RENEWABLE ELECTRIFICATION OF REFUGEE CAMPS

Phase 1 Final Report

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SWECO

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Project manager	Anders Ellegård
Authors and contributors	Anders Ellegård, Christian Holtz, Mikael Andersson, Linda Dyab, Anna-Maria Roslund, Magnus Lindén
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Note on units	This report follows the recommendations of the International Standard Organization (ISO) when representing units and numbers: A comma on the line is used as the decimal delimiter, and a space as the thousand delimiter. References: ISO 80000-1:2009: Quantities and units Part 1 Resolution 10 of the 22nd meeting of the CGPM (2003) General Conference on Weights and Measures

1 SUMMARY

The possibilities to provide electrification for refugee camps and host communities were investigated. It was concluded that full coverage of all energy needs would be difficult or costly to satisfy with local renewable sources. It was found that cooking is by far the largest energy demand and would require large energy storage capacity or very strict demand management.

The most feasible solution would be to aim for less than full coverage, with central electricity supply for a selection of larger consumers, such as camp administration, health services, water pumping and commerce connected through an electricity mini-grid. Households would have to be satisfied with independent energy solutions.

A host community can be connected on similar conditions, i.e. serving larger consumers with an extended mini-gid, while most household cooking uses would be served through individual solutions.

The most applicable energy sources for the mini-grid would be solar photovoltaic arrays, possibly in combination with wind turbines and with a reasonable storage capacity in the form of batteries. Backup power sources would be diesel generators.

For households there is some hope that solar PV based cooking systems can provide the energy required for daily cooking, and some illumination services. Backup for cooking would remain wood and charcoal.

If individual solar PV based solutions for households are found not to be feasible, then it is concluded that liquid petroleum gas (LPG) is the most feasible alternative. It is the most widely and technically mature alternative, and less polluting than any biomass fuel.

The present energy systems in a refugee camp with 50 000 persons using wood and charcoal for cooking, and diesel-generated electricity for administration and services is estimated to emit about 26 000 tons of CO_2e per year. With a fully renewable energy system the current emissions would be zero. However, even if cooking remains with LPG, emissions would still be reduced to one tenth of the present, or about 2700 tons CO_2e. The pattern remains the same in a lifecycle perspective, although total emissions are much higher.

A solution for refugee camp and host community with a limited mini-grid for electricity for administrations, commerce and services and individual solutions for household cooking would require two financial set-ups: A power purchase agreement for the mini-grid electricity, and a subsidised leasing mechanism for household cooking. This would have to take into account the need for subsidies of different customer groups.

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ABBREVIATIONS LIST

AC	Alternating current, such as in large networks
CAPEX	Capital Expenses, investment cost
COO	Chief Operating Officer
CSO	Chief Sales Officer
CSP	Concentrated Solar Power
DC	Direct current, such as in batteries
DM	Demand management
DNI	Direct Normal Irradiation
DP	Displaced Person
GSMA	GSMA Mobile for Development Foundation, Inc. Created in 2007 to demonstrate the positive social impact of mobile technology
ha	Hectares. 1 ha = 10 000 m^2, equivalent to a square 100*100 m.
HTF	Heat transfer fluid
HVO	Hydrogenated Vegetable Oil
IRENA	International Renewable Energy Agency *https://www.irena.org/*
ITP	Australian and New Zeeland company *https://itpau.com.au/expertise/technologies/csp-solar-thermal/*
Jiko	Stove (*Kiswahili)*
kV	Kilovolts, thousand volts
kW	Kilowatts, unit of power
kWh	Kilowatt-hour, unit of energy. 1 kWh = 3,6 MJ
LED	Light-emitting diode. Very energy efficient source of light.
LPG	Liquid Petroleum Gas (Propane or Butane)
LV	Low voltage, 110-250 V
m^2	Square meter
MJ	Megajoule, unit of energy. 1 MJ = 0,28 kWh
MV	Medium voltage, usually 10-20 kV
MW	Megawatts, million watts
MWAC	Megawatts alternating current
O&M	Operation and Maintenance
OPEX	Operating expenditures, running costs
PAYG	Pay as you go, pre-payment
PIC	Products of Incomplete Combustion
PPA	Power Purchase Agreement
PPP	Public-Private Partnership
PV	Photovoltaic
SSA	Sub-Sahara Africa
UNHCR	United Nations High Commission for Refugees *https://www.unhcr.org/*
UNITAR	United Nations Institute for Training and Research *https://unitar.org/*
WB	World Bank. One of the Bretton Woods institutions.
WFP	United Nations World Food Program *https://www.wfp.org/*

2 BACKGROUND

Refugee camps pose demands on many resources in their surroundings, including energy resources. This causes depletion of forests and can create tension with host communities. In order to investigate if renewable energy can be used to ease these demands and tension, Sida has initiated a project to investigate renewable electrification of refugee camps, including host communities. The objectives are to:

- Propose designs of mini-grids with renewable-energy sources and technologies
- Propose financing mechanisms that are attractive to suppliers/contractors
- Promote clean cooking practices

The target scale for the investigation is a "sample" refugee camp with about 50 000 inhabitants and a host community of roughly the same size, located in Sub-Saharan Africa (SSA)

In October 2020, Sida requested proposals for a project to analyse technical and financial opportunities for efficient electrification of refugee camps and surrounding communities. Briefly, the objectives of an initial phase were to:

- Propose electrification solutions with mini-grids based on renewable energy sources and technologies
- Promote clean cooking practices
- Propose financing mechanisms that are attractive to suppliers/contractors

In subsequent phases, provided the results prove feasible, the objectives will be to:

- Identify and propose solutions for a specific, identified refugee camp in SSA
- Prepare a pilot project for implementing the proposed solution

Sweco was selected to provide the services. This report is the first draft report of the first phase. The methods used, apart from the consultant's knowledge and experience, have been:

- Interviews and discussions with members of the organisations, institutions and companies engaged in humanitarian aid, refugee-camp management and energy provision in SSA.
- Analyses of reports and publications regarding energy issues in these circumstances
- Qualitative multifactor assessment of the various conditions, energy sources and technologies
- Creating theoretical scenarios for energy supply to a refugee camp

According to current estimates, more than 90% of refugees in camps have limited access to electricity.[1] More broadly a lack of energy makes it difficult for them to cook, keep warm, learn, work or find their way around at night while also exposing them to various safety and health risks.

A lack of clean energy results in many refugees burning firewood or charcoal to meet their critical household needs, while community and support facilities are often fuelled by diesel generators. All these sources of energy have considerable environmental and financial costs.

[1] UNHCR 2019

3 THE ENERGY SITUATION IN A REFUGEE CAMP

Refugees have the same needs as all other people, but are constrained by crowding, location and scarcity. We have made assumptions on the need for energy for various purposes, and come to realise that by far the largest energy requirement is for household cooking, which dwarfs all other energy needs.

If all the energy needs are to be supported by renewable energy sources, then very large systems need to be put in place, for electricity generation as well as for load management (storage).

One way to overcome this would be by introducing demand management, which might reduce the peak loads somewhat.

Another option may be by not including cooking energy in the renewable electric grid, but to provide cleaner cooking options with other sources.

In order to outline an adequate system for the provision of energy in a refugee camp that can also serve a host community, it is necessary to understand the various conditions that can be encountered in a refugee "camp", and of course the different patterns of energy use that are encountered. The understanding of refugee camp reality was obtained largely from reports and discussions with representatives of Sida, WFP, UNITAR and UNHCR, see section 12.1, page 67.

3.1 A refugee camp

There is no general concept as "a refugee camp", since all gatherings of displaced persons are specific with respect to size, ethnicity and location as well as the reason for being displaced, such as war, drought, flooding, ethnic cleansing etc. The population of a camp can be as small as a few thousand persons, and up to several millions. The displacement can be inside a country, or across a border to another country. The location can be within populated areas or even cities, or it can be in isolation in remote areas. The ethnicity of displaced populations can be different to that of the host community, or it can be the same or similar. Sometimes host populations may refer to the displaced persons as "our brother and sisters", and sometimes they are seen as threats or even enemies. The education levels of displaced persons range from illiterate to university-degree holders. The camp can be long-term and can have developed into a full city with all amenities, or it can be short-term with the displaced persons living embedded in the host population, sharing their conditions and forms of livelihood. The displaced persons can be engaged in income-earning activities similar to those of the host population, or they can be forbidden to even work. Aid agencies supporting the refugees can work according to the principle of distributing free hand-outs, or they can favour market mechanisms. Camps can be make-shift and temporary, lasting for a few months in an emergency, to permanent, lasting for seventy years or more. The host governments can be supportive of the development of infrastructure in a camp, seeing that such infrastructure can help develop parts of their countries currently underserved. Other host governments can counteract such development, for fear of permanenting the refugee situation. Regarding energy provision, there are institutional aspects such as the legal framework for energy generation and distribution; whether private or cooperative initiatives are allowed in these respects, and if so, how far-reaching they can be.

All this variation shows that it will be very difficult to come up with a solution of the type "one size fits all". In this preliminary phase of the project, the aim must, therefore, be to try and identify the most important common issues and features that electricity provision in a camp can contribute to solving. This will be followed by more detailed descriptions of how to provide it.

3.2 Electricity demand

Electricity demand will vary from refugee camp to refugee camp depending on local habits and accessible powered appliances. Figure 1 gives an indicative picture of how large the electricity consumption can be, depending on what powered appliances each household possesses.

Figure 1 Energy demand per household grouped by the use of powered appliances

	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Indicative appliances powered	None, only kerosene lamps or candles	Task lighting + phone charging or radio	Tier 1 + general lighting + fan + television	Tier 2 + medium power appliances	Tier 3 + high power or continuous appliances	Tier 4 + heavy or very high-power appliances
Daily energy use per household		Minimum 12 Wh	Minimum 200 Wh	Minimum 1.0 kWh	Minimum 3.4 kWh	Minimum 8.2 kWh
Typical technology		Solar lighting kits	Standalone or home solar system	Generator or mini-grid	Generator or grid	Grid

In most refugee camps there is little provision of electricity, except for the administration of the camp, which is supplied with high-quality electricity, usually from a diesel generator. Individual households and small commercial enterprises in the camp, as well as in host populations, may have a solar home system to service lower loads. Some camps have larger solar arrays capable of providing more capacity and energy. But by far the largest demand for energy is for preparing food, which is not usually done with electricity. This is also one of the targets of the present assignment – providing clean cooking energy, in a context where the total demand for energy is substantial.

The cooking-energy requirement is what underpins the creation of a mini-grid, as all non-cooking requirements can be satisfied adequately with solar home systems. If cooking is not included, a grid is more costly, less versatile and more technically-demanding than solar home systems

In order to determine the energy demand, we have to make assumptions of consumption patterns and extents, since the use of electricity for cooking is very rare in refugee camps as well as in rural Africa in general. In the present section we are drawing on data from Rwanda, as provided in Practical Action, 2020.[2]

- A majority of households (58%) either have no lighting at night or use only basic sources such as candles and torches.
- Small proportions primarily rely on solar lanterns (21%) or solar home systems (16%) for lighting
- 24% of people in Rwanda with grid connections and 5% have off-grid access.
- Mobile phones, torches and burning sticks are commonly used when moving around the camps at night.
- Solar home systems provide four hours of lighting in the evenings – 45 minutes more than solar lanterns and 90 minutes more than non-electrical sources such as candles.
- Solar home systems provide around 10 hours of electricity in total during the day, compared with around 4.5 hours for solar lanterns when used for lighting and other basic services such as phone-charging.

[2] *Practical Action (2020) Ensuring refugee camps in Rwanda have access to sustainable energy, Rugby, UK: Practical Action Publishing.*

- Households who paid for solar products (lanterns) were less likely to suffer quality or service problems than those who received solar products as donations.

In order to outline possible demand curves, we have made the following basic assumptions:

- Size of camp: 50 000 persons @ 5 per household = 10 000 households (HH)
- Electricity demand for cooking: Hotplate @ 1,5 kW for 2 hours/day = 3 kWh/day/HH = 30 000 kWh/d
- Electricity demand for lighting: 0,2 kWh/d/HH (4*10 W LED lights @ 5 h 7 d) = 2 000 kWh/d
- Electricity demand for entertainment: 0,17 kWh/d (LED TV, cell-phone charge, radio) = 1 700 kWh/d
- Camp administration: 1 500 kWh/day/15 000 person-size camp = 5 000 kWh/d
- Camp street lighting: 1 light @ 80 W per 2 households for 12 h/night= 400 kWh/night

This comes to a total of nearly 40 000 kWh per day. By far the largest individual demand is for electric cooking. Without it the total demand is about 10 000 kWh, where half is for the camp administration.

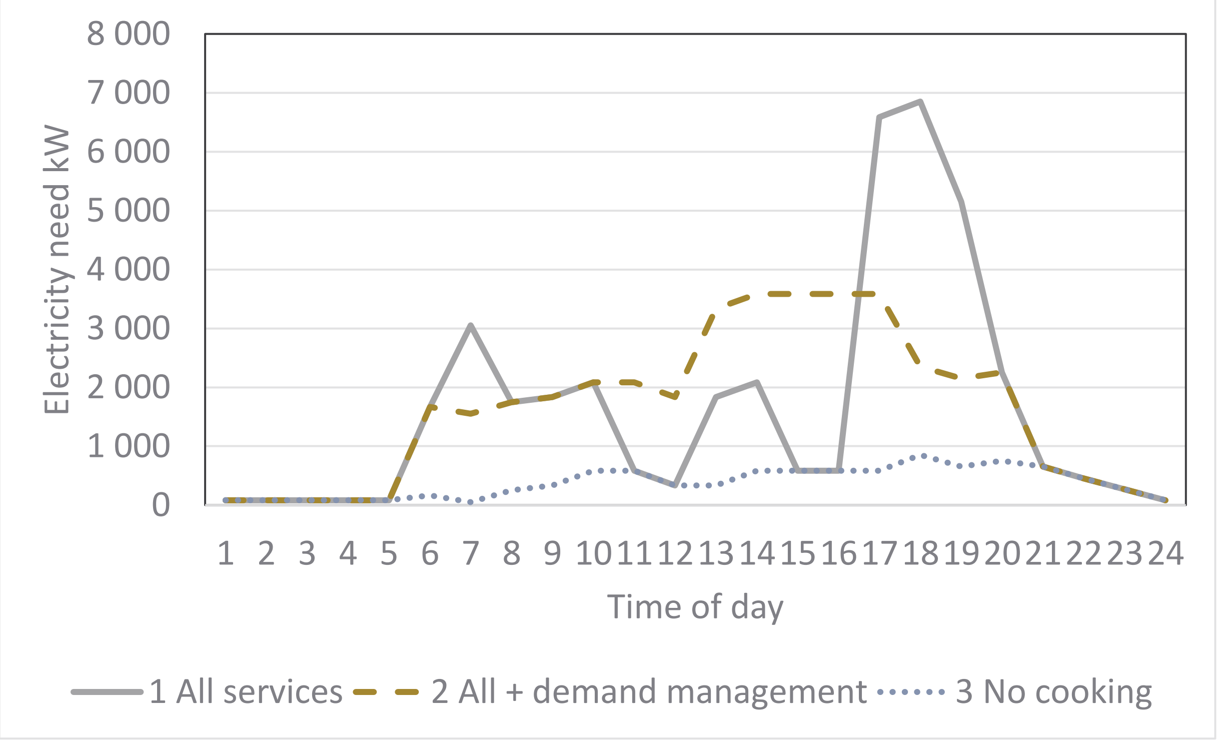
3.3 Energy demand scenarios

Based on the above input, electricity demand over the day was estimated based on theoretical assumptions for cooking time, need for illumination and services, etc. We have created three basic scenarios for the refugee camp:

1. All electricity services provided by the system installed with no restrictions on use;
2. Same as above, but with restrictions (demand management) for cooking, in order to reduce the peak load;
3. Only lighter energy demands provided by the system, cooking kept separate and provided by other solutions.

The electricity demand scenarios are modeled as in Figure 2, and further elaborated in the following sections.

Figure 2 Electricity demand scenarios



3.3.1 Electricity load with cooking and no demand management

With the above assumptions, it becomes clear that the major challenge is to accommodate electric cooking in some form. We have assumed a cooking need curve based on some cooking in the morning, some at noon, and most in the evening. Lighting is briefly in the morning and more in the evenings. Entertainment and phone charging are spread relatively evenly during the daytime, but slightly higher in the evening. The administration is mostly using power during the daytime, and street lighting obviously only in the night. The electricity load curve would look something like the solid line in Figure 2 and in Figure 3. For supply we have used a generic charge cycle for a solar PV system being able to supply the required energy, for which the maximum capacity is about 6 MW.

As can be seen from the figure, the peak demand will be in the evening between 17:00 and 20:00 hours, and it will be at almost 7 MW. This means there has to be either a power-supply system with a capacity of at least 7 MW, or a complementary supply/storage system able to generate 40 MWh per day and redistribute a temporary surplus to periods of shortage. The resulting storage requirement is the integration of the “Net” curve under the x-axis and is at least 25 MWh for cooking use in the evening and morning (there is no generation between end of evening peak and start of morning peak).

3.3.2 Electricity demand with demand management

In order to accommodate cooking in the electricity system, an avenue would be to try and influence the time of cooking for individual households. This could potentially be done in several ways:

1. Load shedding of certain quarters of the camp (see further, centralised demand management, in section 4.1.6)
2. Provision of less than one stove per household (i.e. they have to share the stove and cannot cook at the same time)
3. Technical load limitation of individual appliances (as peak shaving filters or built-in battery support, see example in section 6.7.2)
4. Cash cards for electricity usage in each household, with differentiated tariffs over the day

This may result in a demand curve like the dashed line in Figure 2 and in Figure 3. This results in a peak demand of about 4 MW, and the demand peak lower, flatter and shifted earlier in the afternoon. There is a need for storage of up to 16 MWh each day. The capacity of the system will still be the same as in the previous case, of about 6 MW.

3.3.3 Electricity load without cooking

Removing cooking from the equation, and all other assumptions remaining the same, the load curve would look as the dotted line in Figure 2 and in Figure 5. The peak load is at slightly less than 1 MW, and still in the evening. There is still the need for storing roughly 4 MWh for the night uses of electricity. Installed capacity is strongly reduced, with about 2 MW being sufficient to provide the needs.

