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Ministry of Energy and Petroleum

What size shall it be?

A guide to mini-grid sizing and demand forecasting

The German Climate Technology Initiative
GIZ Promotion of Solar-Hybrid Mini-Grids

What size shall it be?

A guide to mini-grid sizing and demand forecasting

How to assess the electricity demand of a community and determine the appropriate size of a new solar mini-grid

August 2016

The German Climate Technology Initiative
GIZ Promotion of Solar-Hybrid Mini-Grids

Solar-hybrid mini-grids have the potential to bring development to rural areas and profit for the clever investor.

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Foreword

This handbook has been developed as part of a series of handbooks on mini-grids. After the publication of handbooks on site selection ("Where shall we put it?") and licensing ("How do we license it?") this handbook on load assessment and mini-grid system sizing is the third publication in the series. While the first two handbooks focused on the Kenyan context, this handbook is applicable to all the various geographical contexts where mini-grids can be implemented. Practical knowledge has been drawn from the authors' experience in mini-grid implementation in sub-Saharan Africa.

Most of the content of this handbook has general validity for load assessment and system sizing. However, the methodology for the actual sizing (Chapter 2) is based on the approach of the mini-grid builder, an online tool developed by GIZ ProSolar in 2015, based on the experiences made with load assessment and system sizing of a pilot solar-hybrid mini-grid in Talek, Narok County (Kenya). It should be noted that this is just one viable approach for system sizing, some others being mentioned in Chapter 3.

Adequate load assessment and demand forecast, as well as subsequent system sizing, is essential for the appropriate design of mini-grids. The economic viability of mini-grid projects depends on the size of the installed assets — and thus the investments — which need to be backed by a payable demand in the years after commissioning. A wrongly configured system (too small or too large) will either not serve its purpose or not recover the costs required to set it up. We thus deem it highly important to discuss demand assessment and mini-grid sizing in this handbook.

As it is easier to determine the size for capacity additions to existing schemes (e.g. hybridisation of existing diesel mini-grids with solar), this handbook focuses on the more challenging case of load assessment and sizing for new mini-grids in areas without electricity. Such 'greenfield' sites represent the larger share in terms of rural electrification opportunities. Furthermore, as solar-hybrid mini-grids are often the most viable set-up in the sub-Saharan context, the main focus of this handbook is on these systems.

While this handbook intends to display the required knowledge for systems sizing and demand forecast, mini-grid projects are very site specific. The authors of this handbook therefore do not accept any liability for commercial or investment decisions taken on the grounds of the knowledge presented within. It is recommended to always conduct a proper due diligence and closely collaborate with an expert to configure mini-grid systems appropriately.

Households or small business? Mini-grid projects are very site specific in terms of customer mix and power demand.

Acknowledgements

The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH ProSolar team would like to thank all partners that have been directly or indirectly involved with the production of this handbook. We express our gratitude to the Talek Power mini-grid team for their contribution, which helped to better understand mini-grid system sizing and the steps of demand forecasting. Our appreciation goes also to Reiner Lemoine Institute, which has greatly supported the project in compiling the information for this handbook. Furthermore, special thanks go to our valued partners at the Ministry of Energy and Petroleum, the Energy Regulatory Commission and the Rural Electrification Authority, as well as the county governments of Marsabit, Turkana and Narok counties in Kenya, for availing a suitable working framework for promoting renewable energies in the rural electrification space.

The GIZ ProSolar team

List of abbreviations

ABC-Model	Anchor-Business-Community Model
AC	Alternating current
ATP	Ability to pay
BOP	Balance of plant
Capex	Capital expenditure
COE	Cost of energy
DC	Direct current
GDP	Gross Domestic Product
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GPS	Global Positioning System
GW	Gigawatt
HOMER	Hybrid optimisation of multiple energy resources
IEA	International Energy Agency
IPP	Independent power producer
kW	Kilowatt
kWh	Kilowatt hours
LCOE	Levelised cost of energy
MW	Megawatt
NRECA	National Rural Electric Cooperative Association
PPA	Power purchase agreement
PV	Photovoltaic
RE	Renewable energy
RLI	Reiner Lemoine Institute
SHS	Solar home system
TWh	Terawatt hours
WACC	Weighted average cost of capital
Wh	Watt hours
WTP	Willingness to pay

Electrification rates throughout the rural areas of Kenya and sub-Saharan Africa are low. Mini-grids have emerged as a solution for rapid, cost-effective and high quality electrification in rural areas.

1. Introduction

1.1. Prospects for rural electrification

Electrification rates in sub-Saharan Africa are low and imply a major challenge for development despite untapped renewable energy potentials. It is estimated that 86% of people living in rural areas of sub-Saharan Africa have no access to electricity (see Figure 1) [RECP 2014].

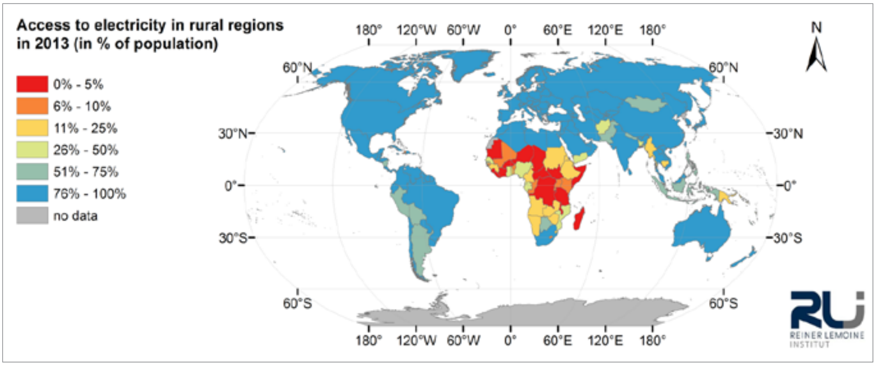


Figure 1: Global map displaying the access to electricity (in % of population) in rural areas for each country [illustration based on IEA 2015 & World Bank 2015]

The International Energy Agency (IEA) expects that by 2040 around 80 million people in sub-Saharan Africa will gain electricity access through off-grid systems and around 140 million people through mini-grids. This will require the development of between 100,000 and 200,000 mini-grids [IEA 2014]. These numbers highlight the necessity for developing off-grid and mini-grid systems, which often are the only feasible solution for the supply of electricity in rural areas of sub-Saharan Africa.

In order to successfully deploy such large numbers of decentralised supply systems and to develop financially viable projects, appropriate system sizing is crucial. The approach for demand forecasting and the guidelines for system

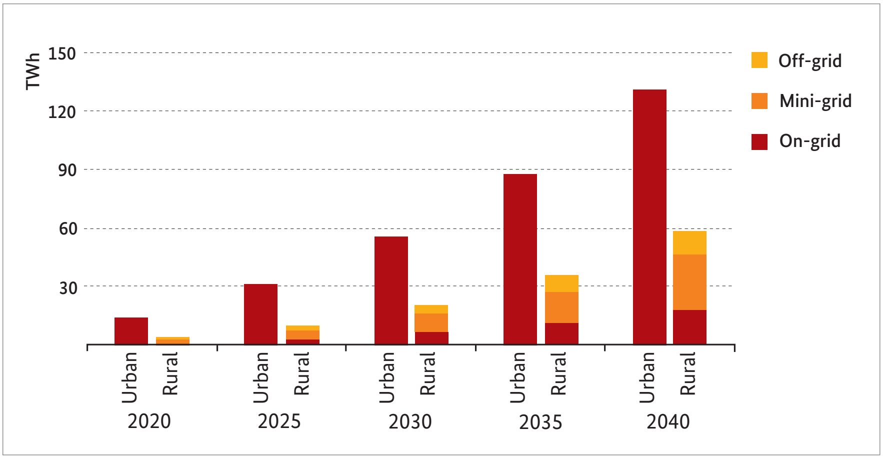


Figure 2: Electricity demand of the population gaining access to electricity in sub-Saharan Africa [IEA 2014]

sizing of solar-hybrid mini-grids provided in this handbook shall contribute to the enhanced electrification of rural areas through mini-grids in sub-Saharan Africa.

This handbook, which allows a quick understanding of demand assessment and system sizing for mini-grids, is divided into four chapters. Chapter 1 gives a basic introduction and overview about sizing mini-grids. Chapter 2 describes the sizing procedure for mini-grids, including a description of required data and information. The methods for the assessment of energy demand are explained in detail, and the correction of the assessed demand to the effective demand is discussed. Furthermore, forecasting energy demand and recommendations on system sizing are addressed. Chapter 3 gives an overview of existing system sizing tools, focusing on the mini-grid builder and HOMER (Hybrid optimisation of multiple energy resources). Chapter 4 entails a conclusion and some final recommendations to users of the tools and handbook.

1.2. Mini-grids and the relevance of accurate system sizing

A mini-grid is a set of small-scale electricity generators and possibly energy storage systems interconnected to a distribution network that supplies the electricity demand of a limited number of customers. It can operate in isolation from national electricity transmission networks and supply relatively concentrated settlements or remote industries with electricity. Mini-grids can be categorized by size as shown in Table 1 below.

Type	Size	Description
Type 1	**> 1000 kW**	Independent power producers (IPP) that are usually grid-connected and sell most of their power to an anchor off-taker based on a power purchase agreement (PPA).
Type 2	**100 kW – 1000 kW**	Delivered usually through a public model in which one authority is in charge of implementation of projects and a corporation is in charge of operation and maintenance.
Type 3	**< 100 kW**	Used in small but densely populated areas. They cover small radiuses with low voltage distribution. Some of them do not provide electricity at grid-quality level.

Table 1: Mini-grid categories for Kenya as defined by the Energy Sector Management Assistance Program [ESMAP 2016]

The quality of electricity provided by the mini-grid can be equivalent to that of the national electricity network. Nevertheless, for initial rural electrification, lower service levels (e.g. 4-8 hours of supply per day) can be considered in order to reach the first tiers of electricity supply as defined by IEA and World Bank [2015] (Table 2). Considering lower service levels (hours) can reduce the cost of mini-grids significantly.

		Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Peak capacity	Power		Very low power, minimum 3 watts	Low power, minimum 50 watts	Medium power, minimum 200 watts	High power, minimum 800 watts	Very high power, minimum 2 kW
	Daily capacity		Minimum 12 watt-hrs	Minimum 200 watt-hrs	Minimum 1.0 kW-hrs	Minimum 3.4 kW-hrs	Minimum 8.2 kW-hrs
Duration	Hours per day		Minimum 4 hours	Minimum 4 hours	Minimum 8 hours	Minimum 16 hours	Minimum 23 hours
	Hours per evening		Minimum 1 hour	Minimum 2 hours	Minimum 3 hours	Minimum 4 hours	Minimum 4 hours
Affordability					Cost of a standard consumption package of 365 kilowatt-hours per annum is less than 5% of household income		
Reliability						Maximum 14 dis-ruptions per week	Maximum 3 dis-ruptions per week of total duration less than 2 hours
Quality						Voltage problems do not affect use of desired appliances	

Table 2: Multi-tier framework for access to household electricity supply [adapted from IEA and World Bank, 2015]

The combination of photovoltaic (PV) systems with a diesel genset and/or storage system is a flexible and usually least-cost solution for rural communities willing to install a mini-grid for power generation. Depending on the operation mode and the components selection, high shares of PV-power can be realised with a diesel generator and/or a battery. The higher the shares of PV, the lower the dependence on diesel fuel and the influence of the diesel price on the levelised cost of energy (LCOE). Other options can include the implementation of small wind turbines, micro-hydro power and/or biogas plants.

Mini-grid operators need to cover their costs and a risk-equivalent return through revenues in order to be attracted to the mini-grid business. The accurate prediction of electricity demand with supply will result in stable revenues, which increases the financial viability of the project. A proper business model will include a tariff structure that is aligned with customer segments within the community. The tariff affects not only the financial status of the users but is also the major revenue for the mini-grid operator beside connection fees and, potentially, grants or subsidies.

The design of a mini-grid directly affects the cost structure of the project and determines not only the price of the energy produced, but also its quality. Lack of knowledge about the load conditions, electrical demand and future load growth during the sizing process can result in:

New vs. hybridized mini-grids
When it comes to sizing a mini-grid system, a distinction between greenfield and brownfield projects has to be made. In the first case, no central system for the electricity supply of the community exists, while in the latter there is a centrally installed and operated diesel generator in the community supplying connected customers with electricity, which can be additionally equipped with solar PV modules. This handbook focuses only on greenfield electrification, which is the most challenging case for demand projection and sizing of mini-grids.

- **Oversized mini-grid systems:** Oversizing a mini-grid results in increased investment and thus higher payback times, as well as higher operational costs and lower overall efficiency. Over-sizing the diesel generator often leads to an operation below the recommended load factor and a low efficiency range. Furthermore, operating the diesel generator below the stated minimum load results in increased maintenance costs, in many

Community involvement
The analysis of local conditions and the consideration of the community's needs at an early stage of the system sizing are advisable. Users' indications on their current electrical consumption and future needs are a key element in the design process of efficient off-grid systems. The involvement of the locals at all project stages increases the chances of success for the project as satisfied users extend the viability of the system. Local capacity building leads to increased skills on site and lower dependence on external know-how.

cases even permanent damage. Furthermore, the operational mode of an oversized system leaves no space for PV-power feed in and leads to unnecessary energy losses.

- **Undersized mini-grid systems:** Undersizing the mini-grid system results in an unreliable supply, leading to blackouts and reduced service quality. Unreliable supply will negatively affect customers and lead to a high dissatisfaction. Moreover, the technical components will suffer from the incorrect sizing, potentially leading to higher operation and maintenance costs of the system. Regulatory issues may also arise when it comes to payments of the defined tariff for the provision of electricity if service quality is low.

Since both cases lead to an incorrect operation of mini-grids and lower quality of electricity supply at higher costs, a detailed electricity demand assessment and accurate system sizing are crucial. Demand assessment has a direct impact on the size of the components and thus the investment costs. Considering the characteristic of the assessed demand profile, peak demand hours and load profile characteristics can be evaluated. This is crucial for the process of choosing the right components in terms of size and specifying the operation mode of the mini-grid. These steps are essential for the establishment of a successful business case. A viable business case, in turn, is a requirement for receiving appropriate financing for the project.

Maintenance of the PV panels at Talek Power mini-grid. The lessons learnt at Talek form the basis for this guidebook.

Lessons learnt from the Talek Power mini-grid

The Talek Power mini-grid is a pilot project set up in the Kenyan rural trading centre of Talek by GIZ ProSolar in close cooperation with the Narok County Government and German Agro Action. The mini-grid consists of a solar-hybrid generation power plant combining PV modules, battery packs and a diesel generator. The power plant delivers solar power to a rural business centre and the community through a mobile money-enabled prepaid metering technology. The pilot project tests the social and economic viability of mini-grids and serves as a learning scheme for stakeholders. The mini-grid has improved the lives of the people of Talek, fostering economic development, education and improved health.

The experiences made when developing the Talek Power mini-grid have been used to establish a methodology for mini-grid system sizing, which serves as the basis for this handbook. Many of the lessons learnt and recommendations displayed in this handbook are derived from the experiences made in Talek.

Name	Talek Power Mini-Grid
Owner	Narok County Government
Type	PV-battery with diesel back-up
Size	40 kWp PV 3210 Ah battery 12,5 KVA diesel generator (back-up)
Distribution	LV 3-Phase (3km)
Metering	Prepaid (mobile money enabled)
Commissioning	June 2015
Regulatory status	ERC licensed for 25 years
Connections	~ 220

2. Sizing a mini-grid

In the sizing process of a mini-grid, several factors and data need to be assessed before proceeding to the size selection of the components and the financial evaluation. It has to be highlighted that every village and community differs in terms of needs and conditions. Hence, there is not one standardised methodology that can be applied, but recommendations that can be used and adapted to specific cases.

The steps during the sizing process can be split into the demand assessment and forecast on the one side and the technical and financial analysis on the other. The described steps and actions to be taken are visualised in the flow chart in Figure 3. The demand assessment is the most critical step in the system sizing process of a mini-grid for a village or community. The results of the assessment have the highest impact on specifying the system size of the

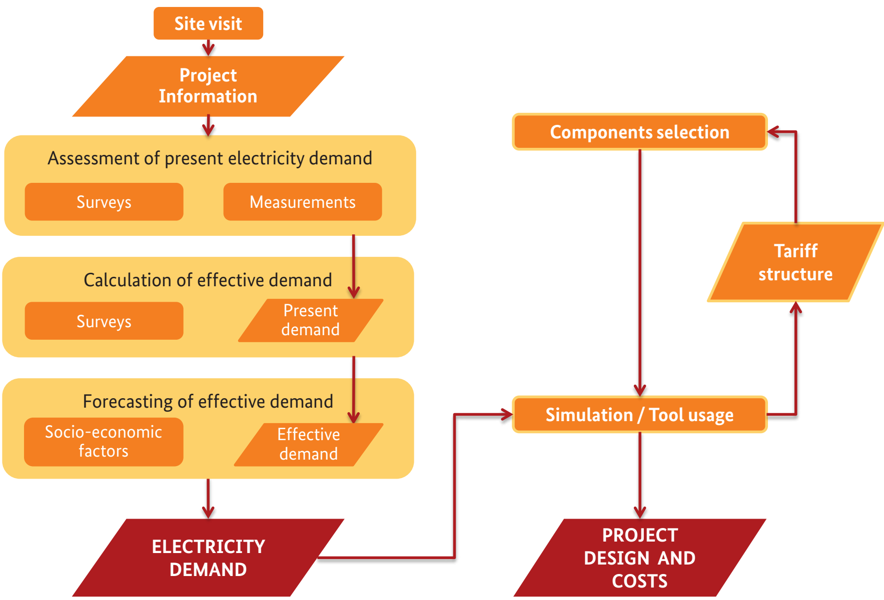


Figure 3: Flow chart of the sizing process

mini-grid. The various steps in this process are explained in the following sub-chapters 2.2, 2.3 and 2.4.

The end-product of the demand assessment is a load curve in kW over time. This is then provided as input to various simulation and sizing tools, which sometimes also require additional specific data and information. By making use of these simulation tools, a tailored technical design and financial modelling of the mini-grid can be provided.

Understanding electricity demand

Demand	The demand is the amount of power, measured in kW or MW, that the project area's loads require, and that the distribution company must provide [NRECA 2011].
Present electricity demand	The present electricity demand is the current electrical demand of all the inhabitants. Where the community is not yet electrified, the present electricity demand amounts to zero. If residents have solar home systems (SHS) installed or if a diesel generator is in place, their present electricity demand amounts to the size of their SHS and/or their diesel generator.
Assessed electricity demand	The assessed electricity demand is the amount of electricity that customers state they would use if there was electricity at this moment. It is assessed using surveys on site.
Effective electricity demand	This is electricity demand backed by the financial resources to pay for it. It is the demand that can actually be converted into money. Consumer 'effective demand' is determined through data acquisition and analysis of prospective consumers [NRECA 2011]. The willingness to pay (WTP) and ability to pay (ATP) influence the effective electricity demand.
Future effective electricity demand	Effective electricity demand in future years (e.g. 20 years from now). The forecast of effective electricity demand is estimated by using certain socio-economic development factors.

Table 3: Definitions of electricity demand used in this handbook

2.1. Initial project assessment

In order to proceed with the demand assessment and forecast or the system sizing, some information is necessary beforehand. Community- and customer-based data, which are specific to every project location, have to be assessed (see Annex 5.1). Firstly, general project information such as GPS coordinates, total number of inhabitants, current local diesel price, existing centralised power generation systems (i.e. installed diesel generator, size and operation mode), its location and distance to the consumers, as well as available land area for possible PV installation and its distance to the village, has to be compiled in order to proceed in the design and sizing process.

