A typical solar mini grid in Africa will have a size of between 10 and 100 kW, though other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

2.1 Key components

The key components of solar mini grids (see Figure 2) 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 by the PV system.
- **Storage**: this component absorbs the surplus power during off-peak hours and dispatches stored energy at times of high demand. 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 options. Second-life Lithium-ion batteries are an affordable source of storage devices in solar mini grids (for more information, please consult the factsheet "Second Life Li-ion batteries" in the catalogue).
- **Distribution system**: composed of 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) or 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 panels to the inverter or the battery. Meters and monitoring equipment allow the collection of data that informs the operation. Energy management systems often allow operators to control the mini grids remotely, to some extent.
- **Consumption loads**: depending on the context, there can be a combination of different users, such as households (using appliances such as TVs and fans), public services (schools, hospitals, street lighting), businesses (using productive use appliances such as water pumping, irrigation, cold storage, or mechanical food processing) or other types of uses (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 mini grid.

Figure 2: **Components of a solar mini grid** (USAID, 2018)



2.1 Mini grid design

The technical design of a mini grid requires careful consideration of the loads, in other words the energy consumption by the end-users. Developers need to have a strong understanding of the maximum peak power required, and how much energy is required at each time. They then make decisions based on the demand profiles and a series of trade-offs regarding, for example, the technology options, their cost, or the applicable national and international standards and regulations (e.g., the IEC 62898 international standard for AC mini grids).

A 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. The DC configuration is common among isolated solar mini grids, as PV systems can be connected directly to many DC appliances, avoiding the use of inverters (Martin-Martínez et al., 2016). However, the potential for connection to the external utility distribution grid (typically AC) is a key factor to consider in the design process (USAID, 2020). If the communities or developers consider that an isolated mini grid might eventually be connected to the national grid, it should be designed with this in mind.

A series of software tools exist to support the optimal design of mini grids (See Section "Tools and training material" below).

2.3 Towards smart mini grids

New technologies are emerging for the efficient management of mini grids. The integration of ICT (Information and Communication) and IoT (Internet-of-Things) technologies is key to the technical and economic viability of the systems: they can manage power quality, allow remote monitoring and control, 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 electronic devices such as smart meters. Smart mini grids need computing platforms that can handle large-scale data analytics.

Examples of application in the African context — 1

KUDURA Solar mini grids, Kenya, Tanzania, Mozambique

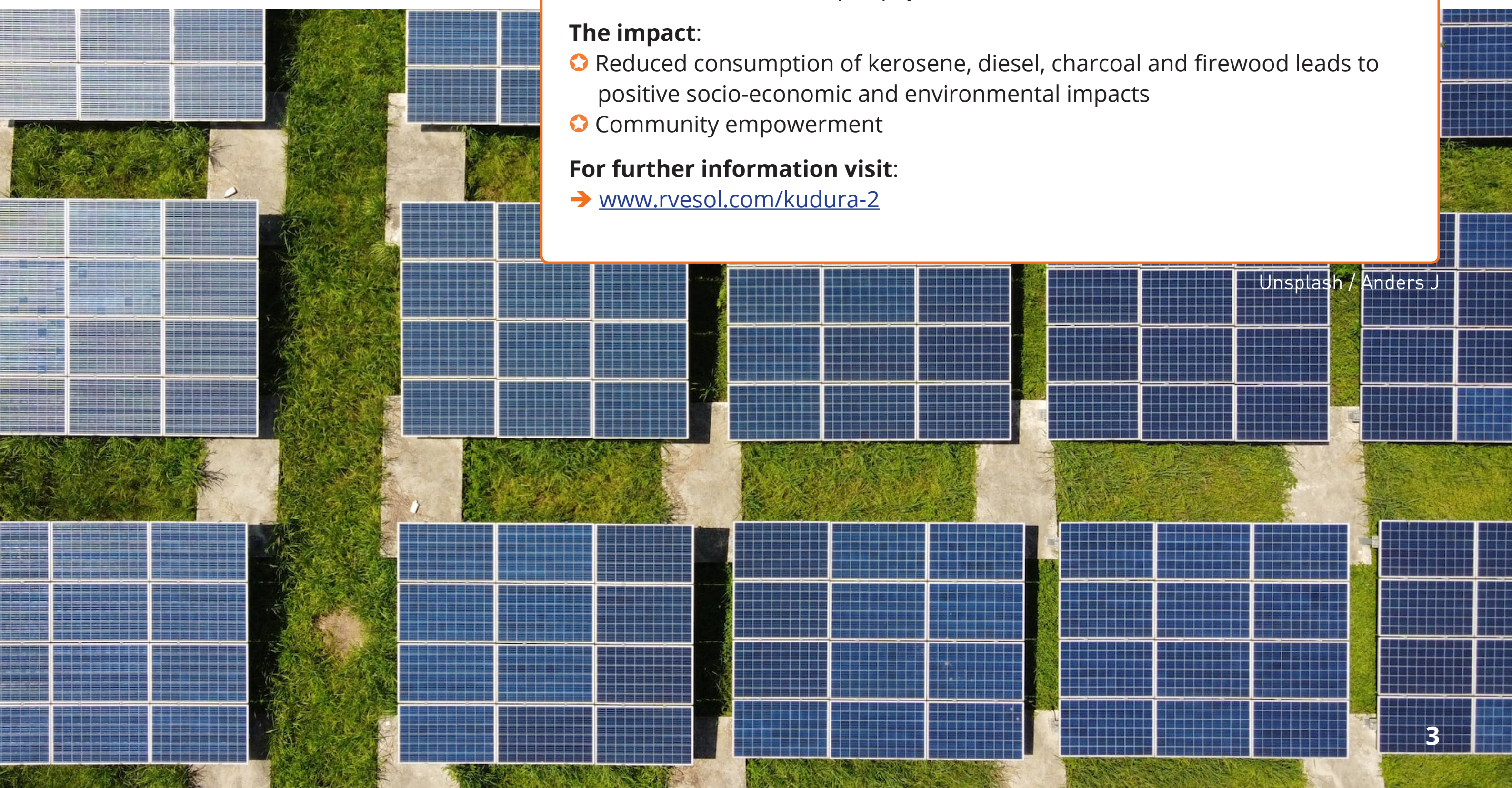
The idea: Mini grid solution that aims at catalysing economic development in rural, unelectrified areas.