Figure 3 Total electricity load with cooking, no demand management

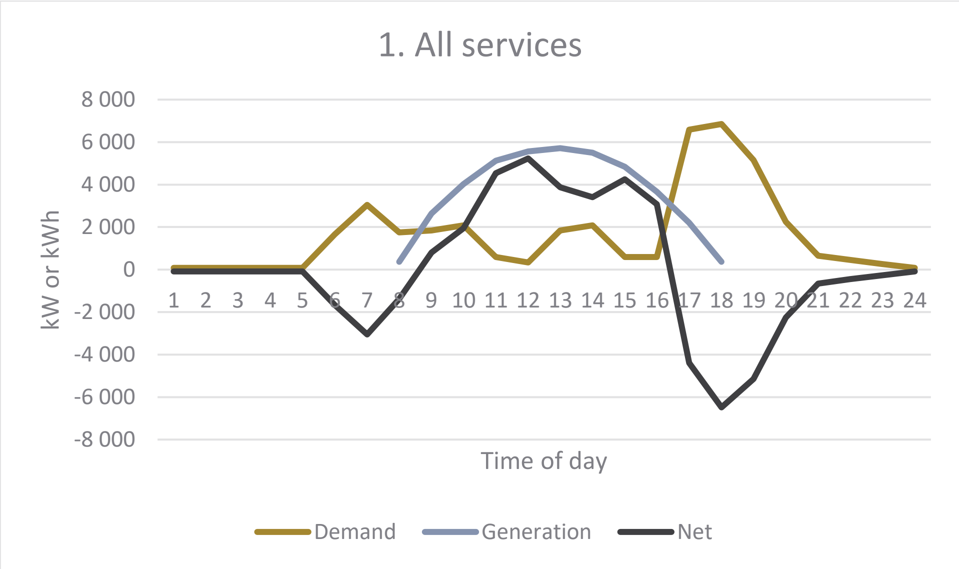


Figure 4 Total electricity load with cooking, AND WITH demand management

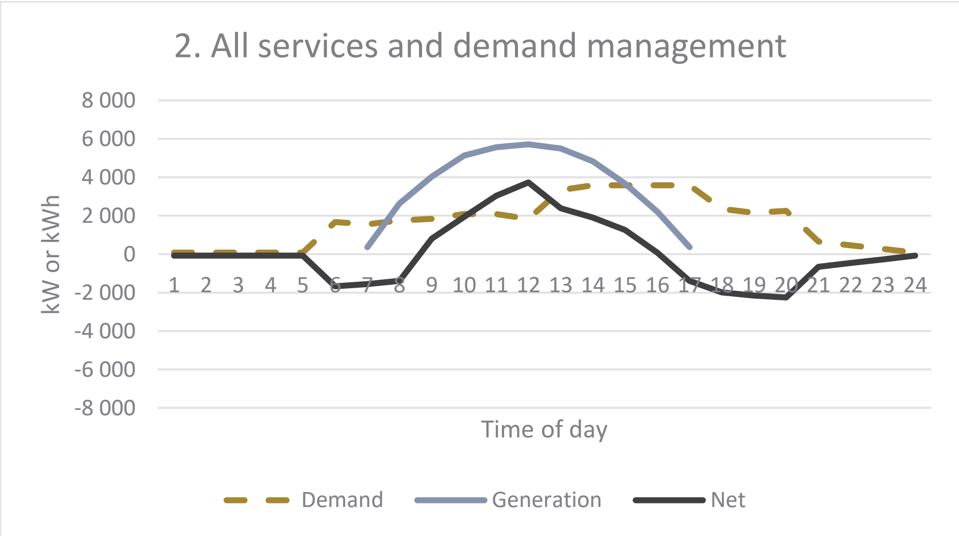
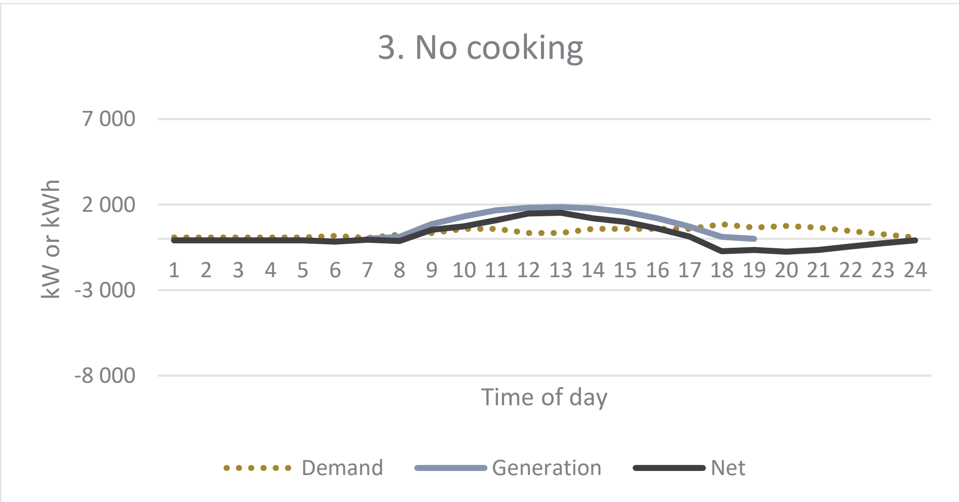


Figure 5 Total electricity load WITHOUT cooking



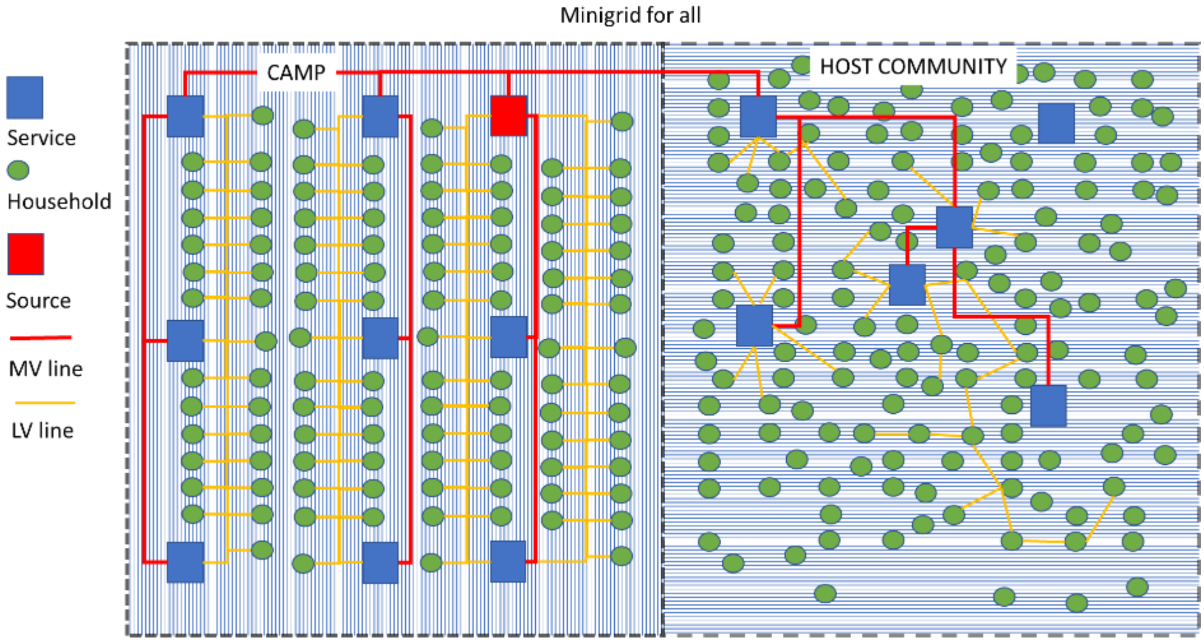
3.4 Project scenarios

A number of scenarios for the design of electrification of a refugee camp and its host population can now be outlined. We have seen that the inclusion of cooking into an electricity system will pose huge demands on storage of electricity in order to manage an evening load peak of substantial proportions. The two main scenarios to be considered are as follows:

1. Mini-grid providing full energy coverage for displaced populations as well as host communities.
2. Mini-grid providing electricity for certain energy services, such as camp administration, health institutions, shops, workshops, schools, etc., but not for households. Household electricity and street lighting covered with distributed solar energy, cooking with distributed sources.

These scenarios are dissected in more detail in the following paragraphs, discussing possible technical solutions, management models, business cases and delivery models.

Figure 6 Illustration of setup with mini-grid for all purposes

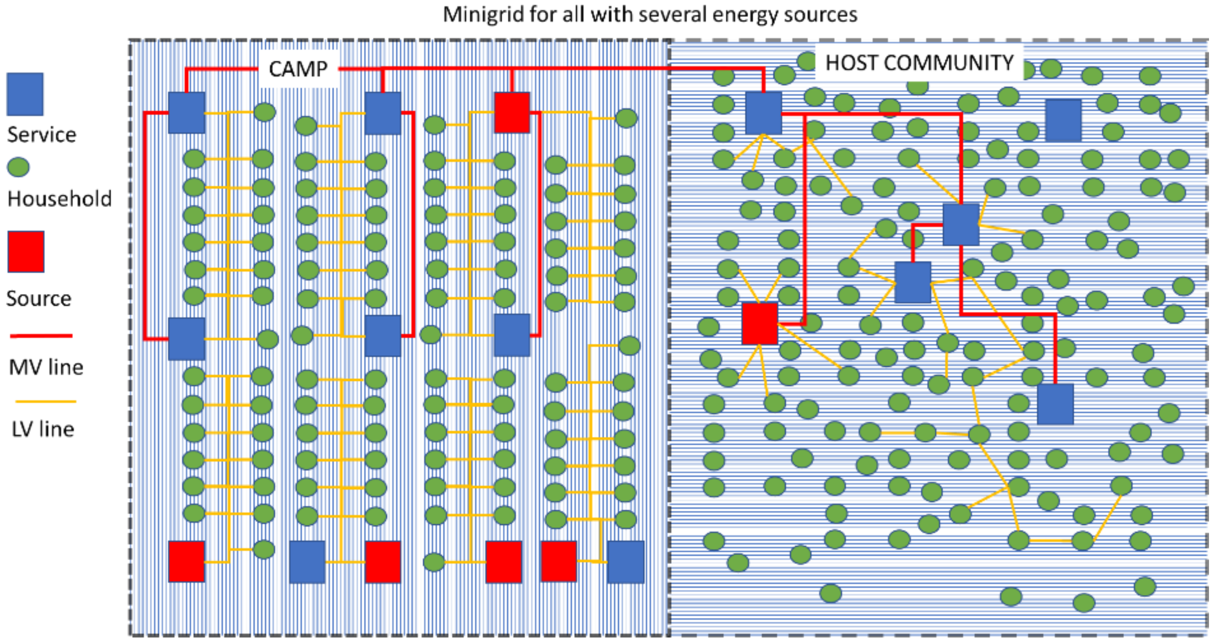


3.4.1 Mini-grid for all purposes and populations

A mini-grid for all purposes and populations needs to be designed to cater for the considerable peak load for cooking in the evening, plus all other uses, including administrations, health institutions, schools, shops, workshops and other services. This requires a very large and robust energy generation scheme, and also possibly a substantial energy storage system, depending on the source of the generation. An illustration of how this could be visualised is shown in Figure 6. This solution is the costliest, technically advanced, and financially risky.

A variation of this scheme is a system with several energy sources, located at various places in the camp or in the host community. Such a system can be built as a number of isolated micro-networks which means that only low voltage (LV) networks are built. It can also be interconnected into a larger network, which requires a medium voltage (MV) distribution grid. The interconnected network will provide more redundancy and hence greater delivery security.

Figure 7 Mini-grid with several sources, some with MV interconnection and some with independent LV networks



Considering a situation where the system is financed through a power purchase agreement, the financial risks for a contractor is increased by the large cost to be recovered, on top of the uncertainty of the duration of the refugee situation remaining. It will also be necessary to come up with an adequate payment mechanism, whereby the cost of operating the system and servicing the debt can be recovered from the displaced persons (DPs) as well as host community in a simple, fair and operational manner.

Institutionally, there may be conditions working against this solution. In some countries, policy is to keep host community services separate from refugees, and does not allow, for instance, electrification of camps through the national grid.

The main technical challenge is probably the need for electricity storage. Storage demand will be considerable, possibly near the limit of current technical capacities. This may offer a possibility to field-test new or relatively unproven technologies in a field situation. However, additional challenges include the form of energy generation, of which there are several of various technical maturity and capacity to be selected from, as shown in section 5 below (page 20). This choice is dependent on several factors, including climate, geographical location, local resources, etc.

The need for storage may to some extent be affected by the possibility to manage peak demand. This is very site-specific and has to do with cultural and social preferences and acceptance of certain solutions, such as community cooking. This is included in the following discussions as a special case of the full-service delivery scenario.

Environmentally, this solution may be seen as vary favourable, as all electricity needs will be covered in a renewable energy system. However, depending on the external factors and the selection of technology, there may be need for back-up through non-renewable systems, at least for shorter periods.

3.4.2 Cooking separate from the electric grid

Excluding cooking from the electricity equation reduces the need for very large storage systems, and electricity may be provided using a number of renewable technologies. Such a mini-grid would include distribution to households, administrations, health facilities, services and commerce. This will entail investing in, and construction of, a rather extensive electricity network designed for comparatively small loads, similar to the one illustrated in Figure 5. The question is if this can be made viable and sustainable, especially when the refugee situation has passed.

This solution also poses the question of how the cooking needs can be satisfied. From what we have seen there are two alternatives, one of which is not renewable, and the other which is not entirely field tested.

- Use of innovative technology for cooking
- Use of gas (LPG) for cooking

Among innovative technologies and practises for cooking we consider any technology that could provide part of, or all, energy requirement for cooking. This includes:

- More efficient cooking technologies, such as pressure cookers, possibly induction cookers. Haybox[3] is efficient but has proven difficult to establish.
- More efficient cooking procedures, such as soaking beans, cooking larger quantities and sharing, sharing kitchens, etc.
- Solar PV-based battery cooking (see section 6.7, page 38). A solution where an individual solar panel provides charge for cooking, while also providing light and other small services such as cell-phone charging. In this case, the question will instead be if a grid system to provide household electricity is the most financially efficient solution. It can also be argued, that if a grid system is established for each household in the camp (and among the host community) it will cement the infrastructure and large investments will be lost upon dissolving the camp.

As mentioned above, designing a mini-grid to cater for all customers in a refugee camp, and also for many in the host community, would require a large investment for a grid that may not reach viable utilisation levels. If instead a slimmer grid is designed to provide only certain relatively large users with electricity, the cost and complexity would be reduced.

It may be simpler and more flexible to provide lighter energy needs (but also heavier, see below) for household customers through the provision of SHS. This would avoid the installation of infrastructure that would be rendered useless after decommissioning of the refugee camp, and indeed would probably be less costly than reticulation of a whole camp plus a good part of the host community, especially if that community is spread out and disorderly. Cooking needs would be satisfied either with LPG, or with innovative[4] solar systems. An illustration is shown in Figure 8, which also gives the option to have the generation technology located in the camp or in the host community.

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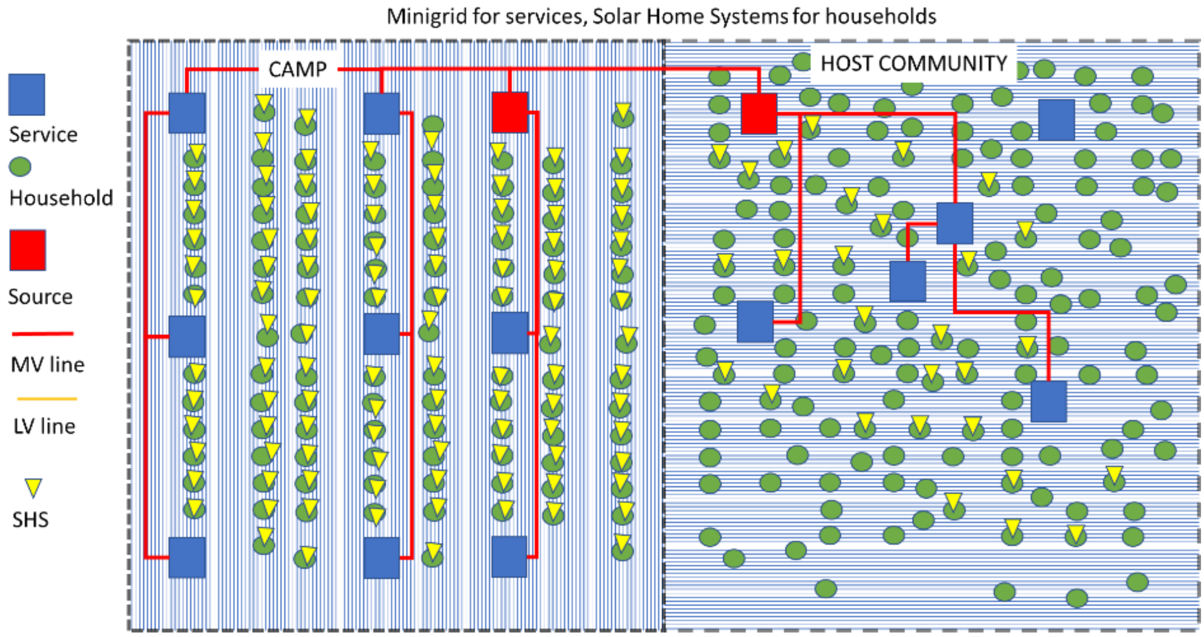
[3] *See section 6.7.1*

[4] *See section 6.7.2, p.39*

Figure 8 Illustration of mini-grid for services (administration, health, commerce, water pumping) with individual solutions for households.



4 THE ELECTRICITY SYSTEM

In this section the different technical network solutions are discussed and evaluated. Voltage level selection as well as system type alternatives (single phase or three phase distribution and alternating current or direct current) are briefly explained. Also, the whole scale of off-grid solutions are categorised from single PV powered appliances through nano- and micro-grid to mini-grids of different sizes. The aspects of electricity storage and peak power / back-up support are introduced as a vital part of an off-grid system.

The adequate sizing of the electricity system for the refugee camp and host community is mapped for the energy situation and electricity demand scenarios outlined. If the mini-grid should be based on a main renewable source, installed at the site of the camp or host community, and be combined with storage and back-up in line with what is available on the market, it makes most sense to aim for the Low demand scenario, with a simpler distribution system either on low voltage only (with limited distribution distances) or a network only for certain services, where transformation to medium voltage could allow longer distances.

This section describes various aspects of an electricity system in a model refugee camp and neighbouring host community. The aim is to create a cost-efficient renewable electricity supply to both the refugee camp and the neighbouring host community, that does not create tension between the people in the area.

4.1 Choice of technical system

There are several options for electricity and energy supply in each specific instance. In this section we are discussing, in general terms, several options for supply and technical management, with pros and cons. In a situation where a system is to be installed, an important issue to resolve is the degree to which the selection of technical solutions shall be made beforehand, and what shall be left to the implementor. If selected in advance, the system boundaries will be more confined, and the possible implementors few. If instead a set of framework conditions is put in place, with more freedom for implementors to pursue their own technologies and solutions, the possible competition among potential implementors may be larger. The choice of modality also depends on the choice of financing model, which is discussed in section 11, page 57.

4.1.1 Categorisation of off-grid electricity

Off-grid electricity can be broadly categorised into mini-grids, that connect many users with one or more common generation source(s), and stand-alone solutions, providing individual users, most commonly through SHS. The concept of mini-grids can also be further categorised depending on the size and degree if interconnectivity. The terms mini-, micro- and nano-grids are commonly used, and their definition vary depending on the source. Sometimes the terms mini- and micro-grid are used synonymously but as a general definition the following can be said:

The term **mini-grid** refers to a network with low voltage (<=400 V) or medium voltage (~10 kV) distribution lines to a limited number of customers, for example a rural settlement or village. The geographical extension of the mini-grid can vary from a couple of hundred meters to a few kilometres and the generation capacity varies from 50 kW to as high as 10 MW.