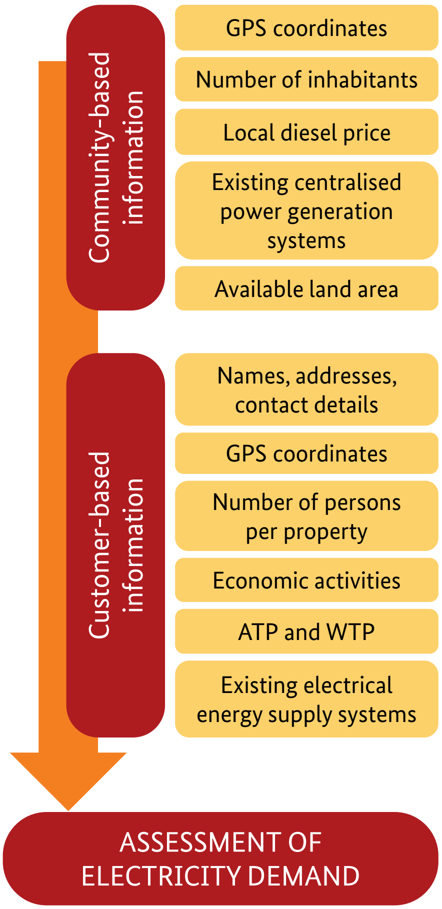


Figure 4: Initial assessment of a project site

Customer-based information also needs to be gathered; this is best done in an on-site survey. Customer-based information begins with recording the name, address and contact details. The GPS coordinates are helpful when it comes to determining the size of the mini-grid, extension of distribution grid and the connection costs of the customers. The number of persons living on each property and their economic activities are necessary for the classification into consumer categories. Classifying potential customers into the categories residential, commercial or industrial is very helpful to determine the market characteristics, the economic activities of the area, and later on the energy demand related to the productive utilisation of electricity (such as workshops, micro-industries, or agro-industries). Existing electrical energy supply systems (solar home systems, batteries, generators) and energy alternatives (kerosene, candles) that are currently used by the customers also need to be listed, since they impact the final energy demand. The source and amount of income and their ability to pay (ATP) can depend the season as well as their current energy expenses, depending on the energy type. These factors can contribute to the calculation of effective demand.

Furthermore, answers to standardised questions provide input to the calculation of willingness to pay (WTP). The best way to collect this information is through an on-site survey, which can also be combined with the data collection required for assessing the present electricity demand (Chapter 2.2).

2.2. Assessment of present electricity demand

The present electricity demand is the electrical energy consumed by the inhabitants at the time of the site visit. Where there are no electricity supply options, not even SHS, the present electricity demand amounts to zero. If residents have SHS installed, if a diesel generator is in place, or if there are solar lanterns installed, the community's present electricity demand amounts to the sum of the demand addressed by these systems.

Present electricity demand can vary

- Within a day, due to various customer types and their power-consuming activities
- Within a week, due to lower business activities on the weekend
- Within a year, due to seasonal effects in tourism and agriculture and weather conditions
- Due to individual circumstances such as power cuts, maintenance, availability of money etc.

In the case where there is no centrally installed power generation source, the present electricity demand is assessed based on the individual statements of the inhabitants participating in the site survey and is thus only an estimate. In this scenario, the assessed electrical demand does not include daily or monthly variations. The variance has to be considered through the application of certain factors (i.e. HOMER) or is neglected if the tool used only a daily load profile (i.e. mini-grid builder).

The present electricity demand is the initial set of information required for system sizing of a mini-grid. As shown in Figure 5, the present electricity demand (assessed with measurements or surveys) is complemented with information gathered from the on-site survey to get the assessed electricity demand.

Factoring in corrective factors such as ATP and WTP results in effective electricity demand (see Chapter 2.3). Finally, applying demand forecasting techniques delivers the future effective electricity demand (Chapter 2.4).

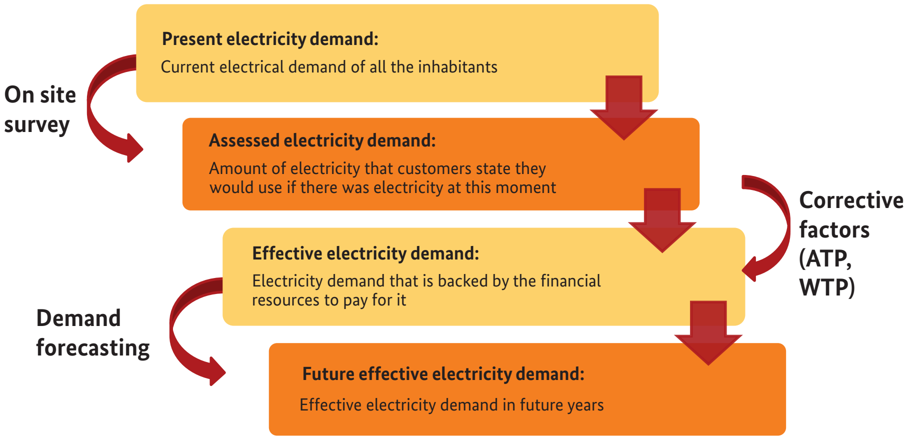


Figure 5: Steps in order to assess the (future) effective electricity demand needed for system sizing

2.2.1. Assessing electricity demand

To determine assessed demand, surveys can be carried out on site while making use of standardised questionnaires that should be filled out by potential customers of the mini-grid. While, ideally, information for every customer is recorded, sometimes a representative sample of the population can be sufficient, which can then be extrapolated. Depending on the method for system sizing that will be applied, various types of questions can be asked. A standardised questionnaire can be found under Annex 5.2.2).

Typical site assessment questionnaires contain a list with appliances, their power rating in watts and their daily use in hours. All the electrical appliances in the household, institution or business have to be recorded. Ideally the power rating can be found on the device itself, but typical ratings can also serve as an estimate. The time range states the duration of usage and at which time of the day the appliances are used. Especially for businesses and industries with high power consumption, the accuracy of the time range is essential.

Operating additional devices and plans for future business expansion impact the projected effective electricity demand (Chapter 2.4) and should also be indicated during the survey.

It has to be noted that all survey results should be viewed with caution. Participants may report false information (e.g. because they do not want to state their real financial resources) or overestimate their future demand. The corrective factors discussed in Chapter 2.3 can address some of these shortcomings, but others will have to be accounted for in the survey and data analysis phase.

Practical recommendations for conducting surveys

- Adequate time should be scheduled in advance as conducting surveys is a costly and time-consuming process
- A workshop or training before data collection is recommended in order to familiarise with the procedure and to avoid reporting errors
- Supervision by experts is recommended to assess the reliability of recorded data
- Information on demand has to be crosschecked and proper judgement must be applied, as interviewees often overestimate their (future) electricity demand
- A review and verification of the assessed data prior to the analysis is important in order to ensure a correct energy demand calculation

If developers plan to use the mini-grid builder for sizing a certain mini-grid, the use of the respective questionnaire (Annex 5.2.2) is highly recommended since it perfectly matches the input data required. If customised questionnaires are used for the survey, it has to be assured that the input data required by the sizing tool used are covered.

2.2.2. Calculation of average daily load profile

Once the data assessment of electricity demand is successfully completed, the data needs to be processed. For the aggregation of the digitalised data to the average daily load profile and the electricity demand of the community, different procedures can be followed. The appropriate approach varies, depending on the method applied for assessing the present electrical energy demand. Both of the following methods described make use of data collected during the site visit.

The electrical load profile is the electrical load on a certain time axis, which varies according to customer type, temperature and seasonal effects.

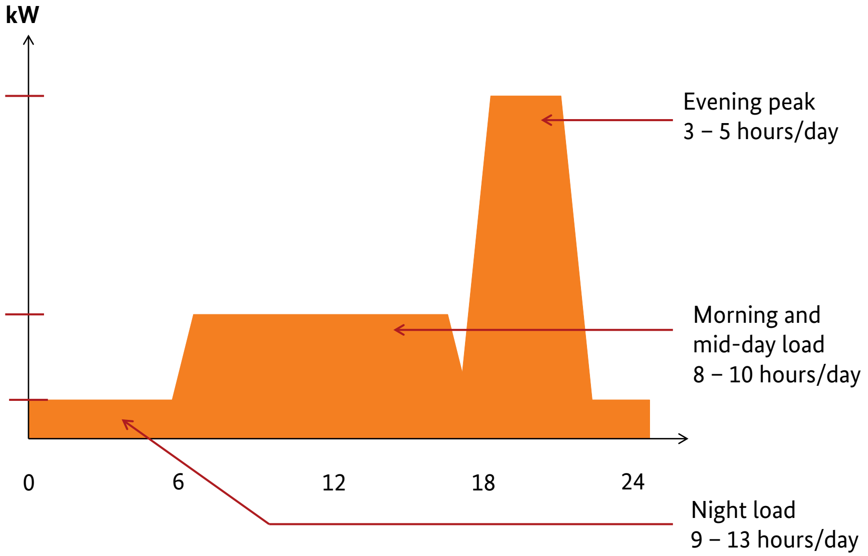


Figure 6: Typical daily load profile in rural areas [IEA 2013]

Once the average daily load profile is calculated, the peak load in kW, which is required for the load forecasting and plant sizing, as well as the energy demand in kWh for forecasted demand and revenue, can be retrieved. The load profile is needed for choosing the right components and determining the operation mode of the mini-grid. A typical daily load profile can be seen in Figure 6.

Individual approach

By processing the information collected during the site survey on amount and duration of use of the electric appliances of each customer and customer category, the total assessed electricity demand can be determined. The hourly aggregation of the power of all the appliances used by one customer will result in his/her typical average load profile [W]. Aggregating the load profiles of all customers of the same class will result in the average daily load profile per consumer category. The aggregation of the load profiles of all consumer categories results in the average daily load profile [kW] of the village, as shown in Figure 7.