The technology:
- Hybrid solar PV system, biogas and organic fertilizer unit, water purification unit and a central monitoring system
- Can be scaled to support anywhere from 1 home or business to 1,200 individual rural customers

The business model:
- Containerised hub that provides potable water and clean energy for lighting, cooking and productive uses
- Fee-for-service model, pre-pay fee

The impact:
- Reduced consumption of kerosene, diesel, charcoal and firewood leads to positive socio-economic and environmental impacts
- Community empowerment

For further information visit:
→ www.rvesol.com/kudura-2


Unsplash / Anders J

SESA Smart Energy Solutions for Africa

3 Business and financing models

A business model defines the way in which a solar mini grid project or business is planned, implemented, and executed to meet its strategic objectives. Mini grid assets and infrastructure in general require high upfront investment and steady and reliable returns over a long time period. Mini grids in the African context face specific challenges due to the low existing electricity demand and ability to pay of consumers, regulatory barriers, and higher financing risks, among others. Fortunately, a range of financial and business models are being designed to overcome these 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. The exact ownership and financing model will vary significantly depending on the type of customer and the final use.

3.1 Typical mini grid financing and operation models

The **Anchor Business Community** (ABC) model leverages 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 productive use consumers, households, or others) (Ramchandran et al., 2016).

The concept of **design, build, own, operate, and maintain** is the business model in which the owner builds the project and then maintains the assets, by paying for new equipment and upgrades, while capturing the entire revenue stream to recover their upfront capital, costs, and risks (Weston et al., 2018).

In some cases, the financing responsibilities can be shared by different actors. For example: first, the developer builds the mini grid, then the mini grid is transferred through a **Purchase and Sale Agreement (PSA)** to a company created specifically to hold the assets and, finally, the Asset Company pays another company to operate and maintain the grid via an **Operating Services Agreement (OSA)**. The OSA stipulates operation and maintenance costs, customer services and tariffs, and insurances. Additionally, a long-term agreement to purchase energy between the developer (and owner) and the consumers is known as **Power Purchase Agreement (PPA)**.

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). The financing of energy use appliances can support the viability of solar mini grids, as they are key to increasing demand for electricity over time. For example, the developer may offer favourable loans, allow payment in instalments, or sell appliances at wholesale prices (Mulupi, 2015).

3.2 Customer tariff setting

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

Examples of application in the African context 2

Rubitec Gbamu Gbamu solar mini grid, Nigeria

The idea: Mini grid aiming to power agricultural processing in the rural farming community of Gbamu Gbamu. Additionally, the mobility company MAX is offering electric motorcycles, powered by the mini grid.

The technology:
- 85kWp capacity
- 600 households and small businesses served

The business model:
- Grant for pilot covered cost of distribution system, further funding via crowdfunding platform Bettervest
- Battery swap charging model for electric motorcycles

The impact:
- Uninterrupted energy supply
- Decreased use of petrol and diesel
- Mostly businesses are benefiting from the electrification

For further information visit:
→ www.rubitecsolar.com

4 Socio-economic and sustainability impacts

Solar mini grids are key to achieving reliable and affordable electricity in many African countries, and can potentially deliver many socio-economic development benefits (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 mini grids 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 (Figure 3).