A **micro-grid** operates at a smaller size generation capacity 1 to 50 kW – serving a concentration of customers, as for example a street, hospital area etc. This type of network usually uses only low voltage (<400 V) distribution lines.

Nano-grids are in the smaller range of the capacity span mentioned for micro-grids but the main difference in definition is that a nano-grid only serves a single customer's premises or a single building and has no distribution lines except inhouse wiring. Nano-grids come close to the concept of SHS. A difference is that usually the nano-grid has is located within the premises while the SHS usually lacks the in-house wiring, instead providing electricity sockets only in the proximity of the stand-alone device.

At the very smallest scale the **pico-solar** systems are essentially very small-scale SHS and tend to be integrated units combining supply for a single appliance use (as light, USB-charger etc.) with a small PV-panel.

4.1.2 Distribution voltage level and system type

When a mini-grid is larger than a certain size it is favourable to distribute at a medium voltage level (10-20 kV) to reduce voltage drop and system losses and permit longer distribution distances. However, the end use is still at a low voltage level and the system, therefore, needs transformation between the voltage levels. The possibility to transform requires that the system is operating with alternating current AC, which is also a prerequisite for most modern household appliances. Micro- and nano-grids are, however, mostly operated with direct power (DC) and on a low voltage level (12-24 V).

4.1.3 Interconnectivity

A mini-grid operated as an AC-system can be completely autonomous, which is the case in its original context in distant rural areas with no access to a national grid, but it can also be connected to a national grid. It can still have the possibility to be operated independently during national load shedding events, or for any other reasons.

Nano-grids, or even single SHS, can be interconnected to form micro grids, between neighbours, in order to increase capacity and reliability.

Similarly, micro- and mini-grids can be connected, as time and development require, forming larger mini-grids with, for example, a couple of neighbouring villages.

4.1.4 Storage solutions

When the generation source is a renewable source, with intermittent nature, the system is often combined with a storage solution to extend the usage hours and increase reliability. Storage is seen throughout the scale from SHS to large mini-grids. In its most common form, the SHS consist of a small solar panel with a battery in order to store power during the day to be used at night. The suppliers of renewable-based mini-grid solutions often provide larger centralised batteries as a compliment to the main source, but there are other commercially-available storage solutions , see further section 6.7.

4.1.5 Peak power support

Even with a central storage solution, renewable based mini-grids may periodically fail to live up to a higher tier of service. A solar based source with battery storage will, after longer periods of overcast weather, need a back-up generator with an alternative source of energy.

For high peak power needs, a system where a renewable main source and storage is combined with some kind of peak power support can be a feasible solution. Including a peak power generator as part of the system allows more realistic dimensioning of the rest of the system. The alternative would be a much larger renewable source as well as storage to cater for the peak of the demand curve, and for longer periods when the renewable source is not generating.

The peak power support is usually provided by a traditional generator on diesel, but alternative, renewable-based fuels, can be used. The alternative fuels bring a higher cost and are in some cases more complex logistically. The most common of alternative fuels are biodiesel, biogas and ethanol.

Biodiesel is a diesel fuel mixed with oils and fats from plant or animal sources and can be used in an unmodified diesel generator.

Biogas from agricultural and human wastes, or municipal sewage, is a gas that can be used for electricity generation as well as cooking. Generators with a gas combustion engine are less common than diesel generators but they represent a mature and proven technology.

Ethanol is a fluid fuel made from e.g. sugar canes. It can be used in a modified gasoline engine. Ethanol is commonly available in some countries, and a gasoline engine with a generator can be operated on ethanol.

Also, modern alternatives like HVO (Hydrogenated Vegetable Oil) are becoming available. HVO is a renewable fuel component that can be blended in diesel or used instead of diesel in diesel engines. HVO consists of a vegetable oil or animal fats, refined using hydrogen under the influence of a catalyser.

Table 1 Peak power support alternative fuels[5]

Fuels for peak power support		
Biodiesel	• Can be used in traditional diesel generators that are commonly available • Depends on the local availability	
Biogas	• Requires gas engines (less common) to run the generator • Depends on the local availability and production possibilities	
Ethanol	• Requires gasoline engine to run the generator • Depends on the local availability	
HVO	• Can be used in traditional diesel generators that are commonly available • Depends on the local availability and could be more costly	
Diesel	• Fossil fuel • Easily available and comparatively cheap	

4.1.6 System demand management

As an alternative to peak power support, and to help extending the hours of use, different demand management solutions can help shave the peak. These solutions can either be centralised at the main feeding source or distribution station, or decentralised to the household level, or even interconnected with single appliances.

The simplest centralised solution is to alternate the provision of power between different lines over the peak power period. This is known as load shedding in a national grid context, but in a mini-grid context the word *rotational use* is better. By splitting supply from a mini-grid into two alternating areas, the aggregated peak power demand can be drastically reduced, but the level of acceptance of rotational use must of course be taken into consideration. Reliable schedules and timing the rotational use periods only during the hours before dusk can be possible success factors. Also separating streetlight, if they exist, from the rotational use can allow the rotational use for households, including cooking, to continue over the hours after dusk. However, this would require some kind of parallel lines for streetlight which would increase the network investment cost.

4.1.7 Evaluation of alternatives and system selection

The right size and system selection for an off-grid project depends on the electricity need and primarily the aggregated peak power, which in turn depends on use of demand management solutions. In this project the adequate system sizing for the refugee camp and host community will be mapped for the energy situation and electricity demand in section 3.3.

[5] *In this and following "traffic-light" tables, the green indicates a positive and the red a negative quality, with yellow in between*

When assessing different alternatives, there are threshold costs to take into consideration, when going from low voltage distribution (on single or three phases) to medium voltage distribution, as well as from DC to AC.

When planning a mini-grid and including the possibility for a future connection to a national grid, it requires certain technical standards to be used. This will initially render higher CAPEX but can be preferable, seen in a life-cycle cost perspective.

Table 2 Energy demand scenarios

Scenario	Description	Peak power	Storage need
High	Electricity load with cooking and no demand management	6,9 MW	26 MWh
Medium	Electricity load with cooking and demand management	3,6 MW	14 MWh
Low	Electricity load without cooking	0,9 MW	4,2 MWh

Some suppliers in the mini-grid business today offers “container solutions” where a renewable source can be connected to a container with standardised storage, usually a battery, and a back-up source for peak power needs together with transformer and the main switching bays for connection of distribution lines.

According to the suppliers, the container solution allows for a “modular approach”, making it easier and cheaper to scale the mini-grid size up and down. According to the suppliers, it also contributes to flexibility in the electrification steps of an area, from a start with single separate off-grid modules, to multiple connected off-grid modules, to future connection to a national grid.

4.1.8 Costs of the distribution grid

The World Bank has analysed detailed cost information from 53 mini-grids in Asia and Africa. The projects span from 10 to 375 kW which means that the study represents the lower range of mini-grids categorised in section 4.1.1 above. Some of the studied projects could even be defined as micro-grids. The range captured in the study is, however, the most common range for renewable solar-based mini-grids. Larger mini-grids are usually based on another main source.

The studied projects keep the distribution on a low voltage level only, and in some cases with a focus on single phase distribution, which keeps the pole and conductor costs lower. The study shows that the distribution grid stands for, on average, 14 % of the total CAPEX. If the power house (the substation and central monitoring equipment) is included this figure increases to 22 %.

The equation in Figure 9 gives the total cost per firm kW output for all the studied mini-grids in the World Bank analysis. A representative unit cost for the larger range of mini-grids in the study is 3 900 USD per kW [WB 2019], which gives 860 USD per kW (22 %) as the cost for distribution grid and the central substation. This unit cost is representable when the distribution grid can be kept on the low voltage level with the source in direct proximity of the camp and without any longer distribution distances.

Figure 9 Total cost of mini grids as a function of total power output [WB 2019]

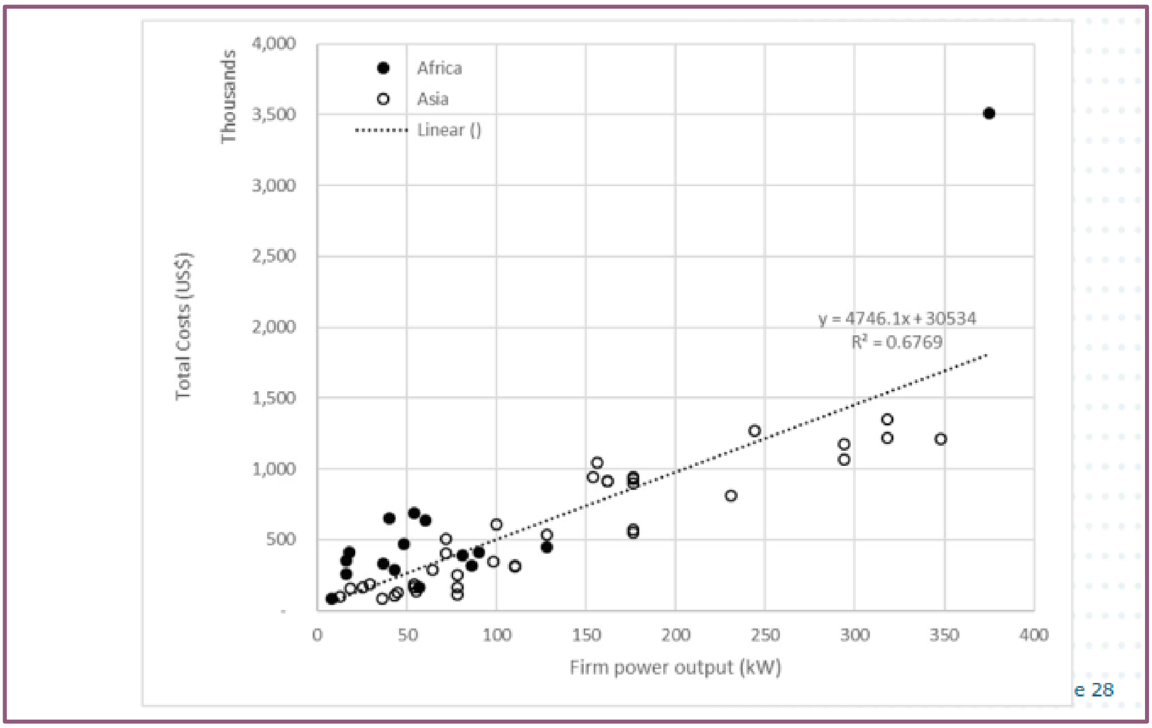


Figure 10 CAPEX split, mini-grid projects in Asia and Africa [WB 2019]

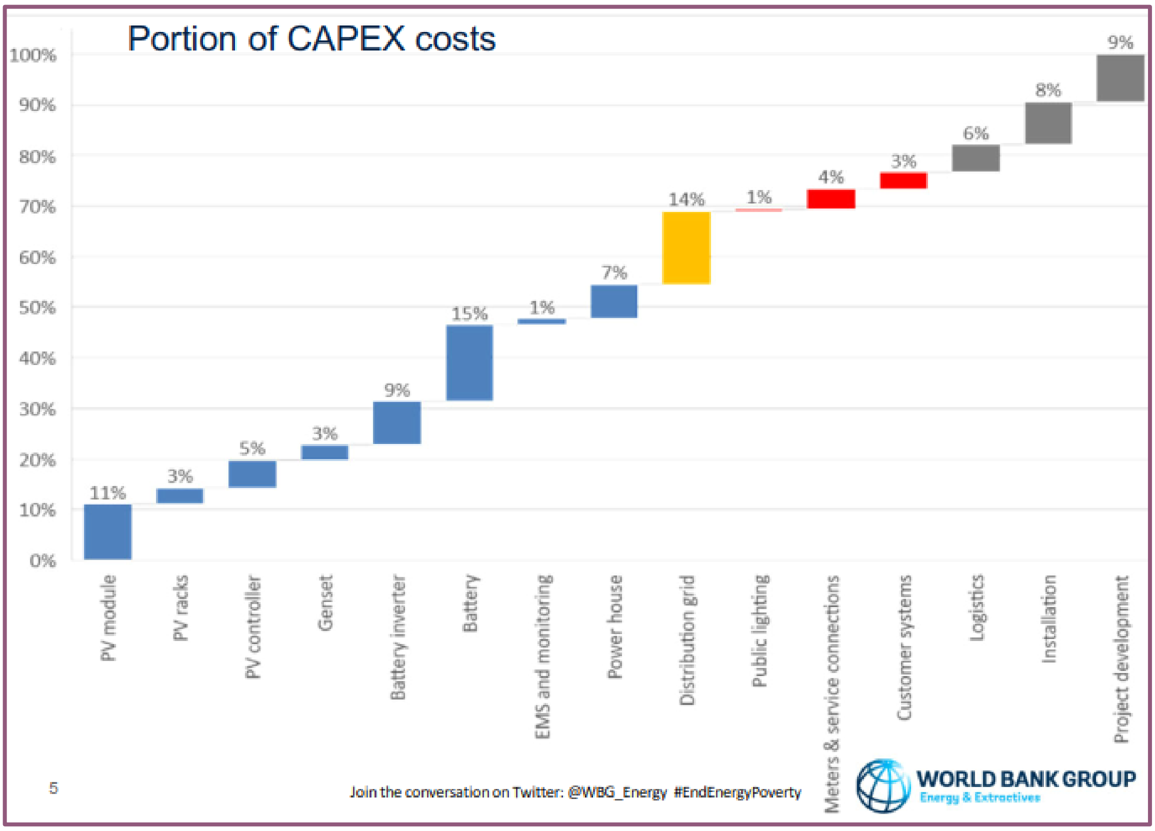


Table 3 Distribution grid solution and cost indications

Electricity demand scenarios	Distribution grid solution and cost indications	
High w cooking, w/o DM 6,9 MW	• Will require **transformation**, and distribution on **medium voltage** levels (10 kV). Structure similar to Figure 6. • Sufficient with one large central substation and source. • The cost for distribution will probably represent a larger share of the total costs than in Figure 10.	
Medium w cooking, w DM 3,6 MW	• Will require **transformation** to, and distribution at, **medium voltage** levels (6-10 kV). Structure similar to Figure 6. • Sufficient with one large central substation and source • The cost for distribution will probably represent a larger share of the total costs than in Figure 10. • Maybe a higher distribution cost weighted per MW compared to the High scenario (as this scenario requires the step to a medium voltage solution but with lower demand)	
Low w/o cooking 1,8 MW	• A simpler distribution network on **low voltage** level and partly single phase can be sufficient. • Distribution distances must be kept short (<500 m) due to voltage drop. • Larger areas can be covered by more than one source within the camp (multiple low voltage mini-grids). Structure shown in Figure 7. • Costs in line with Figure 9 and Figure 10 (multiples with more than one source).	
Low "Project scenario 2" - Electricity for certain energy services	• **Transformation**, and distribution on **medium voltage** levels (6-10 kV) to certain services only. No low voltage distribution to households. Structure similar to Figure 8. • A lower energy demand but still distribution over longer distances. • The cost for distribution will probably represent a smaller share of the total costs than in Figure 10. • Instead the project carries costs for local solutions at household level (e.g. SHS)	

5 ENERGY GENERATION SOURCES

In this section several renewable energy generation technologies and sources are presented and evaluated according to their suitability with regards to different geographic and climate conditions, technological maturity, flexibility in system size, the different demand scenarios set up for the study, investment cost as well as the need for energy storage.

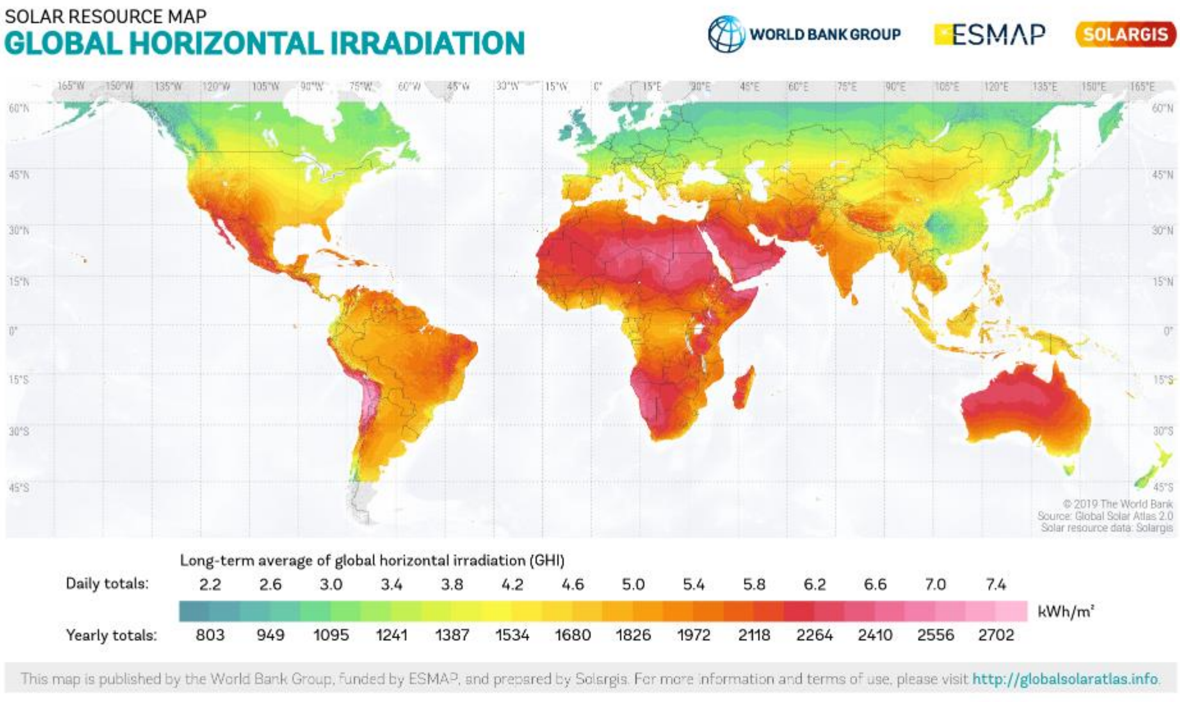
The evaluation is performed in order to find the most suitable energy generation sources for electrifying the refugee camp in the best and most sustainable manner.

Solar photovoltaic systems and wind turbines are the identified technologies which are most generally applicable and suitable for electrification of refugee camps, while other technologies are very site specific.

5.1 Solar power

Solar power is a form of intermittent electricity generation. In addition to providing energy only in the daytime, it varies with e.g. latitude, weather and climate. The generation of solar electricity takes place by converting the energy in the incoming sunlight via a photovoltaic cell, or by using solar concentrators heating up a thermal storage and then converting steam into electricity, or by powering a thermochemical reaction. The theoretical capacity of solar energy is largest in the tropics, but near the equator cloud formations reduce the insolation somewhat.