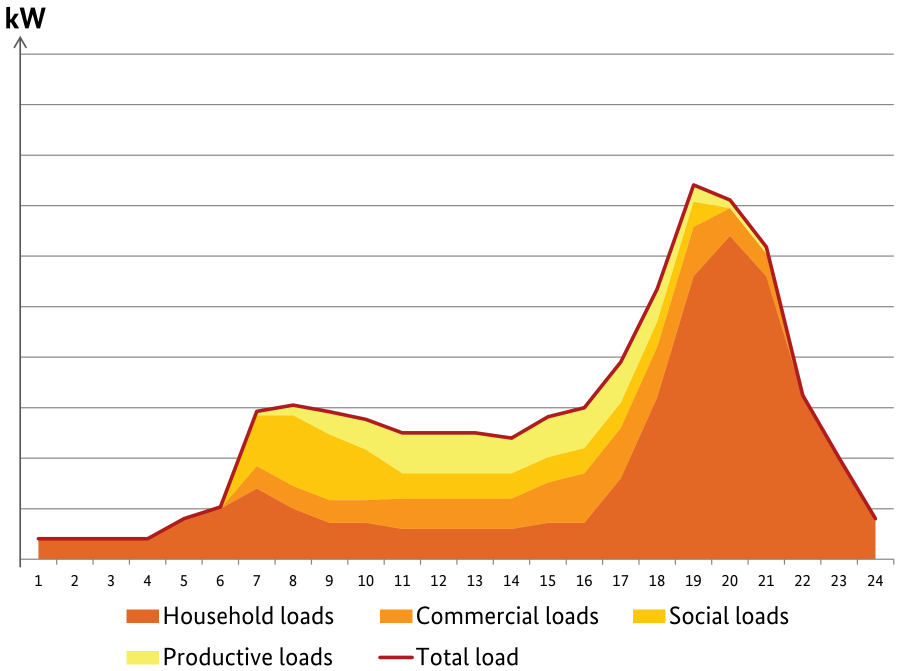


Figure 7: Demand analysis and aggregation of loads of all customer categories of the community [RLI 2015]

The daily electrical energy demand of all assessed appliances can be determined by multiplying the power of the appliances by the number of hours per day they will operate (utilisation factor). The result is the energy [Wh] consumed by the appliances per day.

Standardised approach

When making use of a standardised approach for the determination of the total electrical energy demand, typical daily electrical load profiles are deployed depending on the customer type. Households, institutions, hospitals, schools and industries have respective typical daily load profiles that can be retrieved from databases (i.e. mini-grid builder) and considered in the calculation. Through the number and type of customers that were assessed during the site visit, the respective load profiles can be aggregated to the total average electrical demand curve of the community. Typical standardised load profiles and typical sizes of existing power generation sources depending on the customer type are included in some tools (i.e. mini-grid builder) and are listed in Annexes 5.2.4. and 5.2.5.

This standardised approach is a simplified method for an initial rough calculation and estimation of the mini-grid size. The advantage is that it is less time consuming than the individual approach and needs less specific input data from the site, but this will lead to a less accurate outcome.

2.3. Effective electricity demand and its calculations

The assessed electricity demand is not accurate enough to be used for system sizing of mini-grids without further treatment, as indicated above. As illustrated in Figure 5, corrective factors account for uncertainties, and overestimation of demand and actual monetary resources. Economists define “effective demand” as the demand for goods and services that is backed by the resources to pay for them.

It is important to note, however, that the effective electricity demand is again only an estimate, calculated by multiplying the assessed electricity demand with certain corrective factors, which take into account WTP and ATP.

Willingness to pay (WTP)

WTP is “the maximum amount that an individual indicates that he or she is willing to pay for a good or service” [NRECA 2009]. Since the WTP varies for each customer, it can only be assessed through direct surveys. The WTP can be divided into two subcategories with two respective methods for assessing it:

The “expressed” WTP can be assessed by asking the potential customers what kind of services they want and how much they are willing to pay for them. This method often leads to overestimation by more than 50% as customers answer strategically [RECP 2014].

The “revealed” WTP can be assessed through asking questions on the current energy consumption and expenditure of comparable services. This method often results in underestimation of demand as electricity is seen as an enabler for more services compared to energy alternatives [RECP 2014].

WTP is very subjective because its calculation is based on the individual answers to qualitative questions. It is not a fixed value but strongly depends on the quality of service provided and the available alternatives [RECP 2014]. Limited knowledge about energy service strongly affects the final result.

Ability to pay (ATP)

ATP for modern energy can be estimated based on current expenditure in energy (kerosene, batteries, diesel, etc.) and the individual customers’ stated ATP per month, which is entered into the questionnaire in absolute values [GIZ 2015].

Knowledge about ATP allows for better determining the appropriate size of the system, and also for setting the electricity tariffs in better proportion to the customers’ needs and financial capacity. Non-payment of electricity tariffs can derive from lack of WTP because of bad service offered or from lack of ATP because of low income. In rural regions where many customers’ incomes depend on the harvesting season, temporary inability to pay can also be an issue.

Participants in a workshop calculate electricity demand using the online mini-grid builder tool.

Corrective factors

Initial assessed electricity demand estimates are in most cases very different from the effective demand, which is the payable demand. To design a commercially viable project, it is necessary to correct the load profile, which was derived from the assessed demand. For this adaptation corrective factors are introduced, based on WTP and ATP.

The corrective factors are aggregated to one corrective factor that is then accounted to the hourly present electrical demand.

Corrective factor		How to calculate demand	Explanation
C1	Current demand factor	The proportion of assessed demand willing to quit standalone schemes to the overall assessed demand. FORMULA: 1 – [Capacity of Installed SHS not willing to pay / Maximum demand]	C1 helps in adjusting the assessed demand by taking into consideration existing competing systems such as SHS, whose owners might not necessarily join the mini-grid. Experience shows that some users are happier with standalone systems and are not willing to join recurrent billing schemes. There is an intuitive correlation between C1 and WTP.
C2	Commercial demand factor	The proportion of the investment that can be reasonably collected based on the community's ability to pay. FORMULA: Overall cash that can be realistically collected / Investment required for the assessed demand	C2 helps in adjusting the system size based on the financial situation of the customers and considers their ATP for electricity. The numbers on the ATP stated by the customers during a site survey are transformed into a maximum serviceable demand that can be set in relation to the maximum assessed electrical demand of the community.
C3	Data collection factor	FORMULA: Total users/ sample size (in case only a certain percentage of the population has participated in surveys)	C3 assumes that not the entire population of the community participates in the data entry. A linear projection of the demand is done based on the assumption that the same type of consumers in the same type of social environment will tend to have in most cases the same type of consumption behaviour.

Table 4: Corrective factors and their explanation

Practical recommendations for calculating effective electrical demand

- As consumers sometimes state a higher or lower WTP than what is actually true, the results of the WTP have to be compared with the ATP
- Using the revealed WTP can contribute to better effective demand estimations.
- Comparison of the WTP and ATP data to the other information given in the survey, as well as similar projects, can result in improved results and help avoid sizing a system based on wrong demand estimations.
- There are various methods for taking into consideration WTP and ATP for calculating effective demand.

2.4. Forecasting effective demand

When sizing a financeable and long-term viable mini-grid, future growth in the effective electricity demand has to be considered. While various socio-economic methods for demand forecasting are available, accurate forecasting remains a significant challenge. A very rough forecast of the effective demand can be done through applying a range of linear growth scenarios (often used are around 20 – 40% of assessed electrical demand) to generate a general idea of how demand may look in future years. The factors that can reflect forecasting are very site-specific and can be categorised as follows:

- **Population development:** A growth in population leads to an increased demand.
- **Economic productivity:** Economic growth in the area will result in a growing demand. Trends on the GDP progress of the community over the past years can be used to indicate future trends.
- **Typical consumption patterns:** Changes in lifestyle and financial status, as well as statements on planned number of appliances in the next years, can also give hints on the increase of effective electrical energy demand over the next years. Expenditure increases per capita due to energy cost savings or increased productivity are expected after the installation of the mini-grid. They can lead to a change of behaviour resulting in a growth in energy demand.

All these factors can lead to an increase in electricity demand over the next years. The above factors can be categorised into two demand growth factors for rural communities:

- **Growth of the consumer base:** This growth can be assigned to population growth on the one side and the gradual connection of consumers on the other side (electricity penetration rate).
- **Growth in energy consumption for each category (kWh consumed per consumer-year):** This growth reflects the increased customers' consumption, for example through increase in productive activities. The energy consumption for public lighting can also be assigned to this category and will potentially grow with progressing infrastructure development.

The quantification of these factors can either be expressed in absolute numbers (power demand projection in kW for each year of the analysis) or as a relative percentage (% growth per year). The calculated load-growth per year is added on top of the effective demand. Considering the customer categories and their respective electrical energy demand curves, individual load growth factors can be projected to each segment.

Forecasts should be extended to at least five years after the system's installation date. Forecasts of the evolution scenario after a certain number of years will be necessary for defining the sustainability of the chosen design of the project.

Variation of scenarios

When determining the load growth factor of a community, it is a common procedure to develop three scenarios of electrical energy demand growth over five years and evaluate these with respect to their impact on the financial viability and tariff calculation. This would substitute the detailed analysis of the different load growth influence factors.

- The optimistic scenario expects an increase of 40% per year on the assessed load profile.
- The average/ realistic scenario sees an increase of 20% per year on the assessed load profile.
- The pessimistic scenario foresees no future increase in demand.

Designing systems with the average scenario helps keep the balance between initial financial requirements and future cash flow projections.

The challenge with demand forecast comes when assessing the power demand for the near future in rural areas where people do not have personal experience with electricity, and thus to accurately estimate demand growth over time [RECP 2014].

In rural areas, the challenge lies in assessing the future power demand of people who have not had personal experience with electricity.