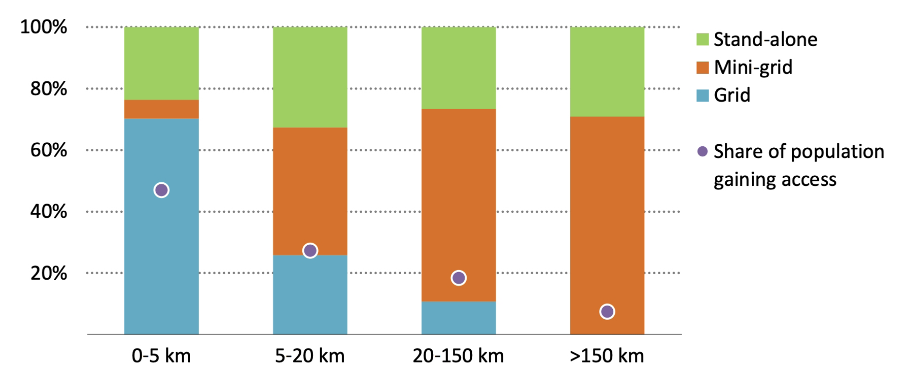
Solar mini grids bring specific benefits to businesses (e.g., higher productivity and improved working conditions), households (e.g., improved educational outcomes), and communities (e.g., electricity in local clinics). They will also play an important role in the promotion of electrified mobility (for more details, see "Sustainable e-mobility" factsheet in this catalogue). Examples around the world demonstrate that in order to realise and maximise the benefits of solar mini grids to the users, and to ensure their long-term viability, the users need to be involved at all stages of project development.

Mini grids have the potential to create high-quality jobs. 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 mini grids (IRENA, 2019). The creation of new value chains in mini grid component manufacture, distribution and maintenance is an additional source of employment (IRENA, 2022).

Solar mini grids displace the use of expensive and polluting diesel and petrol generators, with the corresponding reduction in local air pollution. They are also key to Africa's transition to a low carbon future. Although Africa is a minor contributor to global climate change (responsible for less than 4% of global greenhouse gas emissions), around 40% of its emissions come from electricity and heat generation (IEA, 2022).

Solar mini grids, 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 durability and repairability of solar mini grids and improve the management of the waste produced (for more information, consult the "Circularity in sustainable energy solutions" and "E-waste from solar off-grid solutions" factsheets of this catalogue).

Figure 3: **Share of least-cost choice for electricity connections by technology and distance in the sustainable Africa scenario, 2030** (IEA, 2022)



5 Scaling-up

With 590 million Africans still living without access to electricity, the mini grid sector has great market growth potential. According to AMDA (African Minigrid Developer Association), the major challenges to replicability and scalability of mini grids are the regulatory environment and the lack of finance. Approval processes are slow, taking an average of 58 weeks to get through regulatory compliance, with licensing taking most of this. This results in the slow growth of licensed mini grids 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).

The shortage of concessional funding (i.e., finance below market rates) and subsidies also 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 mini grid projects (ACE TAF, 2021).

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

6 Solar mini grids in SESA

Implemented in nine African countries, the EU-funded SESA project is developing and testing solutions to accelerate the energy transition 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 developing mini grids in their Living Labs. Their activities are briefly outlined below.

6.1 South Africa Living Lab

In the South African Living Lab, the activities are located in the Eastern Cape township of Alicedale and the semi-rural area KwaNonzwakazi on the outskirts of Alicedale. The main beneficiary of the activities is the low-income 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 the cost of transport. Furthermore, there is a lack of access to ICT infrastructure.

Within the SESA project, SESA partner uYilo is testing a containerized off-grid solar PV mini-grid with second-life battery stationary energy storage for community energy access and to charge a small fleet of micro electric vehicles. Additionally, Info Spots will be powered by off-grid solar units and provide free access to the internet.

6.2 Morocco Living Lab

Within the SESA project, the Moroccan Living Lab will develop and implement one off-grid solar minigrid to provide energy to 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

Examples of application in the African context 3

Sitolo solar mini grid, Malawi

The idea: 250 households, several businesses and public services connected. First project in Mchinji district likely to become the base of a multi-site mini grid including nearby villages.

The technology:
- 80kWp/950kWh
- Diesel generator as a back-up

The business model:
- Built, owned and operated by Community Energy Malawi Trading Ltd. (CEMT)
- Household tariff (USD 0.18), business tariff (USD 0.19) and social tariff (USD 0.09)
- CEMT also acts as the liaison with regulatory bodies in relation to compliance and trained local staff

The impact:
- 263k kWh delivered per year, reducing the equivalent of 178 tons of carbon dioxide emissions
- 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 batteries, a diagnosis facility will be installed. The overall objective of this Living Lab is to provide electricity that will enable social and business activities and serve as a model for replication in other parts of Morocco. The SESA partner implementing the activities is Green Energy Park.