Figure 11 Global solar irradiation[6]



5.2 Solar photovoltaics (PV)

For conventional photovoltaic (PV) cells, the conversion takes place through a photovoltaic process where photons create free electrons that can be attracted to positively charged layers in the PV cell by applying different semiconductor materials. The current of electrons in the PV cell gives rise to a direct

[6] *World Bank ESMAP 2019*

current (DC). This direct current can be converted to an alternating (AC) useful current with usage of power electronics (inverters). The main advantage with solar PV is the scalability, providing a vastly modular technology that provides possibilities to offer both small-scale applications for the satisfaction of individual needs, as well as utility-scale applications for larger electricity needs.

There are two main technologies for solar PV; crystalline silicon modules and thin-film modules. The crystalline silicone modules are split into mono-crystalline and poly-crystalline PV cells. The crystalline silicone modules provide a higher conversion efficiency than do thin-film modules, where mono-crystalline modules are the ones with the highest efficiency, even if current technological developments push the efficiency for poly-crystalline modules closer to the level of the mono-crystalline ones. During recent years the price of crystal silicone modules have dropped significantly, and the prices are still dropping.

Thin-film modules are made by super-imposing a thin layer of a photovoltaic substance onto a solid surface. This makes the panels light-weight and, in some cases, flexible. The thin-film modules are still under technical development, even if more and more products have been released on the open market recently. Their lower efficiency compared to the crystal silicone modules causes the crystal silicone modules to be more widely used commercially, even if the thin-film modules are cheaper. But since the crystal silicone modules continue to drop in price and are more effective than thin-film modules, they are often chosen over the thin-film options.

Today the utility size solar PV systems built in Africa are built in the cost range of USD 2000 – 4500/kW.[7]

5.3 Concentrated solar power (CSP)

For concentrated solar power (CSP) mirrors and lenses are used to concentrate sunlight from a large area onto some sort of receiver. The concentrated sunlight is used as heat or as a heat source to drive conventional thermo-electrical turbines or engines, usually by using steam or air. CSP systems can be utilised in order to generate both electricity and industrial heat and cooling, such as air conditioning. Unlike solar PV, the CSP system can store the thermal energy and use it for electricity generation when it is needed, day or night. There are four main types of CSP technologies; Linear Fresnel, Central receiver, Parabolic dish and Parabolic trough.

A **Linear Fresnel CSP** system consists of long rows of flat, or slightly curved, mirrors that move independently on one axis to reflect the sunlight onto a stationary absorber tube filled with heat transfer fluid (HTF). The receiver (absorber tube) is commonly fixed and mounted on a series of small towers. As for the other systems the HFT is used to generate electricity by conversion in turbines or engines. The cost of linear Fresnel CSP systems is lower than that of other CSP systems, but the heat-to-power efficiency is also lower. Fresnel CSP systems can be utilised in various system sizes.

A **Central receiver CSP** has the greatest thermal–electric conversion efficiency (in the power block) among the four types of CSP systems. It is used with several heliostats that track solar movement and reflect sunlight onto a receiver located at the top of a tower. The receiver contains a heat-transfer fluid, which can consist of e.g. water-steam or molten salt. The working fluid in the receiver is heated to a high temperature and then used as a heat source for power generation or energy storage. The high temperature HTF is then fed into a turbine or generator to generate electricity, directly or indirectly when need arises. Central receiver CSP development is less advanced than trough systems, but they offer higher efficiency and better energy storage capability.

A **Parabolic dish CSP** system consists of stand-alone parabolic concentrators, or reflectors as they are called, that concentrate light onto a receiver positioned at the reflector's focal point. The concentrators are placed in an assembly and use a two-axis tracking system that follows the sun to maximise the solar concentration during the day. At the focal point, a Stirling or Brayton engine is placed with an electrical generator to utilise the high temperature HTF at the receiver and convert the thermal energy to elec-

[7] *IRENA (2016), Solar PV in Africa: Costs and Markets*

tricity. Parabolic dish CSP systems provide high conversion efficiency from solar irradiation to electricity. Thanks to their stand-alone layout, they are modular and provide scalability but, on the other hand, the stand-alone layout causes problems for energy storage.

A **Parabolic trough CSP** system consists of linear parabolic mirrors (also called reflectors) that track sunlight along a single axis and reflect solar radiation to a linear receiver positioned along the reflector's focal line. The receiver is a tube filled with a working fluid which is heated of the received sunlight which generates electricity. Parabolic trough CSP systems were the first commercially operating CSP technology. Since parabolic trough systems is the oldest CSP technology, it is also the most developed. A summary of the four systems is presented in Table 4.

Table 4 Summary of the CSP technologies efficiency level and suitability for thermal storage[8].

CSP Technology	Average annual efficiency	Thermal storage suitability
Linear Fresnel	8 – 11 %	Suitable
Central receiver	17 – 35 %	Highly Suitable
Parabolic dish	25 – 30 %	Not suitable
Parabolic trough	15 %	Suitable

The land take for solar PV and CSP systems varies depending on technology[9], see Table 5. These numbers are from 2013 and valid for the United States. Today the technology is more advanced, and the land take can be assumed to be somewhat lower due to technological development.

Table 5 Land area usage for different solar technologies. MWAC describes the installed AC-capacity.

Technology	ha/MWAC	ha/GWh/yr
Small scale PV (fixed)	na	na
Utility scale PV (fixed)	1,0	0,5
Linear Fresnel[5]	2,5	1,0
Central receiver[5]	3,6	1,1
Parabolic dish[5]	1,1	0,6
Parabolic trough[5]	0,8	0,7

It can be concluded that the land take is largest for Linear Fresnel and Central receiver. The most area-effective source is commercial solar PV systems for utility scale applications, or small-scale application solar PV systems that can be scaled down to consist only of a few single cells.

From the different technologies studied above, solar PV systems and parabolic dish systems are the most scalable. Linear Fresnel, Central receiver and Parabolic trough are the most suitable systems for energy storage since they use thermal conversion by an HTF to produce electricity. Often the HTF is passing through some sort of plausible storage on the way to conversion. Only in the case of parabolic dish is the HTF directly converted to electricity through a Stirling or Bryton engine. For solar PV it is necessary to combine the system with some type of energy storage in order to be able to have electricity availability during the hours of darkness.

It is difficult to generate peak power on demand for solar PV as well as CSP systems. Energy storage would be necessary for both types, and the energy storage would be the limiting factor for the output

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[8] *Energies (2020), The Knowledge Mapping of Concentrating Solar Power Development Based on Literature Analysis Technology*

[9] *NREL (2013), Land-Use Requirements for Solar Power Plants in the United States*

performance. In the case of a CSP system, the thermal "built-in" storage, HTF passing through a medium, makes it plausible for the CSP system to generate electricity for a while even after sunset. But it does not provide long-term storage.

Solar PV cells can utilise both direct and diffuse solar irradiation for electricity generation. Shading from surrounding objects or cloudiness will, however, reduce the power output. The CSP systems can only utilise direct solar irradiation for power generation. It is generally assumed that CSP systems are economic only for locations with direct normal irradiation (DNI) above 2 000 kWh/m^2/year (about 5 kWh/m^2/day)[10][11]. This means that they are more sensitive to cloudiness and shading. Areas fulfilling these criteria of low cloudiness and a high share of direct irradiance are commonly located at high altitudes in the tropics. Solar PV can be exploited anywhere, but preferably without unnecessary surrounding objects shading the panels directly, such as high-growing trees. Also, the surrounding temperature of the solar PV cell will affect the efficiency of the energy conversion, cooler temperatures will increase the efficiency in conversion. The same goes for the CSP systems which needs cooling at the back end of the thermal cycle.

CSP systems have a number of negative environmental impacts, particularly on water use, land use and the use of hazardous materials. Water is generally used for cooling and to clean mirrors, sometimes also with hazardous cleaning agents[7]. Utility scale PV systems use similar areas of land as CSP systems. In cases where available land may be limited, solar PV can be deployed as floating solar. Floating systems can be deployed on lakes and rivers to avoid use of valuable land area. Another benefit of a floating solar system is that the panels are kept at a lower temperature than they would have on land, leading to higher efficiency of the energy conversion.

The operating and maintenance costs for photo-voltaic systems are generally relatively low because they have no moving parts. The single largest cost comes from a reinvestment in the form of a converter replacement, the lifespan of which is usually assumed to be around 15 years. The levelized cost of electricity generation in mini-grids consisting of solar PV, wind and/or hydro is between USD 250 and USD 300 per megawatt hour (MWh), which is lower than the levelized cost for diesel-based mini-grids[12]. This does, of course, depend heavily on-site specific conditions as well as the size of the mini-grid system.

Solar and wind power generation technologies have entered a phase of rapid scale up and increasing technological and industry maturity. This leads to reduced costs and stronger growth of the market. Costs for both solar PV and CSP have fallen during recent years. For utility-scale solar PV the price reduction from 2010 until 2017 has been in the order of 70%[13]. The price of CSP systems has not fallen quite as much but the trend is obvious also for them[8].

[10] *ScienceDirect (2015), Solar Energy Potential and Performance Assessment of CSP Plants in Different Areas of Iran*

[11] *ITP (2018), Concentrating solar thermal technology status*

[12] *IEA (2018), Energy Access Outlook 2017: From Poverty to Prosperity*

[13] *IRENA (2017), Renewable Power Generation Costs in 2017*

Table 6 Solar photovoltaic (PV) systems summary

PV systems		
Technological maturity	PV solar systems are well developed and is a mature technology available in SSA.	
Capacity ranges	PV solar systems are flexible in size and installation location.	
Energy availability	PV solar systems can utilise both diffuse and direct solar irradiation and is thus not that sensitive to cloudiness.	
Cost	PV solar systems have been available for a longer time on the market and is thus slightly cheaper than CSP systems.	
Mini grid compatibility	PV solar systems can be built in all kinds of sizes, from SHS to utility-scale PV farms of several MW to GW. Existing mini-grid projects in SSA, have installed capacities between approximately 10 and 500 kW.	
Energy storage need	PV solar systems only generate electricity during daytime and need storage solutions for energy availability during the dark hours.	

Table 7 Concentrated Solar Power Systems (CSP) summary

CSP systems		
Technological maturity	CSP technology is already well developed but is also still developing.	
Capacity ranges	CSP systems are mainly available in the utility-scale range and are not as flexible in size as PV solar systems.	
Energy availability	CSP systems can only utilise direct solar irradiation and is hence more sensitive to shading and cloudiness.	
Cost	CSP systems are more expensive than solar PV systems. The cost for CSP also varies between the different CSP technologies.	
Mini grid compatibility	CSP systems for micro-grid application is mostly at a pilot stage in SSA.	
Energy storage need	CSP solar systems provide energy availability during some of the dark hours after sunset but does not provide long-term storage.	

5.4 Geothermal energy

Geothermal energy is generated by utilising heat from sub-surface reservoirs, varying in depths from just below the earth's surface to several kilometres. Geothermal energy can be used both for heating and cooling and also for electricity generation. There are several different geothermal technologies, all with different levels of maturity. The geothermal energy is carried by water and/or steam to the surface of the earth and then converted to useful energy in different ways. For heating and cooling, modest temperatures of the water or steam is sufficient, while for electricity generation, high to medium temperatures are necessary. It is mainly tectonically active regions which are suitable for geothermal electricity-generation purposes. East Africa has such areas.

The three main types of geothermal energy are Dry steam, Flash steam and Binary cycle. Commonly wells are drilled to reach the hot water and steam in the ground, and then the water or steam is piped to the surface of the earth.

Dry steam is the oldest and also the most mature technology of geothermal energy utilisation and uses steam from fissures in the ground and convert this directly into useful electricity via a steam turbine. The dry steam technology is the most efficient one, but also the hardest one to find naturally since it requires a resource that produces dry steam.

Flash steam is a process where deep-lying, high-pressure water is injected into low-pressure cool water. This creates steam which is used to drive a turbine and generate electricity. When the steam cools, it condenses, in flash plants the condensation of steam to water is used to inject the condensate back into the ground in order for it to be used again. Most geothermal power plants today are Flash plants.

The **Binary plants** are the newest technology. In this process, hot water from the ground is passed by a second fluid with lower boiling point than water. This causes the second fluid to turn into vapor from the hot water surrounding it. The vapor is then used to drive a turbine. Most likely these plants will be the most common ones in the future. The binary-cycle technology is the one requiring the least hot-water source, which makes it suitable for more sites. The other two technologies require more hotter water and/or steam.

Geothermal energy does not need to be combined with storage solutions since the heat is continuously streaming towards the surface to be utilised directly as heat, or for electricity production. It is also possible to use the thermal sources as energy storages where cold water can be pumped down into the reservoirs and then converted to steam ready to be used when needed.

Land take for a geothermal power plant is generally small compared to fossil technologies. The span is between 0,4 – 3,2 ha/MW[14] land which opens up for possibilities to coexist with agricultural land use.[15] Since it is most often necessary to drill a well in order to reach the hot water or steam, it is quite expensive to construct geothermal plants. The drilling is commonly the most expensive part of the construction.

Life-cycle analyses show geothermal energy to be one of the cleanest energy technologies.[14]

Table 8 Geothermal energy summary

Geothermal energy		
Technological maturity	Geothermal energy is a well-developed mature technology with potential in East Africa. There are different technologies within the geothermal field. Technologies applicable at lower working temperatures, and thus suitable in more locations, are under development.	
Capacity ranges	Geothermal energy systems are most suitable in the tectonic regions which means that the location could affect the available capacity	
Energy availability	Geothermal energy production requires natural resources and thus the location is essential to the energy availability	
Cost	Drilling is necessary in order to reach the hot water/stem which is a costly technique	
Mini-grid compatibility	Today geothermal energy is most often constructed for utility-sized systems. Mini-grid solutions are built as pilot projects	
Energy storage need	Energy storage is not necessary	

5.5 Hydropower

Hydropower utilities the energy in flowing and falling water to generate electric energy. Hydropower is available in several forms, utilising different kinds of movement in the water. Hydropower utilising dams and hydraulic head uses both kinetic and potential energy to create electricity while tidal and run-of-river plants use mainly kinetic energy. Hydropower was one of the first energy sources harnessed by humans and its use dates back to more than 2 000 BP. It is, hence, a mature technology and electricity has been generated in hydropower plants since the late in the 19th century.

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[14] *Office of Energy efficiency & renewable energy (UN), Geothermal Power Plants — Minimizing Land Use and Impact*

[15] *ScienceDirect (2014), Geothermal Energy*

Utilisation of small-scale hydropower in a small-scale perspective opens up for different solutions depending on the geographical preconditions. Using conventional hydropower with dams and water turbines requires hight differences as well as a river for the water to flow in. The usage of water in dams is a good energy storage solution that independently from the time of the day can provide kinetic energy to convert into electricity. Tide energy and “run of the river” energy is dependent on close by access to the ocean or a river with natural water flow.

Another hydropower solution is the Pumped hydro. In this case water is pumped from a lower level to a higher level and then the water is streamed back to the lower level passing a turbine generating electricity. A separate energy source needs to produce electricity to run the pump for water pumping. This could for example be done by using solar power pumping the water to the higher level during the day and the utilizing the pumped hydro during the night.

Hydropower does however demand natural availability to water as well as hight differences or flowing water. With the right geographical preconditions’ hydropower is scalable in size and several mini grids exist worldwide.

Hydropower is both an electricity production source as well as an energy storage. Pumped hydro is suitable as energy storage in hot regions.

Costs for hydropower projects are highly site-specific and dependent on size and numerous framework conditions. A plant in the capacity range of 5 – 10 MW would have an estimated investment cost of USD 5000/kW.

Table 9 Summary hydropower

Hydropower		
Technological maturity	Hydropower is a well-developed mature technology with large potential in SSA.	
Capacity ranges	Hydropower is flexible in size and installed capacity, from the single-digit kW range to 22.5 GW.	
Energy availability	Hydropower requires specific geographical conditions.	
Cost	Depending on the technology (reservoir, pumped hydro, tidal etc.) the construction costs vary considerably. Large hydro is generally cheaper than other renewables but can be quite expensive under unfavourable conditions.	
Mini-grid compatibility	Hydropower is suitable both for utility-scale systems as well as for mini-grid systems	
Energy storage need	Energy storage solutions is not necessary if the plant design includes a reservoir and/or the flow in the river/stream is always enough to satisfy the design flow of the plant.	

5.6 Wind power

Wind power utilises the kinetic energy of moving air (i.e. ”wind”) to run turbines which convert that motion into electric. Wind power turbines exist in different locations, onshore and offshore as well as in different shapes, horizontal axes and vertical axes, with the main rotor placed either longitudinally or transversely to the wind direction. The vertical-axis wind turbines are still under development to reach higher efficiency and the largest commercial vertical-axis turbines available are still in the kW-range. Horizontal-axis turbines are available in sizes up to 8 MW. This difference affects several aspects of the usefulness of the two technologies under different environmental and geographic conditions. Wind power has been used for many centuries, from the first windmills to the power-generating technology we use today. The horizontal-axis turbines (similar to the old windmills) is a mature technology while the vertical-axis approach is still in a stage of considerable development.

Large-scale wind power towers can be more than 200 m tall and have a rotor diameter of up to 160 m. Such towers require a large space for their operation, something that most often has a larger impact for onshore wind power than for offshore, since large areas are more easily available at sea. Many wind power turbines are normally grouped together into large wind farms. As a rule of thumb, each MW installed requires around 12 - 56 ha[16] of area and usually the spacing between the wind turbines must be up to seven times the rotor diameter.

The horizontal wind power turbines also exist in smaller sizes that are more suitable for smaller applications and thus for micro-grids. Turbines of sizes down to a few kW are available, and this is the most commonly used size for micro-grids.

Vertical-axis turbines can also be utilised for smaller grids. However, they are not common in the existing mini-grid projects. In the vertical-axis turbines, the gearbox and generator are placed at the base of the turbine to facilitate access for maintenance, unlike in the horizontal turbines where the gearbox and generator are placed at the centre of the rotor blades. Vertical-axis turbines are less sensitive to placement with regards to the wind flow, since they don’t operate in the wind direction. Conversely, horizontal-axis turbines need to be placed perpendicular to the wind direction, and wind assessments are often necessary in order to find out the best placement.

The potential for wind power in Africa has not been assessed in great detail, although there is a substantial potential especially in highland regions and along the eastern coast.

A benefit with wind power compared to e.g. solar power is that wind power generation is available whenever there is sufficient wind speed, and not just during daytime.