Practical recommendations for demand forecasting

Based on an evaluation of the technical and commercial performance of the Talek Power mini-grid, installed in June 2015 in Narok County, Kenya, the following practical recommendations can be derived:

- It was important to determine a mini-grid project size based on a two- or three-year forecast of effective demand, rather than on the assessed demand or projections of the present demand. This helped the project see cash flows aligned with its payback expectations.
- It takes due diligence to properly assess the current demand factor (C1).
- Corrective factors in the demand estimate exercise are meant to help implement commercially viable projects. There are site specific considerations that require applying a sound judgement. For instance, an anchor customer stated at the feasibility study stage that he is already going standalone. The effect of this statement was additional non-serviceable demand in project commissioning. It is recommended to remember that system sizing is site specific.
- Most demand-side management challenges can be addressed by sound planning during the operation and maintenance phase. In the case of Talek Power mini-grid, new connections were done only after validation of the customer's load. Load limitations were applied to all customers upon assessing their specific requirements at connection stage.
- Productive use should be monitored. Observations showed that welding shops were operating late at night when the system was supplying energy from the storage system. A way of monitoring such big loads was with timers and relays, since it was not possible to limit the energy consumption from a regulatory perspective.
- The number of new connected customers was high in the first months of the project implementation, which was due to stepwise connection of customers who had already signed up before project commissioning. Since initial cost of connection is relatively high, some potential customers take the time to save in order to connect to the system. This effect can be considered in the demand growth of the first years after project implementation.

2.5. System sizing and design

Once the basics in demand assessment and forecasting are understood, the interested party can proceed to the system sizing. Depending on which tool is being used, various specific input data will be needed. A general mapping of this input data and the source of the information is listed in the next section. Figure 8 describes the general process when it comes to sizing PV-diesel-battery hybrid mini-grids.

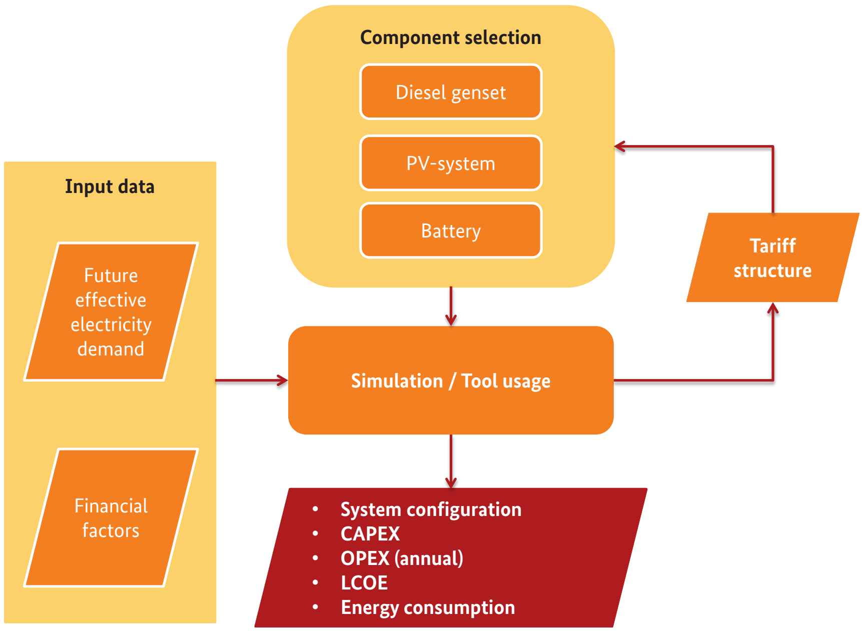


Figure 8: Flow chart describing the process of system sizing

Additional data and information required for sizing mini-grids

For sizing and designing a mini-grid appropriately, data and information have to be collected on site. This collection should be done in parallel to the initial demand assessment. An overview of required data and how to assess the information is given in Annex 5.1. and 5.2.2. Additionally to general project information and the information needed for the energy demand assessment, some financial information is needed, such as the weighted average cost of capital, annual fuel escalation, investment costs and operating costs and some further factors.

Relevance of load profile

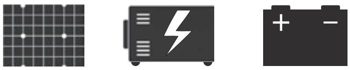
Independent of which sizing, simulation and perhaps even optimisation tool is used, some operational methods and their characteristics need to be known beforehand. The operational strategy of the system will also define the system design. A detailed examination of the assessed demand and the generated load profile are the first steps in order to define the suitable operational strategy and choose the right components. The following data is to be considered when sizing and designing mini-grids:

- Average total daily energy required (kWh)
- Time and value of the average peak power (kW) during the day — PV-systems contribute to power generation and average demand levels
- Time and value of the average peak power (kW) during evening and night hours — diesel generator contributes to power generation
- Energy consumption during evening and night (low base load, kWh)

This handbook addresses three possible models for mini-grids, with special focus on solar-diesel-battery systems. The typical operation modes are illustrated in Figure 9.

PV-battery with diesel back-up: In this setting, the battery is the central element for the cost of electricity over the lifetime of the system. Large shares of PV-power combined with the battery can make the system almost independent. Usual system designs consider three days of autonomy of the system. The diesel generator is used as back-up to ensure quality of service when solar power generation and the state of charge of the battery are low or when demand is especially high. Energy management systems can maximise the lifetime of batteries and reduce overall project costs (due to lower replacement costs).

PV-diesel: This is the lowest cost option in terms of initial investment. Quality of service (voltage and frequency provision) is ensured through the permanent operation of the diesel generator at all times of existing demand. The solar power contributes during daytime while ensuring that the operation criteria of the diesel generator are not violated. An energy management system is connected to ensure the efficient and cost-effective operation of the diesel generator during times where power is generated from the PV-system.



PV-diesel-battery systems:
This setting includes the battery to increase the efficiency of the overall system. In periods of low loads (i.e. during nights) the battery can cover the demand. During daytime the PV-system and the diesel generator contribute to power generation. Excess energy due to overproduction of the PV-system and constraints of the operational limits of diesel gensets, like minimum load requirements of the diesel generator and stability criteria, is used to charge the battery. In this case the battery is not designed for several days of autonomy of the system, which also reduces its size and therefore also the investment costs. Since this system setting is acceptable in terms of investment cost and cost of electricity, considering the service provided, the handbook focuses on this operational model.

The optimisation of the operation mode should target the efficiency of the diesel genset and battery operation, resulting in the prolongation of their operational life. The load factor of the genset and the cycling of the battery are important factors in this matter and have a strong impact on the sizing and life cycle cost of the system [IEA 2013].

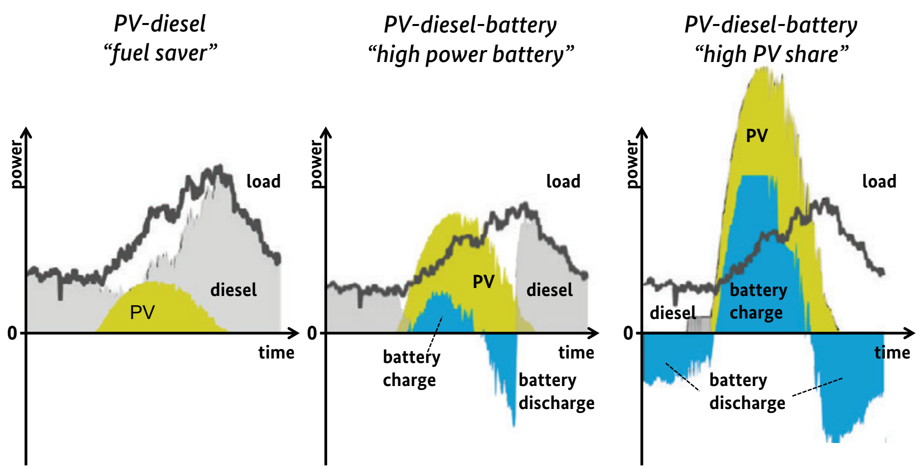


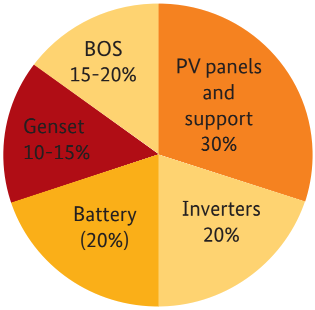
Figure 9: Illustration of different operation modes of hybrid systems, adapted from [Fricke 2015]

Practical guidelines for system sizing

In order to assure the viability of the produced results, the following practical guidelines for sizing can be used to cross-check and validate the results. They apply when it comes to sizing and operating PV-diesel-battery hybrid mini-grids and were developed based on previous experience with installed systems and operators expertise. Some of the most common and important rules are listed below [adapted from IEA 2013]

Component	Rule of thumb
PV array sizing	Able to supply more than 40% of the daily load at year 1
Diesel genset sizing	Peak load demand in high season at last year of load forecast (year 5)
Battery sizing	According to excess PV energy at year 1 and energy required during low load periods at year 5
Multifunctional inverter Rectifier component specification	Charge control able to maximize battery lifespan
Inverter component sizing	According to load level during periods when there is not sufficient solar supply and load is too low for efficient genset use, for high season at year 5
Diesel genset operation	No (or limited) periods with load factor below 40 % (minimum load)
Battery operation	40% maximum depth of discharge (DOD), optimising battery lifespan

A PV-diesel-battery hybrid system design should not only be technically efficient but also optimised according to economic and finance perspectives. Complex optimisation algorithms have been implemented in various design and simulation tools, some of which are listed and explained in Chapter 3.



A typical cost structure of PV-diesel-battery hybrid mini-grid systems is shown in Figure 10. Some tools include default values as cost suggestions, which can be adapted (i.e. the mini-grid builder, see Chapter 3.2) and others only consider the users' input.

Figure 10: Typical cost structure of a PV-diesel-battery hybrid mini-grid [IEA 2013]

Options for energy demand management

When it comes to the installation of mini-grid systems in rural areas, managing the electrical demand and using electrical energy in an efficient and cost-effective manner are important not only for operation, but also for sizing the mini-grid correctly. Managing the electrical energy demand of the consumer can be achieved through various methods such as financial incentives or changing behaviour through education. It can mean shifting loads from peak periods to off-peak hours, but also increasing the energy efficiency (Table 5).