6.3 Kenyan Living Lab

ESESA partner WeTu is developing innovative solar mini-grids as part of the SESA Kenya Living Lab. The main objective in this Living Lab is to demonstrate sustainable energy access solutions that are relevant for both urban and rural contexts in Africa, centred around solar PV off-grid electricity generation for multiple uses, e-waste management, and integration local Info Spots for digital access to information on energy, climate change and digital skills. The Living Lab comprises two project sites: Kasogi, a rural village in Homa Bay County, and Katito, a peri-urban community in Kisumu County.

WeTu has constructed and commissioned two solar hubs, each with a capacity of 36 kWp, in two different living lab locations: Kisegi, a rural site in Homa Bay County, and Katito, a peri-urban site in Kisumu County. The hubs are equipped with solar PV arrays, a hybrid inverter system integrated with swappable lithium -ion battery storage in the rural site, and a traditional SMA inverter system with deep cycle batteries in the peri-urban site. Additionally, charging stations to power various use cases have been installed, and a comprehensive balance-of-system (BoS) has been implemented to improve energy access in the two Living Lab locations.

7 Climate-proofing

Climate proofing is a term that refers to the 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 products and infrastructure. In order to achieve that, projects have to be screened for climate risks, vulnerabilities and opportunities early in the design stages.

Risk areas regarding the impacts of climate change on solar minigrids (European Commission, 2013; IAEA, 2019; Tecnalia, 2020; WBG, 2019) include:

- 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).
- Impacts to the distribution system, with higher line transmission losses and changes in transfer capacity of transformers that can increase the likelihood of outages or malfunction.

The climate-proofing of solar mini grids will depend on the specific location and context. However, measures that can be taken to increase the climate resilience of the system include:

- More robust design specifications to withstand extreme conditions.
- Select solar modules with small temperature coefficient, to ensure that efficiency is not greatly reduced with high temperatures.
- Select batteries and network components to withstand expected temperature ranges, and adapt their operation and maintenance procedures.


Unsplash / Moritz Kindler

8 Relevant tools and capacity building materials

HOMER "Hybrid Renewable and Distributed Generation System Design" Software

HOMER supports the design of generation, distribution, storage components of mini grids and evaluates their cost. It helps to optimise the sizing, operation and load management of utility-scale, distributed generation and standalone mini grids.
→ www.homerenergy.com

GEOSIM software

Geospatial rural electrification planning tool software 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 energy generation options is included.
→ www.ied-sa.com/en/products/planning/geosim-gb.html

Network Planner

Network Planner is a simulation tool to analyse least-cost electrification plans, powered by machine learning and geo-spatial analysis algorithms.
→ https://staging.okrasolar.com/network-planner

Mini grid 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"), feed-in tariffs for selling power into the main grid ("FIT-tool") and generation costs for different technologies. It can support the design of PPAs or joint ventures ("PPA tool") and determine average tariff levels for covering the costs ("Retail tariff tool").
→ http://minigridpolicytoolkit.euei-pdf.org/support-tools

Green Mini-grid Help Desk by Energy4Impact and INENSUS

In this help-desk, mini grid developers and policymakers can find practical information, including 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

Data platform including solar irradiation and temperature data for Africa, in monthly, daily and hourly intervals. Allows design of solar PV systems including different technologies and configurations (e.g., slope or azimuth angles, fixed or variable solar tracking). Can provide a report for estimated consumption and generation profiles of the system and the size of the energy storage system.
→ https://re.jrc.ec.europa.eu/pvg_tools/en

IRENA Global Atlas for Renewable Energy

Supports the evaluation of the national renewable energy potential of developing countries, including solar, wind, geothermal, bioenergy, hydropower, and marine technologies. For a selected location, it provides the annual and monthly irradiation, average wind speed, soil temperature, and suitable crop resource. 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 minigrids, by IRENA

The report describes measures to have in mind to accelerate mini grid deployment, such as existing national policy, cost recovery and tariff regulation, land rights, environment protection, technical assistance and financial support. Four case studies for off-grid mini grids in Africa are presented: Nigeria, Rwanda, Sierra Leone, Tanzania.
→ www.irena.org/publications/2018/Oct/Policies-and-regulations-for-renewable-energy-mini-grids

Renewable Readiness Assessment: Design to action, by IRENA

Comprehensive tool for assessing the suitability of conditions in different countries for the development and deployment of renewable energy. The RRA can also assist in attracting funds and leveraging support. IRENA can an assist in the implementation of the RRA findings.
→ www.irena.org/rra

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