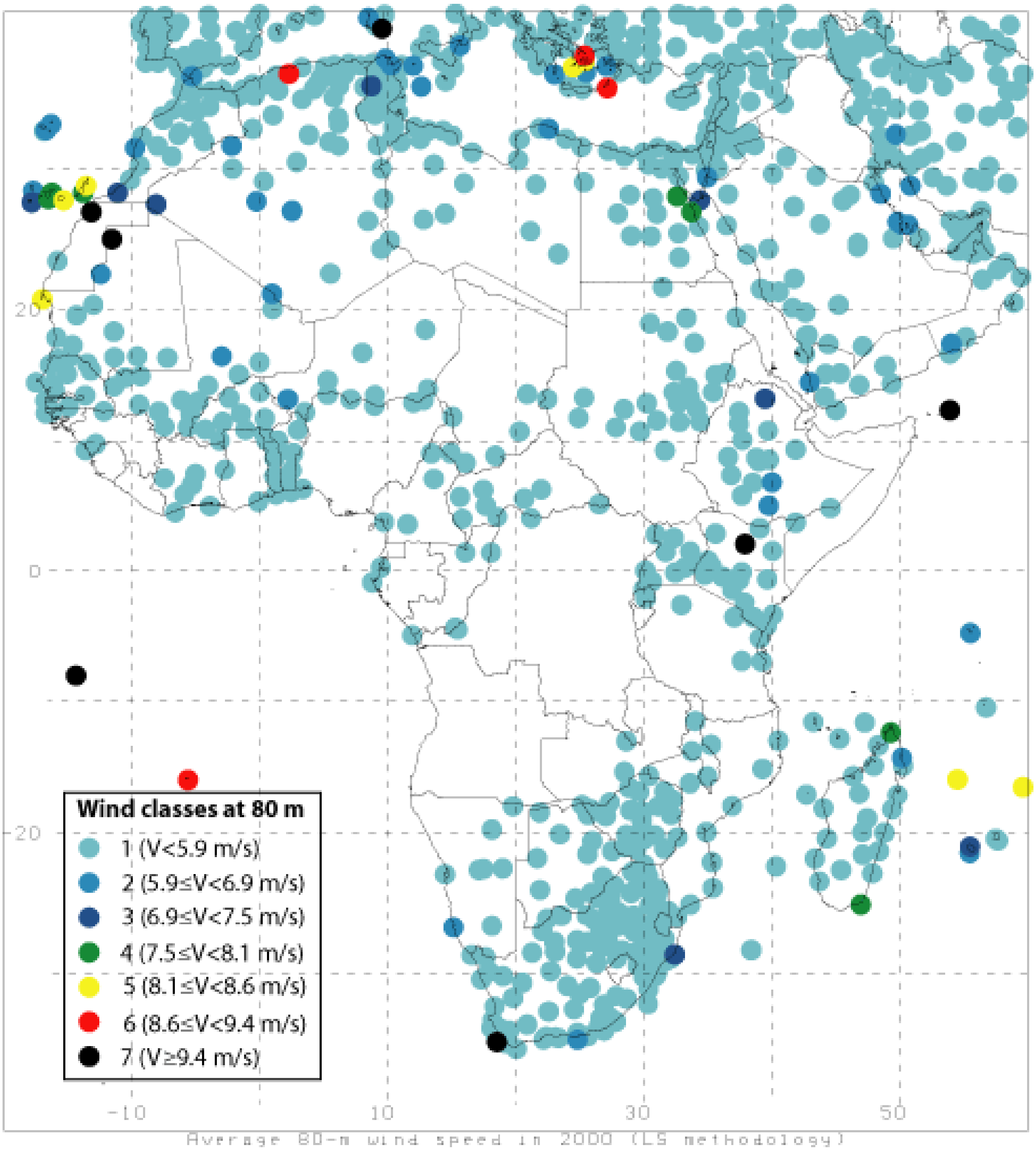
In conclusion, wind power can contribute to a lower electricity price in the mini-grid since less storage capacity is needed. The levelized cost of electricity generation in mini-grids consisting of solar PV, wind and/or hydro is between USD 250 and USD 300 per megawatt hour (MWh), which is lower than the levelized cost for diesel-based mini-grids.[17]. The exact costs obviously depend heavily on the mini-grid system size and site-specific conditions. This applies for horizontal wind turbines, which are the most common ones in small-scale applications and in mini-grids already in operation.

In conclusion: wind power reduces the need for energy-storage capacity but could not be the only source of generation without significant storage in place.

[16] *NREL (2009), Land-Use Requirements of Modern Wind Power Plants in the United States*

[17] *IEA (2018), Energy Access Outlook 2017: From Poverty to Prosperity*

Figure 12 Wind energy map for Africa[18]



[18] *Calculated at Stanford University, based on observations at 10 m elevation.*

Table 10 Summary wind power

Wind power		
Technological maturity	Energy generation with wind power is a well-developed, mature technology, with large potential in SSA.	green
Capacity ranges	Wind power production is flexible in size and installed capacity.	green
Energy availability	A wind assessment study might be needed in order to determine how the turbines are best placed. There is a difference between vertical- and horizontal-axis turbines and their sensitivity to wind directions.	yellow
Cost	The electricity generation cost for wind power (horizontal axis) in mini-grids is comparable to that of solar-PV.	green
Mini-grid compatibility	Wind power is suitable for both utility-scale and mini-grid systems.	green
Energy-storage need	Energy-storage solutions are necessary, but the capacity can be reduced when combined with other generation sources	yellow

5.7 Biogas

Electricity from Biogas is produced by a biological conversion process, fermentation, whereby micro-organisms decompose biomass. This digestion process creates gas that can be utilised to run an internal combustion engine to generate electricity. The biogas can also be used as a cooking fuel and directly for heating purposes.

The raw material used for production of the biogas could be anything from manure, plant remains, food waste to human faeces. The resource, or fuel (raw material), for the biogas production is, hence, available everywhere. The produced gas mainly consists of methane. Biogas production can cause greenhouse-gas emissions of ammonia and methane. With the right handling of raw materials and the digestion process, the emissions can be kept under control and at low levels. The eventual greenhouse emissions are much lower than for traditional fossil sources.

Biogas plants can be built in various sizes and are easily scaled for both domestic and utility-scale purposes. The biogas system is, in itself, rather low-tech and a mature technology. Millions of biogas systems are already in use worldwide, even if plants producing electricity from biogas is still an option under development for rural areas.

Even if the biogas systems are easily scaled and the raw material for biogas production is easily available, there are certain requirements for raw material handling – sewers or carrying buckets, as well as requirements for the distribution of gas, e.g. through a pipeline system, that pose possible obstacles regarding safety and maintenance.

The biogas plant is not dependent on geographical location and has no need for availability of additional natural resources. The biogas plant can operate around the clock and on demand, which means that no energy storage is necessary.

Due to the need for infrastructure to handle raw material and the produced gas, there are costs connected with the biogas production unit itself. For smaller plants in rural areas, this might result in a less cost-effective option for electricity generation.

Human waste may be one of the most abundant energy resources in a crowded refugee camp, and it is associated with health and pollution issues in the camp and outside. A quick calculation suggests that a camp with 50 000 persons, half of them children, would be able to generate 1 800-1 900 m^3 of biogas per day from human faeces alone. This biogas could either be used for direct combustion, generating heat for cooking or other uses, or converted to electricity. Assuming a modest conversion efficiency of 25% from biogas to electricity, this would result in approximately 2,7 MWh of electrical energy per day.

In gaseous form, this amount of biogas would be able to cook about 7 000 meals, assuming a requirement of heat energy of about 1,5 kWh/meal. If electricity is used, a mere 1 700 meals could be cooked with the same energy. This means that biogas could provide a good share of the cooking needs for a camp, but not cover the need completely. It also means that the energy generation capacity is limited on the whole.

If infrastructure investments in sanitation and sewage treatment are done for other reasons, the biogas option seems attractive. If no such initiatives are planned, then the viability of the infrastructure would rest on biogas production, which would probably not be sufficient.

Table 11 Summary biogas

Biogas		
Technological maturity	Biogas production and electricity generation from biogas are well-known technologies. There are specific requirements for the handling of raw materials and gas.	Green
Capacity ranges	Biogas generation is flexible in size and installed capacity.	Yellow
Energy availability	No natural resources and specific geographical conditions are applicable for biogas production.	Green
Cost	The need of infrastructure for raw material handling and gas distribution the construction costs can be high.	Red
Mini-grid compatibility	Biogas-based generation is suitable for utility-scale systems as well as mini-grid systems, but mini-grid options are still under development for rural areas.	Red
Energy storage need	Energy storage solutions are not necessary.	Green

5.8 Biomass energy

Biomass energy is simply based on the conversion of different types of materials such as wood, agricultural waste.

The most common type of conversion for biomass into electricity is by direct combustion or by pyrolytic gasification depending on type of feedstock. Some other available options for electricity generation were described in section 5.7 above. The direct combustion method creates high pressure steam that drives a turbine generator which produces the electricity, while gasification options generate electricity with an internal combustion engine running a generator.

Bioenergy is one of the oldest and most common forms of converting a fuel into useful energy. Even though the reference projects with biomass electricity generation in mini-grids are limited, there are several small-scale applications available in ranges from a few kW to several MW.

Since the production of steam is dependent on the availability of raw material, a raw material storage is usually necessary along with a continuous supply of raw material. According to NREL[5] the land take for biomass-energy generation is around 1,4 ha/MW.

Table 12 Summary biomass energy

Biomass energy		
Technological maturity	Biomass energy is one of the oldest technologies for energy generation. The technology is well-developed and mature, with potential in SSA.	
Capacity ranges	Electricity generation from biomass is flexible in size and installed capacity.	
Energy availability	No natural resources and specific geographical conditions are necessary for biomass electricity generation, but availability of raw material is necessary.	
Cost	The need for infrastructure for raw-material handling can results in high construction costs.	
Mini-grid compatibility	Electricity generation from biomass is suitable both for utility-scale systems as well as mini-grid systems, but the available references from ongoing mini-grid projects utilising biomass energy as a main source for generation are still limited.	
Energy storage need	Energy-storage solutions are not necessary, but raw-material storage and a continuous supply of raw material is necessary.	

5.9 Waste energy

There are different forms of waste energy, the most common being waste from households and industries. Waste from sources such as construction, pulp and paper, forest products, and pharmaceuticals, foods and beverages, biodiesel, manure, landfill gas etc., are usable.

Many of the listed fuels for waste energy are available as soon as there are humans in an area. Waste-energy technology in practice is very similar to that described under section 5.8 Biomass Energy – the waste is combusted, which creates high-pressure gas that is transmitted to a turbine where it is converted to electricity. The process is well-developed and mature. Development is still ongoing in regard to adaptations for new types of waste fuels.

As for biomass and biogas generation, storage of waste is necessary in order to secure continuous electricity generation. If the waste fuel is continuously available, no energy-storage solution is necessary since the generation can be operated in response to the varying demand. This means that the waste-energy plant is not dependent on geographical location and poses no need for availability of natural resources as long as waste fuels are available. The land take for waste energy is similar to that of biomass energy plants, 1,4 ha/MW, and the size and capacity is flexible. Mini-grid reference projects for waste-energy generation are still rare.

Table 13 Waste energy summary

Waste energy		
Technological maturity	The generation of energy from waste utilises one of the oldest technologies for energy utilisation, combustion. The technology is well-developed and mature, with potential in SSA.	
Capacity ranges	Waste-based electricity generation is flexible in size and installed capacity.	
Energy availability	No natural resources and specific geographical conditions are applicable for waste electricity production, but fuel availability is necessary.	
Cost	The need for infrastructure for fuel handling (varies with the type of fuel) results in potentially high construction costs.	
Mini-grid compatibility	Electricity generation from waste is suitable both for utility-scale systems as well as mini-grid systems, but the available references from ongoing mini-grid projects with biomass energy as a main source for electricity generation are limited.	
Energy-storage need	Energy-storage solutions are not necessary, but a fuel storage and a continuous supply of fuel is necessary.	

6 COOKING ENERGY TECHNOLOGY OPTIONS

In this section several cooking energy sources and technologies are reviewed. While focus has been on clean cooking technologies, also traditional technologies are reviewed.

Many of the so-called clean cooking technologies have little to show for their claims, and are rarely evaluated in relation to their objectives, which makes it difficult to recommend them.

Innovative solar PV technologies that claim to be able to fill the cooking needs of a household in real-life conditions are being developed. These are seen as a great opportunity to provide decentralised cooking energy in refugee camps, thereby reducing the load on an electric grid.

LPG is a mature cooking energy technology that also seems very adequate in this respect.

Since cooking energy will be the major energy demand in a refugee camp, and since "Clean cooking" is one of the objectives, we present a brief summary on cooking energy. Some of what is included here will have been presented elsewhere in this report.

6.1 Biomass energy as a fuel for cooking

Wood and charcoal are the energy sources discussed here, although waste energy and the substrate for biogas production could also be considered forms of biomass energy.

6.1.1 Wood

Wood can be used untreated as a cooking fuel, and with extremely limited additional resources. The simplest form is to use twigs and branches in a fire built between three stones. The large demand for wood in a refugee camp either forces people to spend time collecting wood in the surroundings, or it creates a market for wood collected by others and sold to refugees. In both cases, the use of wood places a strong pressure on local resources, and can cause deforestation in the areas around camps, as well as competition for resources with host communities, and animosity between them and refugees.

Wood use has been seen as a problematic fuel during the past fifty years.[19] Several reasons have been used depending on what is considered the major problem of the day. These have usually been formulated by persons and groups outside the communities using the resource. Very broadly summarized:

1970: "The poor man's energy crisis": Energy shortage

1980: Deforestation, depletion of natural resources

1990: Air pollution and health

2000: Women and energy

2010: Emission of greenhouse gases

Depending on the problem of the day, similar responses have been put in place: Improved stove programs, training and awareness programs, all with donor support. Regardless of the objective, the effectiveness in these measures have not been unambiguously documented in real-life situations.

6.1.2 Processed wood - briquettes

In processed wood biomass, such as briquettes, the fuel is in small pieces and intended for used in an enclosed combustion compartment. Unless a very careful estimate can be made of how much is

[19] *Or even seventy years. In India, improved stoves were being developed as early as 1953, see Gill (1987)*

needed, and to manage the cooking in accordance with the various burning phases of the fuel it is likely that using briquettes is going to be more wasteful than using traditional wood.

A way to come around the issue of deforestation has been to try and exploit “waste” wood, such as from the wood of *Prosopis* spp., considered to be an invasive and thus unwelcome species in many parts, although previously popular for reforestation. However, any processing of wood, no matter the source, will involve several steps that add to the cost of fuel. These include investment costs in the equipment, operating costs such as cutting and chopping, transportation, adding binder, pressing at high pressure, transporting and commercialising. This means that briquettes will come at a cost that has to compete with local sources of “free” wood, which it usually cannot do.

6.1.3 Charcoal

Charcoal is the major fuel for the urban poor in Africa. Its popularity stems not only from its actual properties (high energy density, ease of transport, simple to use and that it does not deteriorate during storage), but rather because it is integrated in the informal economy, able to provide fuel for cooking at all times. It is true that charcoal prices fluctuate over seasons, increasing in the rainy season and decreasing towards the end of the dry season. This is partly due to rural transportation difficulties, but also because of its role as a source of income for rural people. They burn charcoal in the dry season to generate cash for buying seeds, fertilizer and farm implements for the coming cultivation season. This increases supply at the end of dry seasons, reducing the price. When it is time for farming as the rain comes, farmers do not burn so much charcoal which increases the price.

The main reason charcoal has maintained its position in providing the poor of sub-Saharan Africa’s megacities with household energy is the failure of the societies to provide modern energy sources. Most attempts to do that have failed for a number of reasons. Subsidy programs for kerosene and gas have not been upheld or been possible to uphold due to lack of funds, corruption, and diversion of resources. Electricity networks are poorly extended, and poorly maintained and repaired. This means even those connected to electricity cannot use it in a sustainable way. The most blatant example at present (2020) is Zambia, with over 20 hours of load-shedding per day. Sometimes power comes on in the middle of the night. This makes it impossible to rely on energy for cooking, let alone for refrigeration or other purposes requiring uninterrupted supply. While not everywhere is as bad as Zambia, blackouts are frequent and repair times are long. This makes many people rely on charcoal, which, in spite of price fluctuations, is always available.

In comparison with wood, charcoal is a relatively benign fuel in terms of emissions in the kitchen, as most of the associated emissions will have occurred at the place of production. While charcoal users in a study were exposed to about 50% higher doses of respirable particulates than electricity users, they were exposed to less than half the doses of wood users.[20] Still, the carbon laid down in the woody biomass is all released, whether in the forest or in the kitchen.

The same cost factors as for briquetting come in for “improved” charcoal production, which is charcoal produced at (possibly) higher efficiency in industrial kilns than that produced in the artisanal kilns used by local people in much of Africa. Charcoal produced in this way has never not able to compete with the artisanal charcoal, except in very specific instances, such as if it can be produced where there is a waste flow of wood left-overs with no other use. This is found at timber mills and carpentry workshops. In addition to the higher cost, this form of production also competes with an income source for poor rural people, whose only source of monetary income charcoal burning frequently is.

6.1.4 Ethanol

Ethanol as an energy carrier is another example of biomass energy. The production is based on fermentation of sugars or cellulose using yeast. Production can be feasible in areas with rich supply of low-cost cellulose/sugar substrates, such as nearby sugar processing industries. The process as such can be seen as a conversion of energy from a less to a more convenient form of energy carrier. Ethanol as a

[20] *Ellegård, A. and H. Egnéus, 1992. Exposure to biomass fuel pollution in Lusaka. Energy Policy 21(5) 615-622*

cooking fuel has been established with donor assistance in Jijiga refugee camp in Ethiopia. It includes community engagement and business cooperatives.[21]

Ethanol projects have had limited success, largely due to its strong sensitivity to political measures, which have tended to promote as well as counteract development. In the setting of a refugee camp, ethanol as a fuel is only feasible if there is a reliably supply relatively nearby. In a project in Kakuma refugee camp, ethanol stoves made some early success, but the initiative was ended due to shortage of fuel and transportation restrictions.[22]

6.2 Wood stoves

Improved stoves have not been a success, regardless of the problem they have been proposed to solve. Regarding efficiency, this is hardly surprising since most improved stove developments have measured their success against the three-stone fire, which has generally been assumed to have an efficiency of about 5% of energy from the wood reaching the pot. This turned out to be an estimate made by a World Bank officer in the early seventies, when he was citing a grey research paper by himself, quoting a paper with no efficiency figures in it. Instead, the actual realistic efficiency of three-stone fires was more likely around 15%, reducing the advantage of improved stoves substantially.[23]

A part of the lack of success comes from the lack of data and sound monitoring practises, but also of a lack of understanding of the actual cooking situation and practises used by the women cooking. For instance, a three-stone fire makes it perfectly feasible to remove the remaining wood once cooking is finished, quench the burning bits in the sand and use them as fuel for the next meal. This makes the three-stone fire more efficient than any “improved” stove requiring fuel to be chopped in small pieces – or using briquettes – and burning them - however efficiently - in an enclosed fire compartment. All fuel that goes in there is lost, regardless of whether it is actually used for cooking or for other purposes, and how efficiently it was combusted.

An issue relating to efficiency and air pollution is that “improved” stoves have tended to improve efficiency by burning more slowly, i.e. with less combustion efficiency. This might improve the energy efficiency, but at the expense of more pollution. On the other hand, reducing the emission of pollutants, especially smoke or “particulates” requires combustion efficiency to be high, and draught through the stove to be increased. This increases the temperature and efficiency in converting carbohydrates (wood) into carbon dioxide and water. But it often reduces the efficiency of the heat absorbed by the pot.