Load shifting	Annual peak demand	Shifting the customers demand during few hours of the year where the highest demand for electricity is recorded
	Daily peak demand	Shifting the customers demand during approx. one hour of the day where the highest demand for electricity is recorded
Energy efficiency	Usage of less power for same tasks	Reducing the demand permanently by using more efficient appliances and lights

Table 5: Explanation of load shifting and energy efficiency

The options and ambitions of the system operator for achieving demand management have to be considered when determining the right size of a mini-grid.

Setting the right tariff

Various models for client segmentation in the course of mini-grid implementation in rural communities exist, with the Anchor-Business-Community (ABC) model being the most established one. The ABC model splits the customers into three categories as shown in Figure 11. Anchor customers of a mini-grid can be telecommunication towers, mines, agricultural and processing industry, tourism lodges etc.

The A(nchor) – B(usiness) – C(ommunity) Model

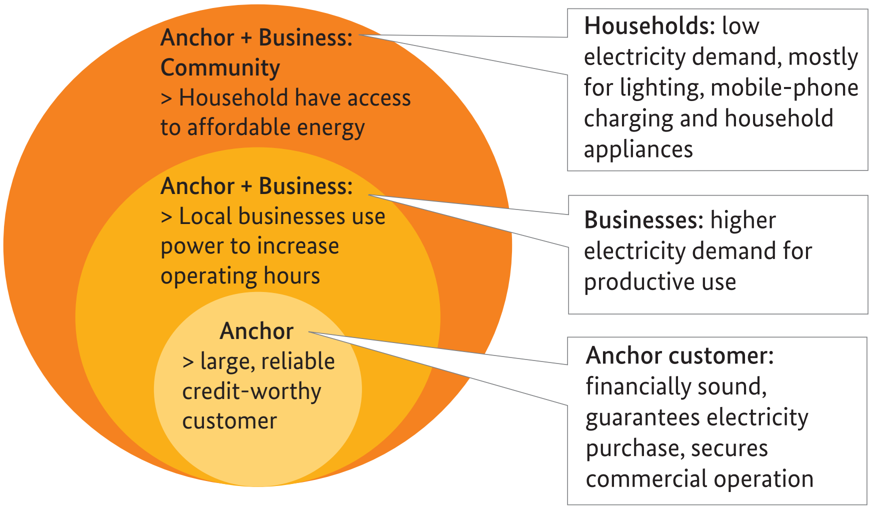


Figure 11: The Anchor - Business - Community Model [GIZ]

While other sizing or simulation tools do not make any suggestions on applicable tariffs in the community, the mini-grid builder suggests three scenarios for possible tariff structures:

- **Uniform tariff:** Households, businesses and anchor clients have the same rating in the tariff calculation and pay the same amount per kWh.
- **ABC tariff:** Households and businesses have a low weighting factor while the anchor clients have the highest weighting in the tariff calculation.
- **ABC tariff with maximum household discount:** In this case households receive a significantly lower weighting factor, while businesses and anchor clients get a higher weighting factor.

Defining an acceptable tariff structure for the residents of the rural community is crucial for the financial viability of the project. If the chosen tariff structure is too high and not applicable for the community, it will lead to defining a different operation mode of the system and selecting new components. An optimised tariff will finally lead to the project design and cost structure of the mini-grid project.

Defining a tariff structure that is acceptable for the residents of the rural community is crucial for the financial viability of your project.

3. Tools for system sizing

Validating the steps of electricity demand assessment and the technical and financial analysis with tools that have complex algorithms is necessary to increase the success and viability of the project. For mini-grids there are a variety of tools with different functionalities, some of which are introduced below.

3.1. Overview of existing tools for system sizing

Commercial simulation and optimisation software such as HOMER Energy or self-developed tools as used by research institutes already exist. The scope of these tools, as well as the range of technological and economic conditions they take into consideration, vary broadly. In this section some of the most known tools are introduced and their suggested usage and accuracy of results are discussed.

The **mini-grid builder** is a tool developed by GIZ. Its scope is to deliver a standardised approach towards the load assessment, sizing of generation capacity and financing aspects of mini-grid projects. An initial mini-grid project in Talek, Narok County, has already been implemented based on this approach and was commissioned in July 2015.

The **HOMER Pro**® microgrid software by HOMER Energy is the global standard for optimising microgrid design in all sectors, from village power and island utilities to grid-connected campuses and military bases. Originally developed at the National Renewable Energy Laboratory (NREL), and enhanced and distributed by HOMER Energy, HOMER (Hybrid Optimisation Model for Multiple Energy Resources) nests three tools in one software product, so that engineering and economics work side by side [HOMER 2016].

The **SMA Sunny Design** was developed by SMA Solar Technology AG and allows the user to receive an optimum PV system configuration based on the required data entered.

	Mini-grid builder	HOMER Pro	Sunny Design
Software	Dimensioning	Simulation / Optimisation	Dimensioning
License	Free	License required	License required
Purpose	Survey-based electrical energy demand assessment and sizing of mini-grids	Simulation of micro-power systems	Design of off-grid systems
Considered components	Diesel-PV-battery	Diesel genset-PV-Wind-Battery	Diesel genset-PV-Battery (only SMA components)
Economics	LCOE	LCOE	LCOE
Time step	1 hour	1 minute to 1 hour	Depending on own data
Demand forecast	Yes, user based	Yes, based on percentage	No
Consider meteorological/ irradiance data	Yes	Yes	Yes
Sizing recommendation	One system configuration	Optimised scenario	One system configuration
Determines CO_2 savings	No	Yes	Yes

Table 6: Overview of existing tools for system sizing

Since SMA Sunny Design only uses SMA components for sizing and therefore does not analyse financial conditions or further components, this report focuses on the mini-grid builder and HOMER Energy, which are explained in detail in the next sections.

3.2. Description of mini-grid builder

The mini-grid builder (www.minigridbuilder.com) is a publicly available tool that allows interested parties to enter data from site surveys into a database and perform calculations on the energy demand and thus the required generation capacity. It further includes financial aspects and gives the user an initial project budget and initial tariff recommendation.

The tool's special focus and distinctive feature is that it uses data collected during site surveys, a categorisation of this data into consumer categories and correction of the load with corrective factors.

The tool is divided into sections including:

- **Getting started:** creation of a new user account or proceeding with an existing account
- **Project overview:** the user can start a new project or edit an existing one by entering a project ID
- **Load profile:** this section is split into multiple pages, where the user has to fill out one page for each customer who participated in the survey, according to the answers they gave
- **Financial factors:** this section allows to enter financial data
- **Report:** the user gets a report for the location containing information about the final load profile, the system sizing and financial aspects

All data is stored in the database and can be retrieved for further review and changes.

A special feature of this tool is that ATP and WTP are considered in the electrical demand correction and forecast. In the mini-grid builder approach the customers can state their WTP by answering certain questions. A factor

The mini-grid builder's distinctive feature is that it uses data collected during site surveys, so it is important that the information collected is accurate.

indicating the WTP of the customer can be calculated from the given answers. The mini-grid builder does not carry out a simulation or optimisation. The sizing of the components and system design are based on the hourly electrical load profile for one typical day. Furthermore, a basic financial calculation is carried out using the input variables. Default financial values are provided in case the user does not have this information (see Annex 5.2.3). The default values are based on the pilot project in Talek, Kenya. Data regarding financial investment factors can be retrieved from persons who have market knowledge or from recent literature. Investment costs can be provided by persons who have knowledge of the costs of the equipment or from manufacturers.

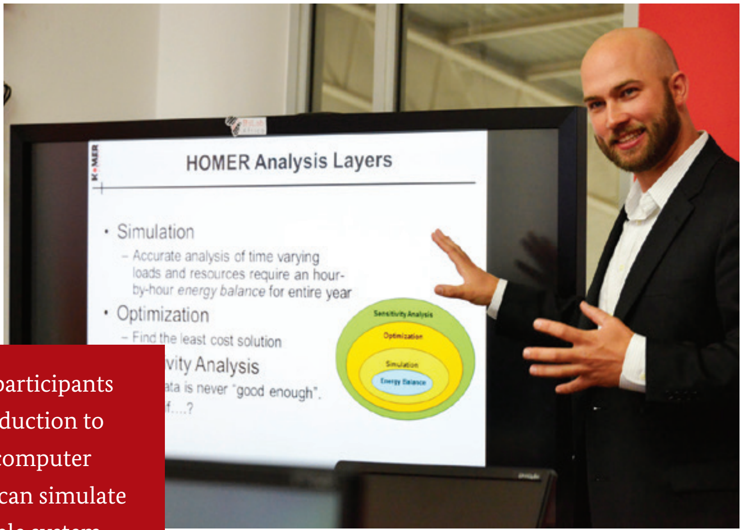
The final output from the mini-grid builder is the report, where the results of the system sizing are provided. An explanation of the output of the mini-grid builder is given below.

The user can also export the result as a PDF document, in case he or she wants to compare multiple project locations or present the results to the investors or the community.

While the mini-grid builder is a useful tool to assist developers to design mini-grids, neither the website nor the developers of the tool assume any

Type of result	Explanation
Results from initial load assessment	The generated electrical load profile from the site visit and the questionnaires. It is listed per customer category and also as a hourly load profile for the community.
WTP	Distribution of WTP over the percentage number of customers. The result is a weighted total average indicating the community's WTP.
ATP	Gauss-distribution of ATP for electricity on a monthly basis. The result is divided into the categories and five groups of monthly energy expenses.
Corrected load profile (future effective electrical demand)	The total electrical demand of the community, with corrective factors applied.
Technical design	Details on sizing of the electrical system, annual production of generating assets, global solar irradiation on site and the energy balance of plant.
Project costing	Overview of assumptions and inputs, as well as information on investments, expected annual operating costs, and LCOE (of PV, gensets and total LCOE).
Tariff model	Overview of energy consumption per consumer category, as well as tariffs according to different tariff schemes.

Table 7: Output of the mini-grid builder



Workshop participants get an introduction to HOMER, a computer model that can simulate many possible system combinations.

liability for investment decisions made on the grounds of the mini-grid builder output. Investors are advised to make their own due diligence and independent assessment prior to any investment decision. The tool only facilitates a first level feasibility assessment.

3.3. Description of HOMER Energy

The HOMER Micropower Optimisation Model is a computer model that can simulate many possible system combinations of the equipment that the user wants to be considered in order to finally have a viable system setting for the hybrid mini-grid.

An assessed load profile can be imported into the tool via a CSV-file, with the time step being automatically detected. The load profile can either be synthesized from one or more 24-hour load profiles, or a data-file containing time series for the whole year can be imported. In the first case, a different 24-hour load profile can be entered into the tool for each month of the year or even a one weekday profile and one weekend profile for each month of the year. In the case of a data file, the complexity of the data is defined by the user.

Type of result	Explanation
System configuration	Overview and simulation of all possible configurations as specified by the user
Component size	Size of components depending on the system configuration
Initial capital costs	Initial capital costs [$]
Operating cost	Operating costs per year [$/yr]
NPC	Total net present cost [$]
COE	Cost of energy [$/kWh]
RE - Fraction	Renewable fraction on energy generation [%]
Diesel consumption	Diesel consumption of the generators per year [l/yr]

Table 8: Output of HOMER

The user has to define the system configuration and can choose between various components that are stored in the database. The diesel generator, PV-system, battery type and AC/DC bus have to be specified. The latest version of HOMER can also simulate a grid-connected system while indicating the availability of the grid in hours of the year and the percentage of power blackouts. Depending on the location, specified appropriate irradiation data is retrieved from the National Aeronautics and Space Administration (NASA) database for simulating the solar yield.

The simulation is carried out for one year for the specified time step (from one minute to one hour). HOMER not only simulates the behaviour of the various components, but the behaviour when they act as a system (system dispatch). The dispatchable power sources (generator, battery) are operated in a cost minimising way. An important aspect of dispatch strategy in a generator/battery/PV-system is whether to charge the battery with the generator; this can be specified in the programme [Homer 2016].

Depending on the user's optimisation variable, the tool sorts all possible system combinations. Least cost options are simulated with the algorithm implemented in HOMER Pro.

The outputs of a HOMER Simulation are shown in Table 8 on the previous page. The programme also gives the possibility to show the results graphically.

In summary, HOMER is a powerful simulation tool for designing and simulating hybrid mini-grid systems. It provides valuable information to evaluate several options both technically and financially for off- and mini-grid systems for remote and stand-alone applications. The added value comes with allowing the user to consider a large number of technology options to account for energy resource availability and other variables.

The high cost of a HOMER Pro license must be considered. A trial version exists, but it is only active for 30 days. When it comes to developing new projects, a full license is recommended.

4. Conclusion

The following key points summarise the most crucial aspects of this load assessment and sizing guidebook:

- Correct sizing is essential for successful business models.
- Site assessment, electricity demand assessment, calculation of effective demand and demand forecast are essential steps for sizing a viable mini grid.
- A powerful database is the most essential input to any sizing or simulation tool for defining the size, operation mode, project costs and tariffs for a mini-grid system in rural areas.
- The inclusion of the local community at all stages of the project's development is crucial for its successful implementation.
- While load assessment methods and sizing tools can give a better picture of what a viable system design might look like, they are only based on estimates and thus do not guarantee a successful project.

> Include the local community at all stages of the project's development. It is crucial for successful implementation.

5. Annex

5.1. Required information for load assessment and system sizing

5.2. Mini-grid builder

5.2.1. Introduction to the tool and its outputs

5.2.2. Standard load assessment questionnaire

5.2.3. Default financial values

5.2.4. Standardised load profiles per customer category

5.1. Required information for load assessment and system sizing

Information category	How to assess information
Project information	
GPS coordinates	During assessment of project location
Country	
County	
Name of village	
Total number of inhabitants	
Diesel price	
Available land area (size, distance)	
Existing infrastructure (roads, distance to grid, etc.)	
Energy demand assessment	
Customer information	On site survey
Name, address (GPS coordinates), contact details	
Number of people living on premises	
Economic activities – customer type	
Current energy sources (SHS, battery, generator, other)	
Energy alternatives used	
Amount of income	
Current energy expenditure, ATP, WTP	
Electrical appliances of user	
Financial information	
Financial investment factors (WACC, annual fuel escalation)	Literature / tool
Investment costs (cost of solar PV, batteries, diesel generator, BOP, connection cost, additional project cost)	From manufacturer / literature / tool
Operating costs (maintenance, cost of diesel fuel, annual cost increase, annual plant maintenance)	On site survey / literature / tool
Other factors	
Annual increase of demand, annual PV power output reduction	Literature / on-site survey / tool

5.2. Mini-grid builder

5.2.1. Introduction to the tool and its outputs

The tool can be accessed at http://minigridbuilder.com/. In order to use the tool it is required to create a user account with login data, to prevent inappropriate usage.

The tool is divided into sections as shown in Figure 12. The data and information listed in this section are based and retrieved from the FAQ and How To sections of the mini-grid builder [GIZ 2015].

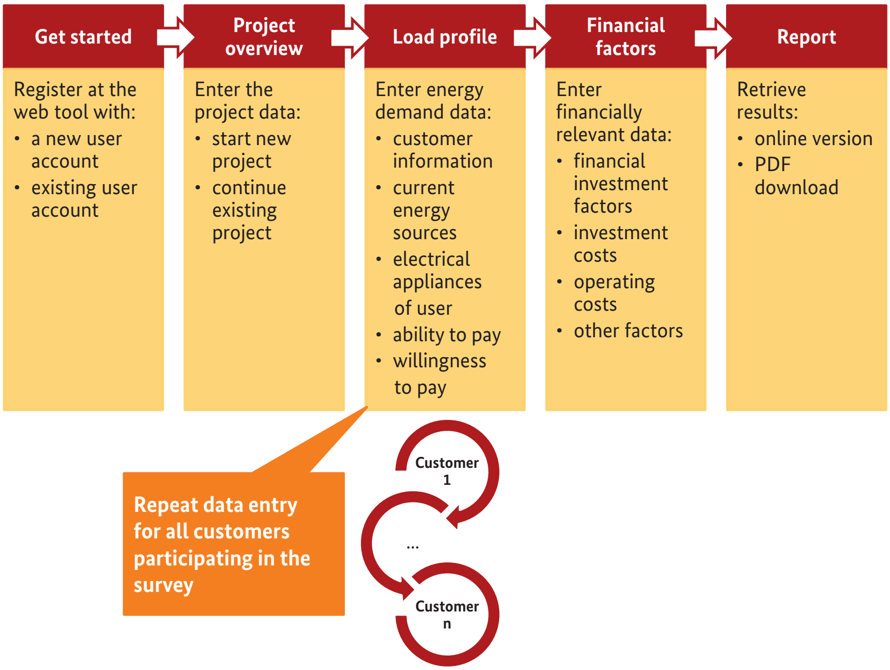


Figure 12: Graphical illustration of mini-grid builder and data required

Section 1: Get started

In this section the user has to register or, if he or she already has an account, log in, providing the information shown below:

New user account	When using the mini-grid builder for the first time, the user has to register providing the following data: • Name of user, name of company, position of user • Address, phone number, email • User name and password
Existing user account	When the user already has an account, he or she needs to log in providing: • User name or email address • Password

Section 2: Project overview

In the project section, new projects can be generated. Each user only has access to their specific projects. Every project receives a project ID, which is unique and allows the user to retrieve the provided information, but also to adapt or change values later in the process. Furthermore, the country's currency should be selected here, as this will be used later in the tool for further calculations (in the following examples, the currency used is USD).

Start new project	In order to start a new project, the user has to provide the following data: • Notes/project information • GPS latitude and longitude • Country, county and village/ community name
Continue existing project	When the user already has a project, the ID number of the project has to be selected

Section 3: Load profile

In this section, information can only be entered after an initial project has been set up. The load profile section has to be filled out for every customer who participated in the site survey. It consists of five sections. The following data and answers to the questions have to be entered:

Customer information	General information for mapping the customer data to the questionnaire: • Serial number • Name and contacts • Type of customer * Household * Business * Anchor client • GPS coordinates • Choose between manually entering the load profile or using a standard load profile
Current energy sources	Enter the sizes of current energy sources: • Solar home systems [W] • Battery capacity [Ah and V] • Installed generator power [W or VA] • Other energy source consumption [l/month of diesel/kerosene]
User electrical appliances	Enter the electrical appliances of the user: • Appliance type (light bulbs, audio, video, fan, fridge, computers, mobile phone, pump/motors, others) • Number of appliances • Power of each appliance [W] • Start and end time of usage range

Ability to pay	Enter ATP related data: • Occupation • ATP per month for energy [USD/kWh] • Income per month [USD] • Current energy expenditure per month [USD]
Willingness to pay	Enter the answers that were given by each user: • What is important to you? • What most likely will drive you to connect? • Will electricity improve your life or business somehow? • On which basis do you think the provision of electricity should be? • Who decides for you to pay for electricity? • Do you already have an individual solar system? • How satisfied are you with your current electricity supply? • Does your solar system cover your current electricity needs?

Section 4: Financial factors

The financial factors input page is divided into four sections. These factors can be either specified by the user, depending on the specific location, or the default values provided are used.