Turning to the climate issue, there is a real argument to be made for improved stoves. In this case an improvement in energy efficiency (less wood used) as well as improvement in combustion efficiency (less smoke emitted) would work to reduce greenhouse gas emissions. The latter is to a large extent due to the reduction of particulates emitted, as these are “products of incomplete combustion” (PIC) and are even more potent greenhouse agents than carbon dioxide. However, it has not been systematically shown that any improved stove program can deliver on either of these tasks.

6.2.1 Three-stone fireplace

Probably dating back to the time of the Neanderthals, this cooking technology requires no input other than fuel and three stones. Originally thought to have been extremely wasteful and inefficient, this has been re-evaluated. The efficiency is probably around 15% from wood to pot, maybe higher if the half-used fuel is removed and quenched.

Developments have taken place in Asia, where additional stones are inserted to increase thermal momentum. This is said to be able to reduce wood consumption by 50-80%, based on laboratory and field

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[21] Moving Energy Initiative 2019. Cooking in Displacement Settings Engaging the Private Sector in Non-wood-based Fuel Supply. Annex 1: Establishing Community-owned Ethanol Business Cooperatives

[22] SNV/MBEA 2020

[23] Gill, Jas (1987). Improved stoves in developing countries - A critique. Energy Policy, 15, 135-144

tests. There was, however, no claim that this would improve health outcome due to less exposure to pollution.[24]

Cost = none

Availability = ubiquitous

6.2.2 Improved woodstoves

Improved cookstoves come in a variety of shapes and forms. For use with wood fuel, the most common approach is to create a closed firing compartment which will cause the fire to benefit from higher temperatures. The stove can be made from bricks and clay, forming rather large stoves with considerable thermal momentum and useful for space heating where such is required. A chimney is sometimes introduced in order to reduce exposure to harmful smoke pollution, however with the effect that fuel efficiency deteriorates. Stoves with several pot seats may increase efficiency, since more can be cooked with the same fire. The efficiency and cleanliness gains are, however, defeated if a multi-seat stove is used without covering vacant pot seats. Steel or ceramic wood stoves suffer from the need to cut the fuel into small pieces or to use briquettes. This also reduces the possibility to salvage part of the fuel if cooking is finished before the fuel has burnt out.

The claims of improved woodstoves to be able to contribute to reduced deforestation or improve health of women using them have not been systematically substantiated. Evaluation of improved stoves programs tend to evaluate what is possible to assess, such as number of stoves distributed, number of manufacturers trained, etc. Hence improved wood stoves are not considered realistic options either to reduce energy demand or to improve environmental variables. They have not proved be able to reach their efficiency targets, and virtually no project has taken off beyond donor-funded pilot schemes.

Cost = low

Availability = patchy

Meeting clean cooking requirements = doubtful

6.3 Improved charcoal stoves

While a number of improved charcoal stoves have been presented, there is only one technology that has been really successful: The “Umeme jiko”[25], presented at the UNDP energy conference in Nairobi in 1981.[26] This stove is a development of the traditional charcoal stove, and mainly consists in inserting a ceramic lining inside a sheet steel casing. This stove took off to the extent of self-propagation in Kenya but has also been disseminated through World Bank and other programs in other parts of sub-Saharan Africa.

The probable reason for the success of this stove is: It is a better stove!

The traditional charcoal stove which is just a sheet-steel bucket with holes in it deteriorates within a few months. The stove actually burns up from the heat of the charcoal. With the ceramic lining, the casing is protected, and it can last for several years. Even if the lining cracks, the stove remains functional since it is held together by the casing. Also, once production is up, the lining does not cost much, as raw material (clay) is mostly available for free, production is simple, and creates local income.

The Umeme jiko and its siblings has been able to expand in the normal markets of SSA, to the extent that a charcoal stove with ceramic liner, or a ceramic liner without steel sheet is now almost the standard among charcoal users in many countries.

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[24] *Stockholm Environment Institute 2020*

[25] *Kiswahili for “Lightning stove” as it was marketed as being faster than the traditional one. Incidentally it also means “Electric stove”, as “Umeme” is the word for lightning as well as electricity in Kiswahili.*

[26] *UN Conference on New and Renewable Sources of Energy Nairobi, 10-21 August 1981*

Figure 13 Improved stove of the Umeme Jiko type

Photo by Inhabitat®

6.4 Electric cooking

Since the objectives of this report include to investigate electrification and clean cooking technologies, the various forms of electric cooking need to be addressed, especially since we have found that cooking is by far the largest energy need in a refugee camp, and most likely also among host populations.

Electric cooking can be very efficient, but on occasion also rather wasteful. It is wasteful if the electric stove is a heating coil, and heat is transferred to the pot by radiation. It is also wasteful if the stove and pot are not smooth and even but have bumps or warps. It can be assumed that many of the pots used in refugee situations are far from smooth and even, adding a requirement to include a suitable pot with the electric stove.

The US Department of Energy has made tests of various electric cooking technologies, including smooth plate, coil and induction cooking.[27] There it was found that the efficiencies in a simulated cooking test were rather similar for the various technologies, but significantly higher than for cooking with gas. Earlier reports of 85-90% efficiency in the induction cooking appear not to be substantiated. However, the induction stove has advantages in that it is very fast, and can be instantaneously regulated, which is important if loads need to be managed in some way.

Table 14 Cooking technology efficiencies according to USDOE

Stove technology	Efficiency
Smooth hotplate	70%
Electric coil	71%
Induction unit	72%
Gas stove	44%

[27] *Federal Register* / *Vol. 79, No. 232 / Wednesday, December 3, 2014 / Proposed Rules*

6.5 Gas cooking

Using liquefied petroleum gas (LPG) for cooking is convenient, fast and without smoke, other than that from the food itself. It is easily adaptable to different cooking procedures and foods, quick and simple to regulate, which is why it is a favourite source of cooking energy for professional chefs and many housewives alike. In some locations, such in Bangladesh and Rwanda, LPG is favoured as a fuel in refugee camps, largely in order to preserve scarce resources of wood for fuel. In Kenya, an initiative was launched by Moving Energy Initiative to engage the private sector for supply of energy to a camp, where the selected option was with an LPG distribution company.[28] A recent study concludes that LPG causes minimal household pollution and negative health impacts, much less than biomass fuels (including improved cookstoves), and on par with biogas and alcohol fuels.[29]

The drawbacks of LPG include that it is a fossil fuel, hence adding to GHG emissions but to a less extent than wood, see section 10; that it requires specific appliances (stove, gas bottle and pressure reduction valve); and a distribution network. In addition, use of LPG is associated with risks of fire, and even explosions from leaking tubes. A further drawback is that LPG always has an operating cost, i.e. the gas purchase is a running cost throughout. As noted in Table 14, the efficiency of a gas stove is less than 50%.

6.6 Pressure cooking

Regardless of the source of energy, using a pressure cooker can reduce the energy need for cooking substantially. This is largely because less water is needed in the cooking process. Pressure cooking is also much faster than conventional cooking and can reduce cooking time by about 30%, while using up to 75% less energy. [30] Hence pressure cooking can reduce the need for energy for cooking, regardless of the source.

The main drawbacks of pressure cooking include the relatively high cost of the cooker, and that it contains some delicate details that need to be kept clean, which may be a challenge in scarce circumstances and with lack of water. There is also a considerable risk of scalding, when pressure is released after cooking is finished. The steam and vapour are very hot and can easily inflict burns, for instance in children sitting near the stove.

6.7 Solar cooking

Solar cooking can be done essentially using three technologies, passive heat, concentrated heat, and solar electricity.

6.7.1 Passive solar heat – the hay box

This technology uses the green-house effect in a small scale. It is a box with a glass or plastic lid, where pots can be placed. Pots are insulated downwards with hay or grass or other insulating material. Cooking is then a very slow process, which will take several hours, and with the food exposed in the sun. For various reasons this technology has not taken off. For lack of evaluations, it can be speculated that the method is not very adaptable, requires a rather long planning perspective, leaves food out in the sun (where traditionally it is not supposed to be), does not lend itself to dishes that require stirring or stomping, etc.

Cost: low

Availability: Theoretically available everywhere

Applicability: Not very

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[28] Moving Energy Initiative, 2018. *Laura Patel and Katie Gross: Cooking with Clean Fuels: Designing Solutions in Kakuma Refugee Camp*

[29] *Norad 2020. Study on the potential of increased use of LPG in developing countries. Multiconsult*

[30] Fine Cooking Magazine

6.7.2 Solar PV cooking

Recently, systems have been developed for solar PV cooking. We have encountered two of these, one is the Danish (PESITHO[31]) and the other is the Swedish (Solar Bora[32]), working with slightly different concepts.

PESITHO[33]

The PESITHO system is a solar home system built around a cooking unit. It consists of a solar panel, and a cooking unit with a well-insulated pot. Two lamps and a chargeable torch are also provided. The system is modularized, consisting of eight modules. A system can then be assembled in eight minutes only. The key component is a Li-ion battery of high quality. The solar panel has a capacity of 275 Wp, and is able to charge the battery with 614 Wh per day. The cooking unit has a 400 W heat element that is operating in cycles and keeps the pot contents within 5 °C of set temperature. The unit is said to be 95% energy efficient.

The system has been tested in the field, in Myanmar (50 units) and in Uganda (10 units) and is able to provide cooking energy sufficient for cooking three meals per day for a family. PESITHO works through local subsidiaries, such as for instance local solar PV providers. PESITHO has started an assembly industry in Kampala with a capacity to produce 750 units per month, however presently not operational due to current pandemic restrictions.

The business model is to provide the stoves on a credit that is to be repaid within certain period of time, selectable 1, 3 and 5 years. Surprisingly many have so far selected the shortest payback period, indicating that people using the system value its services. The full cost of the system is USD 525.

The business model allows to provide a subsidy component, for instance when targeting refugees. In current experience they have two levels of subsidy, with users paying USD 175 or 240 up-front.

Calculations made by the company claims that the purchase of a unit will result in net profit after some years, when comparing to other commercial fuels such as LPG. There is also a great saving in time, allowing the person cooking (usually a woman) time for more beneficial activities, such as studies or commerce.

PESITHO is cooperating with CARITAS, a large charity organisation, as well as with the UN World Food Program.

Solar Bora[34]

Solar Bora provides two sizes of system, one for households and one for larger entities such as schools, health centres and enterprises. The system is based around a solar PV panel which provides energy to one or more induction cookers.

The business model is not to sell the units, but to lease them to users. Users are estimated to save 4-5 hours per day, thereby freeing time for sustainable income-earning activities. Solar Bora encourages cooperative cooking.

Solar Bora collaborates with UN Habitat and World Vision and has a pilot project in Mali with 10 households and one in Kenya with two health centres.

[31] *https://pesitho.com/*

[32] *https://www.solarbora.com/*

[33] *Simon Buss la Cour, Chief Operations Officer PESITHO, pers. comm. Dec 2020*

[34] *Robert Sundqvist, Chief Sales Officer, Solar Bora, pers. Comm Dec 2020*

7 Energy storage

Energy storage can be achieved using a number of technologies.

Energy storage solutions can be categorized as chemical, electrical, electrochemical, mechanical or thermal energy storages

The simplest being storage in the form of fuel, which is applicable to liquid and solid energy sources. Storing electric energy can be achieved through several techniques, such as chemical energy in batteries, conversion to hydrogen, pumped water, flywheel technology etc.

The need for energy storage can be reduced by careful selection of energy sources and adaptation to demand patterns as well as supply patterns of intermittent energy sources such as wind and solar energy.

7.1 Chemical energy storage

Chemical energy storage usually means storage as the gas hydrogen. Electrical energy is used to electrolyse water into oxygen and hydrogen. Typically, this can be used if there is excess renewable generation (solar or wind) where and when the usage is smaller than the generation. The hydrogen is stored in tanks, and when electricity is needed again hydrogen and oxygen are combined producing electricity, heat and water. Using fuel cells is an advanced mode of electricity generation from hydrogen, but traditional combustion of the gas to produce steam in combination with a turbine can also be used.

Hydrogen has a high energy density and can be used for long term energy storing. It can provide energy storage for the capacity needs discussed in the energy demand section 3.2. The storage itself can be cost effective but the overall feasibility depends on the electrolysis solutions and the re-generation of electricity from the stored hydrogen.

Table 15 Chemical storage evaluation[35]

Storage solution	Capacity ranges	Cost per kW or kWh	Technology maturity and availability in SSA
Hydrogen from electrolysis in Fuel cells / combustion	1 kW – 1 GW 10 kWh – several GWh	Storage costs low, but electrolysis and re-generation costs are high. 2000 – 5000 USD/kW	Low in general, but several test sites in South Africa

Table 16 Chemical storage vs electricity demand scenarios

Electricity demand scenarios	Capacity ranges	Cost per kW or kWh	Technology maturity and availability in SSA
High – 6,9 MW	■ (green)	■ (red)	■ (red)
Medium – 3,6 MW	■ (green)	■ (red)	■ (red)
Low – 0,9 MW	■ (yellow)	■ (red)	■ (red)

[35] *Sweco 2018*

7.2 Electrical storage

Electrical storage can be done with capacitors or super conducting magnetic energy storages. These are advanced storage technologies that are hardly commercially viable and probably not available locally in the targeted regions. They are also adapted for short energy needs at high power and the cost per kWh therefore becomes high.

Capacitors consist of two conductive separated plates. Capacitors store electrical energy in the form of electrical charge accumulated on the plates.

In a superconductor a current will flow even after the voltage source is removed. The energy is stored as a magnetic field generated by the current and is released by discharging a coil.

Table 17 Electrical storage evaluation[36]

Storage solution	Capacity ranges	Cost per kW or kWh	Technology maturity and availability in SSA
Electrical storage	200 kW – 40 MW 0,01 kWh – 20 MWh	Adapted for short high power needs only. Cost per kWh becomes high. 900 – 9000 USD/kWh	Low

Table 18 Electrical storage vs electricity demand scenarios

Electricity demand scenarios	Capacity ranges	Cost per kW or kWh	Technology maturity and availability in SSA
High – 6,9 MW	🟥	🟥	🟥
Medium – 3,6 MW	🟥	🟥	🟥
Low – 0,9 MW	🟨	🟥	🟥

7.3 Electrochemical storage

Electrochemical energy storage includes the entire range of different battery types. The Lithium-ion batteries are now the dominant type of batteries found in small portable electronic applications due to their high energy density, low weight and high efficiencies. This battery type is also used on a larger scale for power grid storage purposes and can provide energy storage for the capacity needs discussed in the energy demand section 3.2. The costs have been high but are falling as the technology development is driven by the electric vehicle industry.

Other battery types, that could also be scaled up to the needs discussed, include lead-acid batteries, Nickel-Cadmium batteries and Nickel-metal hydride batteries. These are commercially mature technologies for re-chargeable batteries, and they can be a cheaper solution than the Lithium-ion batteries especially when considering local availability in some areas, but depending on how they are handled, they can give a negative local environmental impact.

Other battery types are deemed unsuitable, either due to lower maturity, maintenance need, cost or capacity limitations. These include Flow batteries, Sodium Nickel Chloride batteries, Sodium-Sulphur Batteries and Metal-air batteries.

[36] *Sweco 2018*

Table 19 Battery storage evaluation[37]

Storage solution	Capacity ranges	Cost per kW or kWh	Technology maturity and availability in SSA
Lithium-Ion Batteries	1 kW to 50 MW Up to 20 MWh Increasing	700 - 1300 USD/kWh 605 USD/kWh [WB] avg. mini-grid projects. 209 USD/kWh [WB] EV industry benchmark 150 - 1000 USD/kW Decreasing prices WB]	High/medium
Lead-Acid batteries	Up to 20 MW Up to 40 MWh	100 - 200 USD/kWh 219 USD/kWh [WB] avg. mini-grid projects. 100 – 500 USD/kW Increasing prices [WB]	High/high

Table 20 Battery storage vs electricity demand scenarios

Electricity demand scenarios	Capacity ranges	Cost per kW or kWh	Technology maturity and availability in SSA
High – 6,9 MW	🟨	🟩	🟨
Medium – 3,6 MW	🟩	🟩	🟩
Low – 0,9 MW	🟩	🟩	🟩

7.4 Mechanical energy storage

Mechanical energy storage such as flywheels or pumped hydropower are mature technologies, but emerging alternatives as compressed air (with heat recovery), pumped heat electrical storage and cryogenic / liquid air energy storage also exist.

In a flywheel a rotor is accelerated to high speed and energy is stored as kinetic energy in the rotating mass. Flywheels are mainly used as frequency balancing solutions in short time frames but can also provide energy storage in longer time frames and could possibly meet the energy needs discussed in section 3.2, page 6. However, the scale of the wheels and the cost might not be compatible for these large needs, except as frequency support.

A pumped hydro storage system requires two water reservoirs, upper and a lower, and water is moved between these two levels. By using surplus (or cheap) electricity to pump water from the lower reservoir to the upper reservoir, energy can be stored in the form of gravitational potential energy, which can then be converted back into electrical energy at a later time by allowing the water to flow back down from the upper to lower reservoir though a turbine and generator using conventional hydroelectric technology. The technology is mainly used for larger needs than what is discussed in section 3.2, but the small-scale pumped hydro is becoming more and more feasible for mini-grid sizes. However, the local topology and geographical conditions make it suitable only at specific sites.

[37] *Sweco 2018, WB 2019*

Table 21 Flywheels storage evaluation[38]

Storage solution	Capacity ranges	Cost per kW or kWh	Technology maturity and availability in SSA
Flywheels	10 kW - several MW 25 kWh - several MWh	1300 - 3800 USD/kW	Low

Table 22 Flywheels storage vs electricity demand scenarios

Electricity demand scenarios	Capacity ranges	Cost per kW or kWh	Technology maturity and availability in SSA
High – 6,9 MW	Red	Red	Red
Medium – 3,6 MW	Red	Red	Red
Low – 0,9 MW	Yellow	Red	Red

Table 23 Pumped hydro storage evaluation[39]

Storage solution	Capacity ranges	Cost per kW or kWh	Technology maturity and availability in SSA
Pumped Hydro	50 MW – 3 GW 0,5-20 GWh	12 - 26 USD/kWh 550 - 1800 USD/kW	Medium, site specific

Table 24 Pumped hydro storage vs electricity demand scenarios

Electricity demand scenarios	Capacity ranges	Cost per kW or kWh	Technology maturity and availability in SSA
High – 6,9 MW	Yellow	Green	Yellow
Medium – 3,6 MW	Red	Yellow	Yellow
Low – 0,9 MW	Red	Yellow	Yellow

7.5 Thermal energy storage

Thermal energy storage is mostly spoken of in the form of molten salt solution, which is used in Concentrated Solar Power, CSP. The heated molten salt solution is stored in tanks and can be used at any time to make steam out of water. Typically, the CSP extends the generation curve, compared with direct PV power, for a couple of hours after sunset.

[38] *Sweco 2018*

[39] *Sweco 2018*

Table 25 Thermal storage evaluation[40]

Storage solution	Capacity ranges	Cost per kW or kWh	Technology maturity and availability in SSA
CSP with molten salt for steam generation	several MW	-	Only large-scale solutions commercially viable

Table 26 Thermal storage vs electricity demand scenarios

Electricity demand scenarios	Capacity ranges	Cost per kW or kWh	Technology maturity and availability in SSA
High – 6,9 MW			
Medium – 3,6 MW			
Low – 0,9 MW			

[40] Sweco 2018

8 MINI-GRID CONCEPT RECOMMENDATIONS

This chapter puts together the assessments in the previous chapters into recommendations for the concept of a mini-grid. The recommendations concern the network (grid) aspects, and include source, storage and back-up for electricity provision only. Individual solutions for clean cooking are not discussed. The recommendations are kept generally applicable and not site specific.

For the concept of a renewable based mini-grid the Low demand scenario with a simpler distribution network makes most sense. The sources most feasible are solar PV, maybe wind, but also hydro if the site allows and if the demand is in the higher end. The storage should be battery-based if the site conditions and demand does not motivate pumped hydro.

8.1 Distribution network

If a mini-grid should be based in a renewable source, installed at the site of the camp or host community, and be combined with energy storage with back-up generator in line with what is available on the market, it makes most sense to **aim for the Low demand scenario**. The Medium and High demand scenarios would be more dependent on other sources and take up very large land areas and be very dependent on the back-up system which is costly to base on only renewable fuel. Both the back-up and the storage would also have to be at a scale that is in the higher end (or even outside) of what is common for renewable mini-grids.

Looking at the distribution grid alternatives described in section 3.4 the recommendation lands in either a **simpler distribution system on low voltage (<400 V) where the consumers are close to the source** (<500 m) or as described in the project scenario 2, a **distribution network only for certain uses, where transformation to medium voltage (>5 kV) could allow longer distances**, but where the total load probably still is in line with the Low demand scenario. By having multiple generation sites within the camp and host community also larger areas could be covered.

Table 27 Qualitative assessment of distribution network solutions

Energy demand scenario	**High** 6,9 MW Project scenario 1 – Full electricity coverage	**Medium** 3,6 MW Project scenario 1 – Full electricity coverage with DM	**Low** 0,9 MW Project scenario 1 – Full electricity coverage but not for cooking	**Low** ~0,9 MW Project scenario 2 - Electricity for certain energy services
Network solution	-Single source -MV-network	-Single source -MV-network	-Multiple sources -Multiple isolated LV-networks	-Single/multiple sources -MV-network
Overall mini-grid concept suitability	■ (yellow)	■ (yellow)	■ (green)	■ (green)
	■ (yellow)	■ (yellow)	■ (green)	■ (green)

8.2 Energy sources

Several different technical solutions for electricity production covering the electricity need according to the three demand scenarios; low, medium and high have been discussed in section 5. The generation source must provide renewable electricity to meet the refugee camp demand as well as to provide surplus electricity production for the host community. If cooking is to be covered by the electricity production source and storage solution it is necessary to provide a system meeting the high capacity scenario.

Table 28 Qualitative assessment of energy sources

	Solar PV	Wind Power	Hydro-power	Solar CSP	Biogas	Biomass Energy	Waste Energy	Geo-thermal Energy
Technology maturity	Green	Green	Green	Green	Yellow	Green	Green	Yellow
Capacity ranges	Green	Green	Green	Red	Green	Green	Green	Yellow
Energy availability	Green	Yellow	Red	Yellow	Green	Yellow	Yellow	Red
Cost	Green	Green	Yellow	Yellow	Red	Red	Red	Red
Mini grid compatibility	Green	Green	Green	Red	Red	Yellow	Red	Red
Energy storage need	Red	Yellow	Green	Yellow	Green	Yellow	Yellow	Green
	Green	Green	Green	Yellow	Yellow	Yellow	Red	Red

A few of the studied technologies for electricity production have been found to lack references from successful and ongoing projects while other have lacked feasibility for smaller solutions and included specific demands on site and access to natural resources.

Even if all studied technologies have shown to offer good potential in SSA, the lack of references and in some cases high demands on geographical conditions or access to natural resources leads to the conclusion that the most feasible solutions accessible without consideration to site location and system size (depending on whether cooking should be included or not) should be put for further study.

According to the evaluation performed for each studied technology **solar PV systems** and **horizontal axis wind turbines** are the most easily adapted electricity production sources and also the most cost-effective solutions. They are both scalable and complement each other with regard to difference in production profile. However, for the high demand scenario, none of these sources could provide sufficient electricity generation on its own and neither of them can with ensure uninterrupted electricity production throughout the day and night. According to this, an energy storage solution is needed as well as a peak power solution to cover the highest peaks. Otherwise the sizing of the power generating system will be unrealistic large in order to cover the whole demand.

If the geographical conditions allow some other of the studied technologies above to be feasible an evaluation for this should be performed in order to find the best system solution. But for a general case applicable at any location the combination of solar PV systems and wind turbines together with storage solutions and peak power is the recommended solution.

8.3 Energy storage and peak power support

Different technologies for energy storages have been evaluated as being part of a mini-grid providing electricity for the three energy demand scenarios in section 3.3. Most of the evaluated storage solutions could provide support in the outlined capacity ranges but they are deemed unsuitable due to costs, technology maturity or availability.

The suggestion will be to **use batteries as the storage** in the mini-grid. Both lead-acid batteries and **lithium-ion batteries** are proven solutions in many mini-grid projects. While the cost per kWh for lithium-ion batteries is falling, the cost for lead-acid batteries is increasing. It is likely that the lithium-ion batteries will be the cheaper alternative within the coming years. Batteries are appropriate for all the demand scenarios, but maybe more feasible in the two lower scenarios as the high scenario will require battery capacity at the larger end of what is usually provided in mini-grid projects.

By having peak power support from a **flexible back-up** source, the dimensioning of both the main source and the energy storage can be reduced. If the peak demand must be met at any time it will require, in the case of PV-panels, an extremely large area, and batteries of a size that is unusual on the market. The peak power support is usually done by a traditional diesel generator, but alternative, **renewable-based fuels**, can be used. The alternative fuels bring a higher cost and are in some cases more complex logistically.

Combining different renewable sources, for example, wind and solar, increases the diversification and reduces the need for storage and back-up.

Pumped hydro could be a solution if the geographical circumstances are suitable, but pumped hydro solutions are feasible mainly for larger installations. Maybe it could be a solution for the higher of the three demand scenarios, but this must be evaluated after the location is selected since it is very site specific.

CSP with molten salt as short-term storage is a maturing technology for renewable power plants, but it is usually not used for the capacity demands in the outlined demand scenarios, and not common in mini-grid projects. If there are strong incentives from any of the stakeholders to embark on emerging technologies, the solution could be considered mature enough also for mini-grid projects, but probably only for the higher of the demand scenarios. The molten salt is a short-term storage that only extends the solar production a few hours after sunset. For other needs an additional storage solution will be needed which makes the alternative less compatible.

Table 29 Qualitative assessment of energy storage for the low demand scenario

	Hydrogen	Electrical	Battery	Flywheels	Pumped hydro	CSP Molten salt
Technology maturity/ availability	Red	Red	Green	Red	Yellow	Red
Capacity ranges	Yellow	Yellow	Green	Yellow	Red	Red
Cost	Red	Red	Green	Red	Yellow	
	Red	Red	Green	Red	Yellow	Red

9 Combined recommended energy provision scenarios

The analysis shows that a scenario providing renewable-based electricity for all energy needs in a refugee camp will be very difficult to accommodate, and will come at a high cost. If this full energy coverage is to be achieved, also including the energy needs of a host community, very large solar PV arrays, probably in combination with large wind farms will be required.

Our recommendation is to go for a scenario where renewable, grid distributed electricity is provided in a limited grid, providing services for administrations, health services, commerce and productive activities, and similar larger uses in the host community. This implies that household cooking and illumination will have to be satisfied by independent energy sources. New solar PV cooking systems give some promise here, while a cheaper and more easily available option is to provide cooking energy with LPG and illumination with small solar PV systems.

Based on the scenarios, assessments and analyses outlined above, a number of energy provision scenarios begin to crystallize. These include various options regarding energy supply, energy end-use and institutional setups that appear applicable in various on the framework conditions. Some of the issues and questions are discussed in the present section. We are considering the scenarios of section 3.3, which are:

1.
    a. A renewable energy system that provides all energy services including cooking in camp and host community through a large electricity network.
    b. A renewable energy system that provides all energy services including cooking in camp and host community through a large electricity network, but where demand management is introduced to even out peak loads.
2. A renewable energy system that provides energy services for administration, institutions and services in camp and host community through a limited electricity network. Cooking energy provided separately.

9.1 Option 1a: all services provided

This option requires a large energy generation potential, a huge storage capacity and a robust backup system. Installed capacity needs to be very large in order to satisfy demand. A robust network with medium voltage as well as low voltage is required.

It should be noted that backup alternatives actually imply some form of hybrid systems. In the case of diesel generation this will probably build on existing structures and services (such as trained operators) but may require extension to cover a higher demand. In the case of renewable backup systems, it entails introducing an additional, different, technology with its specific requirements.

Table 30 Option 1a: Alternatives for total service provision

Generation technology	Storage technology	Backup	Comment	Cost	Assessment
Solar PV array	Batteries	Diesel/Wind	Large area required	[green]	[yellow]
Wind power	Batteries	Diesel/Hydro/Solar	Location specific	[yellow]	[yellow]
Hydropower	Water reservoir	Wind/Diesel	Site specific	[red]	[yellow]
Biogas	None	Diesel	Additional infrastructure required, insufficient capacity	[red]	[red]
Biomass energy	Raw material storage	Diesel	Requires feedstock, processing	[red]	[red]
Geothermal	None	Diesel	Site and location specific	[red]	[red]

9.2 Option 1b: All services provided with demand management

This option also requires a large energy generation potential, a large storage capacity and a robust backup system. The major challenge here is whether demand management in terms of technical or social intervention can be feasible. The demands are slightly less than in Option 1a, but a robust network with medium voltage as well as low voltage is still required.

Table 31 Option 1b: Alternatives for total service provision with demand management

Generation technology	Storage technology	Backup	Comment	Cost	Assessment
Solar PV array	Batteries	Diesel	Large area required	[green]	[yellow]
Wind power	Batteries	Hydro/Diesel	Location specific	[yellow]	[yellow]
Hydropower	Water reservoir	Wind/Diesel	Site specific	[red]	[yellow]
Biogas	None	Diesel	Additional infrastructure required, possibly insufficient capacity	[red]	[yellow]
Biomass energy	Raw material storage	Diesel	Requires feedstock, processing	[red]	[yellow]
Geothermal	None	Diesel	Site and location specific	[red]	[red]

9.3 Option 2: Only specific services provided by central electricity, cooking is separate

9.3.1 Electricity network

This option requires a reasonable energy generation potential for the electricity network, some storage capacity and a robust backup system. The electricity network can be less extensive than in option 1, since it is only intended to serve larger consumers. Cooking energy will be provided separately and is treated separately below.

Table 32 Option 2: Alternatives for limited electricity service provision through grid

Generation technology	Storage technology	Backup	Comment	Cost	Assessment
Solar PV array	Batteries	Diesel	Large area required	🟨	🟩
Wind power	Batteries	Hydro/Diesel	Location specific	🟨	🟨
Biogas	None	Diesel	Additional infrastructure required, insufficient capacity	🟥	🟨
Biomass energy	Raw material storage	Diesel	Requires feedstock, processing	🟥	🟨
Hydropower	Water reservoir	Wind/Diesel	Site specific	🟥	🟥
Geothermal	None	Diesel	Site and location specific	🟥	🟥

9.3.2 Clean cooking energy

Providing clean and renewable cooking energy will be a challenge for this option, however, there seem to be alternatives in sight. In our assessment the new developments of solar PV cooking would be the most attractive alternative, provided they can be supplied in sufficient quantity and quality. LPG is also a versatile and clean cooking fuel, however with the drawbacks that it is a fossil fuel, requires distribution and comes at an operational cost throughout its lifetime.

Table 33 Option 2: Cooking energy options

Cooking/ stove technology	Storage technology	Backup	Comment	Cost	Assessment
Solar PV	Battery	Wood, charcoal	New solar PV cooking systems	🟨	🟩
LPG	Cylinder	Wood, charcoal	Requires distribution	🟨	🟨
Improved charcoal/ wood stove	Fuel	Traditional 3-stone fire	Not really delivering clean cooking or saving fuel	🟩	🟥
Haybox	None	Wood, charcoal	Not previously successful	🟩	🟥
Parabolic solar	None	Wood, charcoal	Not previously successful	🟨	🟥

9.3.3 Overall recommended: Option 2

The overall recommended option is Option 2, where one (or more) renewable energy sources are providing electricity into a network that serves larger consumers, i.e. administrations, health facilities, institutions and service/manufacture. This renewable energy source is feasibly a rather large solar PV system, possibly linked to a wind power system if the location is suitable. Backup and load management will be with batteries. For backup, diesel generators are used.

Cooking is provided with individual solar PV systems, that also provide some household illumination. Backup for failures or periods without sunshine is probably wood and charcoal, although the demand on these sources will be hugely reduced. If existing solar PV solutions are found insufficient or unavailable, then cooking energy should be supplied with LPG.

10 AVOIDED GREENHOUSE GASES

This section the avoided emissions when using renewable energy sources according to the GHG-protocol scope 2 are presented. The comparison is presented through two scenarios based on the traditional electricity generation and cooking fuel used in a refugee camp with 50 000 inhabitants divided into 10 000 households.

In Scenario 1 the electricity is generated from a diesel generator, and the cooking fuel consist of wood and charcoal. The calculation shows that the emitted emission per day in the refugee camp is 80 tons of CO_2e, equal to about 26 000 tonnes per year. This should be compared to a fully renewable energy scenario, providing all electricity and cooking needs, which is assumed to come at zero GHG emissions.

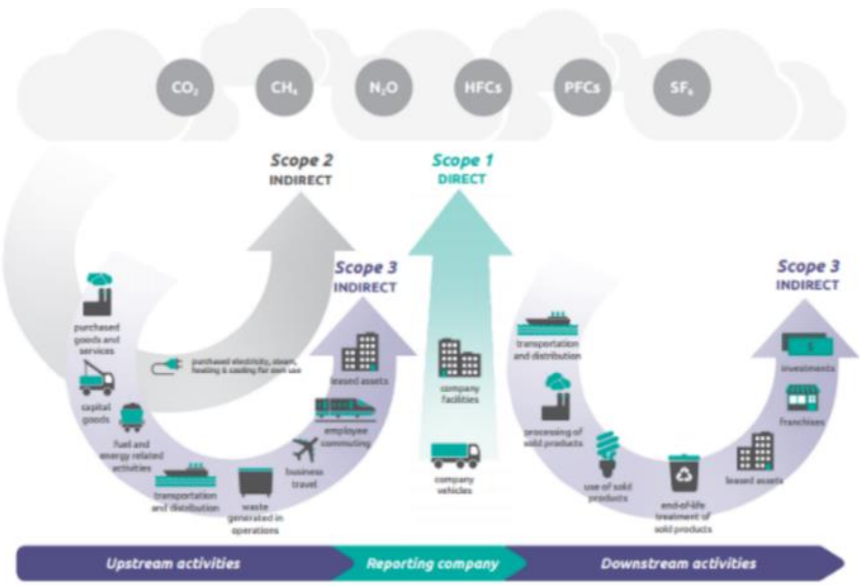
In Scenario 2 the electricity is also generated from a diesel generator, and the cooking fuel consist of LPG-stoves. The calculation shows that the emitted emission per day in the refugee camp is 8 tonnes of CO_2e, or 2 700 tonnes per year. This suggests that even by using a fossil fuel such as LPG, the GHG emissions can be greatly reduced. In addition, natural resources are saved, and exposure to harmful smoke is reduced.

In reality there have to be back-up systems in place for delivering energy when the SHS or other renewable systems are not being able to do that. Most likely these will be diesel generator for electricity and wood/charcoal/LPG-stoves for cooking. The avoided emission will therefore account for less than the total CO_2e emissions presented in these scenarios.

With a reliable supply of renewable electricity, emission of greenhouse gases can be avoided from fossil fuelled cooking and lighting devices. This section will analyse how much greenhouse gas emissions can be avoided through electrification of a refugee camp.

Emission of greenhouse gas emissions can be measured in different ways. The greenhouse gas protocol (GHG- protocol) is widely used as a standard to measure and manage emissions. The GHG-Protocol uses different scopes to measure emissions. Figure 14 illustrates how the different scopes are measured. In this study GHG-protocol scope 2 will be applied where emissions from purchased or acquired electricity as well as direct emissions from fossil fuelled cooking and lighting are included. Furthermore, emissions from a lifecycle perspective, including for example emissions from producing solar panels used to produce electricity, are presented shortly based on previous studies.

Figure 14 Scopes under the greenhouse gas protocol



While renewable electricity is considered carbon free under scope 2 (GHG protocol), emissions from primarily cooking can be avoided if the refugee camps are given access to a reliable supply of electricity.

Avoided emissions have been calculated in two different scenarios of a refugee camp with 50 000 inhabitants, divided on 10 000 households. In **Scenario 1** the households are assumed to use wood and charcoal for cooking, and a diesel generator for electricity production for the administration of the camp. It is assumed that one household needs either 4,8 kg wood per day or 2,8 kg charcoal per day to cover their needs. Generally, wood is more commonly used in refugee camps in central Africa, therefore an assumption has been made that 70% of the households use wood and 30% charcoal. If the energy sources presented in Scenario 1 were replaced by renewables the avoided greenhouse gases would amount to approximately 80 tonnes of CO_2e per day for the refugee camp in total, see Table 34.

Table 34: Emitted GHGs in Scenario 1

Scenario 1		
Total amount of wood used	34	t
Total amount of charcoal used	8	t
Diesel needed for electricity production	0,3	t
Emissions divided per source		
Wood	54	t CO_2e
Charcoal	25	t CO_2e
Diesel generator	0,6	t CO_2e
Total amount of emissions per day	**80**	**t** CO_2e
Total amount of emissions per year	**26 000**	**t** CO_2e

In **Scenario 2** the households are assumed to use LPG for cooking and diesel generators for electricity production for the administration of the camp. LPG is commonly used in refugee camps and is expected to still compete with renewable sources such as solar energy in the near future. If the energy sources presented in Scenario 1 were replaced by renewables the avoided greenhouse gases would amount to approximately 8 tonnes of CO2e per day for the refugee camp in total, see Table 35.

Table 35: Emitted GHGs in Scenario 2

Scenario 2		
Total amount of LPG	3,7	t
Diesel needed for electricity production	0,30	t
Emissions divided per source		
LPG stove	7,5	t CO_2e
Diesel generator	0,60	t CO_2e
Total amount of emissions per day	**8,0**	**t** CO_2e
Total amount of emissions per year	**2700**	**t** CO_2e

The emissions factors used for the calculations above are shown in Table 36.