Financial investment factors	Enter financial investment factors: • Weighted average capital cost [%] • Annual fuel escalation [%]
Investment costs	Enter typical investment costs of the components of the mini-grid system: • Cost of solar PV system [USD/kWp] • Cost of batteries [USD/kWh] • Cost of diesel generator [USD/kWe] • Overall cost of electrical balance of plant [USD/kW] • Connection cost [USD/customer] • Additional project cost (e.g. SCADA or Fuel Save Controllers) [USD/kW]
Operating costs	Operating costs that are necessary input values are: • PV plant maintenance (% of capex [USD/yr]) • Annual diesel maintenance cost [USD/yr] • Cost of diesel fuel [USD/litre] • Overall annual operating cost increase [% USD/yr] • Annual plant maintenance – incl. staff [USD/yr]
Other factors	Further costs that have to be keyed in by the user are: • Annual increase of demand [%] • Annual PV power output reduction [%] caused by degradation of the modules

Section 5: Report

The results of the system sizing are provided in the report section of the mini-grid builder. The results can be retrieved online through the browser or downloaded as a PDF document. The information is listed in tables or visualised in graphs, and includes the data listed below:

Results of report	The report includes the following data and information:
	• User/site data
	• Input summary and assumptions
	• Results from load assessment
	• Willingness to pay and corrective factor
	• Ability to pay
	• Corrected load profile
	• Technical details
	  * Sizing of the electrical system
	  * Annual production
	  * Global irradiation on site
	  * Energy balance
	• Project costing
	  * Assumptions and inputs
	  * Investment
	  * Annual operating cost
	  * LCOE
	• Tariff model
	  * Uniform tariff
	  * ABC tariff
	  * ABC tariff with maximum household discount

5.2.2. Standard load assessment questionnaire

Name of village		Date:	Questionnaire number:
Type of electricity consumer	Household ☐ Business ☐ Institution ☐ Anchor client ☐		
Reference data	Street number:	Household number:	

Consumer data			
Name	Phone number		Other
Number of persons living in the premise			
Energy for productive use, activity type (tick the box)			
Barber	Welding		Retail kiosk
Salon	Chemist		Boutique/tailoring
Mobile charging	Restaurant/food kiosk		Pub/bar
Small industry	Lodge		Other:
Sources of income			
	Income source	*Amount (low season)*	*Amount (high season)*
1			
2			
3			
4			
	TOTAL:		
Stated ability to pay			
		In low seasons	In high seasons
Amount per month			

Current energy expenses	
Type of energy	*Expenses per week*
Diesel/fuel	
Kerosene	
Candles	
Batteries	
Battery charging	
Mobile phone charging	
Firewood	
TOTAL	

Electricity needs of the consumer					
Nr	*Appliances*	*Power (in W)*	Number of appliances	Daily use (in hours)	Range used: (time, from-to)
1	Light bulbs (8-20)				
2	TV (45-120)				
3	Radio/CD (20-60)				
4	Phone (2-5)				
5	Fan (45-60)				
6	Fridge (80-150)				
7	Computer (45-200)				
8	Pump/welding				
9	Others:				
		TOTAL:			

A link to the standard questionnaire can be found at http://www.minigridbuilder.com/faq/

Planned load and demand forecast (only if the consumer plans to stay in the village the next 2 years)						
	Planned appliances	Number in 1 year	Number in 2 years	Number in 3 years	Number in 4 years	Number in 5 years
1	TV					
2	Fridge					
3	Air conditioner (1500-2200)					
4	Fan					
5	Radio					
6	Phone					
7	Computer					
8	Light bulb					
9	Iron (1000-1500)					
10	Others:					

Willingness to pay				
		Please tick one option		
1	What is important to you?	The cost of electricity	The quality of electricity	The duration of the supply
2	What will most likely drive you to connect?	Neighbours connected	Own need for electricity	Low connection fee
3	Will electricity from a mini-grid improve your life or business somehow?	Yes	No	Don't know
4	On which basis do you think the provision of electricity should be ?	On a free basis	On a commercial basis	
5	Who decides for you to pay for electricity?	Myself	My boss	Elders/Familly
6	Do you already have an individual solar system?	Yes	No	Under consideration
7	How satisfied are you with your current electricity supply?	Very satisfied	Not satisfied	Can live with it
8	Does your solar system cover your current electricity needs?	Yes	No	Percentage (if partially):

5.2.3. Default financial values

The following default financial values are are provided by the mini-grid builder. While they give a good first indication of values, they should be updated to match the framework conditions within which the system is being designed.

Financial investment factors		
WACC	9	%
Annual fuel escalation	5	%
Investment costs		
Cost of solar PV-system	1750	USD/ kWp
Cost of batteries	400	USD/ kWh
Cost of diesel generator	650	USD/ kWe
Overall cost of electrical balance of plant	300	USD/ kW
Connection cost	800	USD/ customer
Additional project cost	200	USD/ kW
Operating costs		
PV plant maintenance	5	% of capex (USD/ year)
Annual diesel maintenance cost	5000	USD/ year
Cost of diesel fuel	1.35	USD/ litre
Overall annual operating cost increase	3	% (USD/ year)
Annual plant maintenance – incl. staff	3000	USD/ year
Other factors		
Annual increase of demand	5	%
Annual PV power output reduction	0.8	%

5.2.4. Standardised load profiles per customer category

The mini-grid builder gives the user the option to use standard load profiles for the projection of the electricity demand. However, especially for businesses and anchor clients, it is highly recommended *not* to use a standard profile but to determine the load profile individually.

The typical load profiles for each category of user of electrical appliances.
For more information, go to http://www.minigridbuilder.com

	Appliance	No. of appliances	Power per appliance [W]	Usage range 1		Usage range 2	
				Start time	End time	Start time	End time
Typical household	Light bulbs	2	12	6:00	8:00	18:00	22:00
	Audio	1	20	0:00	0:00	18:00	22:00
	Video	1	40	9:00	12:00	15:00	19:00
	Fan	1	50	7:00	8:00	19:00	23:00
	Fridge	1	120	0:00	24:00	0:00	0:00
	Computers	0	180	0:00	0:00	0:00	0:00
	Mobile phone	2	5	0:00	8:00	0:00	0:00
	Pump/motors	0	0	0:00	0:00	0:00	0:00
	Others	0	0	0:00	0:00	0:00	0:00

The typical load profiles for each category of user of electrical appliances (continued from previous page). For more information, go to http://www.minigridbuilder.com

Typical business	Light bulbs	1	20	6:00	12:00	14:00	20:00
	Audio	1	20	0:00	0:00	18:00	22:00
	Video	0	40	0:00	0:00	0:00	0:00
	Fan	3	50	7:00	12:00	14:00	20:00
	Fridge	3	120	0:00	24:00	0:00	0:00
	Computers	1	180	8:00	12:00	14:00	20:00
	Mobile phone	2	5	8:00	12:00	14:00	20:00
	Pump/motors	0	0	0:00	0:00	0:00	0:00
	Others	0	0	0:00	0:00	0:00	0:00

Exemplary anchor client	Light bulbs	4	20	6:00	8:00	18:00	22:00
	Audio	1	20	0:00	0:00	18:00	22:00
	Video	20	40	0:00	0:00	20:00	22:00
	Fan	15	50	7:00	8:00	19:00	23:00
	Fridge	5	120	0:00	24:00	0:00	0:00
	Computers	6	180	8:00	12:00	13:00	18:00
	Mobile phone	20	5	0:00	0:00	23:00	5:00
	Pump/motors	2	300	0:00	24:00	0:00	0:00
	Others	0	0	0:00	0:00	0:00	0:00

Bibliography

Fricke, D. (2015): "Qinous Energy Solutions: PV Hybrid in Off-Grid and Mini-Grid solutions". Presentation given in Manila, October 2015.

GIZ (2015): Mini-grid builder: Web-Based Mini-Grid Tool. Available from http://www.minigridbuilder.com/ [accessed 21 June 2016]

HOMER (2016): Homer Energy Support Knowledgebase. http://support.homerenergy.com/index.php?/Knowledgebase/Article/View/272/90/10070---dispatch-strategy [Accessed: 17th June 2016]

IEA (2015): *World Energy Outlook 2015.* International Energy Agency, Paris, France. Available from http://www.worldenergyoutlook.org/weo2015// [accessed: 17 December 2015]

IEA (2014): *Africa Energy Outlook 2014.* International Energy Agency, Paris, France. Available from http://www.worldenergyoutlook.org/africa/ [accessed 15 June 2016]

IEA (2013): *Rural Electrification with PV Hybrid Systems.* International Energy Agency, Paris, France. ISBN: 978-3-906042-11-4

IEA and World Bank (2015): *Sustainable Energy for All 2015—Progress Toward Sustainable Energy 2015.* World Bank, Washington, DC. Available from http://www.se4all.org/sites/default/files/l/2013/09/GTF-2105-Full-Report.pdf [accessed 15 June 2016]

IRENA (2015): *IRENA Off-grid Renewable Energy Systems: Status and methodological issues.* International Renewable Energy Agency (IRENA) Innovation and Technology Centre, Bonn, Germany

NRECA (2011): *Guides for Electric Cooperative Development and Rural Electrification,* NRECA International, http://www.nreca.coop/what-we-do/international-programs/

RECP (2014): *Mini grid policy toolkit.* European Union Energy Initiative Partnership Dialogue Facility (EUEI PDF), Eschborn, Germany

SDGH (2014): *Solar/Diesel Mini-Grid Handbook.* Power and Water Corporation (PWC), Darwin, Australia

World Bank (2016): Current Activities and Challenges to Scaling up Mini-Grids in Kenya. Energy Sector Management Assistance Program (ESMAP). World Bank, Washington, DC.

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The German Climate and Technology Initiative
GIZ ProSolar – Promotion of Solar-Hybrid Mini-Grids
Westcom Point 5th floor
Mahiga Mairu Road, off Waiyaki Way
PO Box 41607
00100 – Nairobi, Kenya
T +254 20 2731826/28/34
E jasmin.fraatz@giz.de
I www.giz.de

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Peta Meyer / Tara Consultants Ltd
E info@taraconsult.com

Photo credits
All photos ©GIZ by Alex Kamweru
except pages 30 and 48 by Eric Gitonga

Authors
Dr. Philipp Blechinger (RLI)
Elisa Papadis (RLI)
Martin Baart (Ecoligo)
Pierre Telep (GIZ)
Florian Simonsen (GIZ)

GIZ is responsible for the content of this publication

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The German Climate and Technology Initiative
GIZ ProSolar – Promotion of Solar-Hybrid Mini-Grids
Westcom Point 5th floor
Mahiga Mairu Road, off Waiyaki Way
PO Box 41607 – 00100 Nairobi, Kenya
T +254 20 2731826/28/34
E jasmin.fraatz@giz.de
I www.giz.de