Table 36: GHGs per kilogram fuel

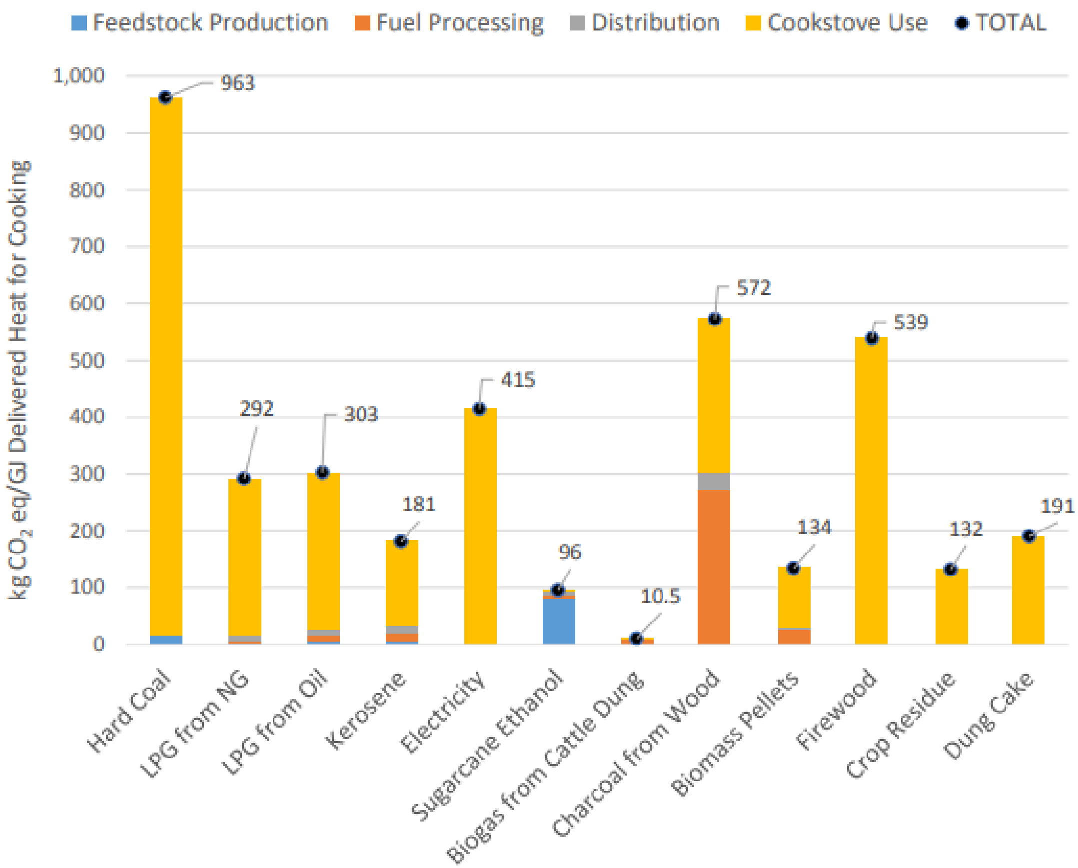
Fuel	Emission factor	
Wood	1,6	kg CO_2e /kg fuel
Charcoal	3,0	kg CO_2e /kg fuel
LPG	2,0	kg CO_2e /kg fuel
Diesel	2,2	kg CO_2e /kg fuel

The presented scenarios 1 and 2 are two examples on common energy supply traditionally being used in refugee camps. When replacing these energy sources with renewables, calculated according to the GHG-protocol scope 2, the avoided daily emissions amount to 80 and 8 tonnes CO_2e respectively in the camp. Emissions from renewables are considered to be zero.

In reality, this will not be true for each day of the year. During the rainy season for example, the solar panels will not deliver the demanded electricity to the households. This will require a back-up system to be in place, most likely a diesel generator with fossil diesel as a fuel. Biofuel is also an option for the diesel generator, this will however increase the costs and may also be logistically challenging. For cooking wood, charcoal, or LPG stoves will likely be used. This means that even though a SHS is in place, weather conditions or technical difficulties, may cause obstacles for it to deliver and this may also mean that fossil alternatives replace it. The exact emissions released in these exceptional cases are difficult to assess, but assuming the disturbances are mostly caused by the rain season, generally being one month a year, the average emissions avoided during one year will amount to 26 000 and 2700 tons of CO_2e in Scenario 1 and Scenario 2 respectively.

The large difference in emitted emissions between the two scenarios is mostly explained by the inefficient nature of cooking with wood and charcoal. The efficiency rate for these fuels is around 15%, meaning that the majority of the energy contained in the fuels is lost. From a climate perspective LPG-stoves are more efficient and releases ten times less greenhouse gases. Wood and charcoal may in some cases be seen as renewable alternatives since they are biomass. In this study we do not consider them as renewables because there is generally no sustainable forestry plan for regrowing the forest.

Figure 15 Cookstove Fuel Global Climate Change Potential for India[41].



[41] *Cashman et al, 2016*

10.1 Life cycle perspective

The CO2 emissions from current energy use shows that using renewable fuels emits slightly less than the scenario where diesel and LPG is used. The question, then, is what the situation would be if the lifecycle emissions in the different scenarios were accounted for. In this case we take support in the analysis of life cycle emissions for different cookstove fuels in India and China based on life-cycle analysis (LCA) shown in Figure 15. This data shows that LPG generates less than charcoal and wood over its lifetime as well. The main part of the emissions is generated during use, except for charcoal.

The accumulated lifecycle emissions for solar PV electricity amount to a mean of 53 g CO_2 eq. per kWh and median of 44 g CO_2 eq. per kWh for the most widespread PV technologies, based on crystalline silicon.[42] Other PV technologies are less well studied in terms of LCA, which is commensurate with their lower market share: in 2015 multi- and mono-crystalline Si accounted for 93% of the global PV market. In recent years the PV manufacturing has been transitioned from Germany, Japan and the USA to mainly China and Taiwan. From a LCA perspective, it means a worse environmental impact due to the large share of inefficient coal power plants in China. For diesel, the LCA emissions we have used are from data compiled by the Swedish Agricultural University (SLU).[43]

Although the total emissions from the LCA perspective are much higher, the pattern of emissions in a lifecycle perspective is very similar from that based on current emissions only, as shown in Figure 17. Compared to the emissions in the scenario 1, using mainly wood and charcoal for cooking, and diesel for electricity, the scenario 2 with LPG instead of wood fuels emit only 15% in a lifecycle perspective. Using solar PV for all energy needs for 11 months of the year would result in only 9% of the emissions from the woodfuel scenario.

[42] *Stamford and Azapagic, 2018*

[43] *Eriksson and Ahlgren, 2013*

Figure 16 Emission of GHG in the various scenarios according to scope 2 analysis (current emissions only)

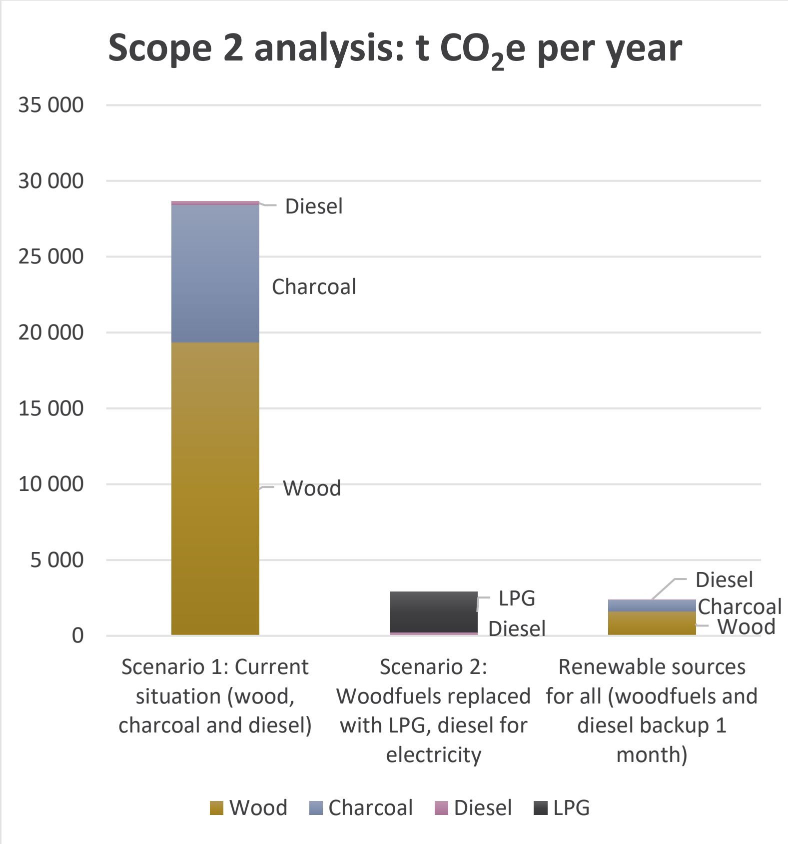
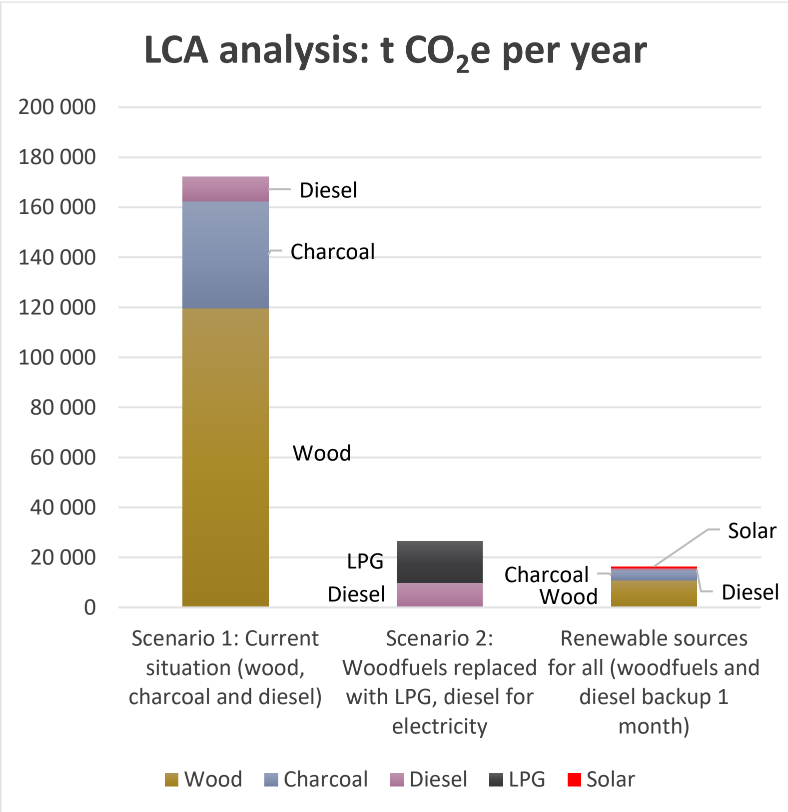


Figure 17 Emission of GHG in the various scenarios according to Lifecycle analysis (LCA)



11 FINANCING

A market-based solution is favourable to create efficient energy use and to facilitate the transition back to normal society for refugees.

Sweco recommends a combination of aid-as-cash to promote a market-based system and low electricity tariffs/low cost lease of small-scale household electricity generation units. This would also facilitate electricity use for income earning activities.

The recommended choice of financing solution depends on the choice of technical solution, capacity for long-term commitment and access to investment capital.

In a case where the promoting (humanitarian) organisation has high capacity to commit long-term to the project, owning and operating the power supply is preferable. This requires that the organisation also has access to investment capital. If the organisation lacks the resources and technical know-how, procurement and maintenance services are preferably outsourced.

If the humanitarian organisation lacks sufficient investment capital or capacity for a larger investment, but has the tenacity for long term commitment, a leasing alternative is advisable. Especially for small-scale portable household solutions leasing is attractive as the leasing duration can be flexible and not tied to the lifetime of the technical appliances. The promoting organisation can organize procurement of a service supplier and favourable terms, in combination with subsidising the lease cost for the refugees and acting as an ultimate financial guarantee towards the supplier. Leasing has the advantage that it does not require capital from Sida (or other financier) and that it incentivises the investor to prioritise quality and low lifetime cost rather than a low one-time selling price.

If the promoting organisation lacks capacity to commit long term to the project, it is advisable with a power purchase agreement or result-based financing. These solutions have advantages in the low requirements for the promoting organisation regarding commitment and investment capital, at the same time as it utilizes the expertise and inventive capacity of market players and entrepreneurs.

A solution where the new power production is connected both to the refugee camp and the host community, enables an investor to sell more electricity and decreases the risk from a closure or reduced power consumption from the refugee camp. The refugee camp can effectively work as an anchor client, while the rest of the production can be sold to the host community both to increase an investors income and to give the host community a positive incentive to host the refugees.

Sida is looking for a financing solution where private sector can contribute to design and implement innovative market-based solutions, in order to get the most out of their investment. The aim is to find the most cost-efficient solution, with the prerequisite that new energy supply must be renewable. The new energy supply should also benefit both the refugee camp and the nearby host community. The electricity users in the camp and community should preferably acquire their energy through a market-based solution, however a large share of the refugees as well as host population will likely need some sort of subsidy/cash-aid to be able to pay for the electricity.

11.1 What are the different alternatives for financing the power supply to the refugee camp?

Traditionally humanitarian actors have often invested directly in electricity production and distribution to supply areas without reliable electrification, including refugee camps. There are, however, a number of advantages with bringing in private investors. If Sida wants to bring in private investors it is important to keep risks low for the private investors. This will attract several potential investors and increase competition as well as keeping cost of capital low. The cost of capital is strongly connected to the risk in the project. Investments in renewable energy are typically very capital intensive, while operational costs are low, which makes it important to obtain a low cost of capital in order to keep the cost of electricity low. If Sida can act as a contract counterpart or give guarantees for procuring the produced electricity, this will reduce the perceived risk of an investor.

Key enablers to reduce the perceived project risk are to be able to offer a long-term contract for procuring a large share of the produced electricity and a reliable counterpart. The investor will seek a contract with a duration that matches the lifetime of the investment as much as possible. However, an issue with a long-term contract may be that it sends a signal that the refugee camp will be a long-term installation. In general refugee camps are long term installations of up to 20 years, or in some cases longer, although the ambition generally is to decommission the camp as soon as possible. It can also be negative for the acceptance of the refugees by the host community if the camp is perceived as a long-term installation. This can be avoided by setting up a solution where the power supply can also be used to supply the host population, which may reduce tensions between the refugee camp and the host community.

Portable household cooking solutions offer flexibility in their financing as they are not site specific and can be moved to another geographical spot and owner at any time. They are often based on a small solar panel, in some cases together with an energy storage unit and a cooking device. These units can be rented/leased for a flexible period of time, which reduces the risk connected with the unknown time that the refugee camp will exist.

Figure 18 Financing alternatives

Financing model	Advantages	Disadvantages
Invest and operate	• Full control	• Often inefficient • The donor doesn't want this operational responsibility • Demands a large amount of money up front • Risks for the donor with technical difficulties
Power Purchase Agreement or leasing	• Efficient and innovative with a professional electricity supplier • No need for money up-front • No technical risk for the donor	• Requires a long-term contract and a reliable off taker to minimize costs • May be legally challenging
Individual household financing solutions	• Flexible contract duration as the appliances are moveable • Leasing solutions are available to avoid ownership • Regulatory/legal benefits by not including the national energy company in the contract	• Excludes larger centralized solutions that may be more efficient for higher tier electricity usage

11.1.1 Invest and operate - The traditional purchase model

Traditionally when humanitarian organisations were to procure renewable electricity, they would establish the technical specifications for the system, purchase the equipment through a tender, hire a company for the installation and take responsibility for the operations and maintenance (O&M) themselves.[44] This means that organisations takes the risk if there are technical difficulties with the installation, and they would be required to cover the full cost of the installation upfront.

The use of private sector approaches can apply both to the procurement and O&M. Both can be outsourced to the private sector if the donor wants to reduce the technical risk and does not consider this as its core area of expertise. To invest and operate often demands a high access to investment capital and may be beneficial in situations with a high ability to long term commitment as an electricity system owner and operator.

[44] IRENA (2019), *Renewables for refugee settlements: Sustainable energy access in humanitarian situations, International Renewable Energy Agency.*

As this solution offers full control, it may make it easier to adopt to changed circumstances than what can be the case with a long-term supply agreement. The level of involvement/outsourcing in the procurement and O&M phase can be varied depending on the organisation's experience and know-how of both the local conditions and investing and operating electricity supply.

11.1.2 Power Purchase Agreement or leasing – Leave it to the experts

Assuming that private sector actors specialised in power production/distribution are more efficient in building and maintaining the power supply than Sida is, an interesting alternative to owning and operating is to let a private actor own and maintain the power supply. Sida may than procure the electricity produced through a Power Purchase Agreement (PPA). A closely related option is to lease the power production/distribution units or buying energy supply as a service. The main criteria to keep costs low for these alternatives are to keep risks low. For investors in renewable energy and distribution, the O&M costs are typically low, while the initial investment is high, making low capital costs essential to keep costs low. Low risk, including PPA/leasing contracts with a duration that matches the lifetime of the investment (assuming that the electricity production/distribution units are not portable), is key to low capital costs.

In the case of supplying a refugee camp with renewable electricity through a PPA, a challenge is that it is unknown when the refugee camp will close, and for how long the electricity demand will last. Therefore, it may be challenging for Sida to be able to offer a contract length that enables a private investor to offer a competitive electricity price. An option to handle this is to enable the new power supply to connect to the national grid in the nearby/integrated host village. If the electricity supply can be redirected to the national grid once the refugee camp is closed, this enables a long term PPA with low investment risk and thus low costs. If the refugee camp closes, the produced electricity can be redirected to the national energy company. To take some risk away from the investor and make the PPA more attractive, Sida can guarantee the price difference between what the national energy company offers and what the investor requires if the refugee camp is decommissioned before the end of the PPA duration. This solution requires further investigation regarding the local technical and legal situation.

PPAs are mainly attractive when a humanitarian organisation wants to get a high amount of energy supply with limited access to investment capital and limited ability to commit at the same time as a private partner is believed to be able to increase efficiency in the project. Different PPA structures and agreement lengths can be desired depending on the specific case. The private investor will typically strive towards an agreement length corresponding to the expected lifetime of the technical equipment, while the humanitarian organisation often wants a shorter contract. PPAs are today common in for example Europe and USA, while they for different reasons are rarer in sub-Saharan Africa. The size of the camp is one important factor that influences the viability of the market for public- or private-sector investment in general and not least in the case of a PPA.[45] One aspect of an PPA that may be a challenge for Sida is that it requires annual payments over a long period of time, something that may be a challenge as Sida is granted funding on an annual basis.

An option if Sida wants to avoid long-term financial commitment is that Sida pays fully or partially for the initial investment, then procures a private investor to handle O&M and run the electricity supply at lowest possible cost/tariff over a period of time that matches the lifetime of the technical equipment. The private investor than sells the electricity in the first place to the refugees and secondly to the national energy company. This solution can be formed as a PPA.

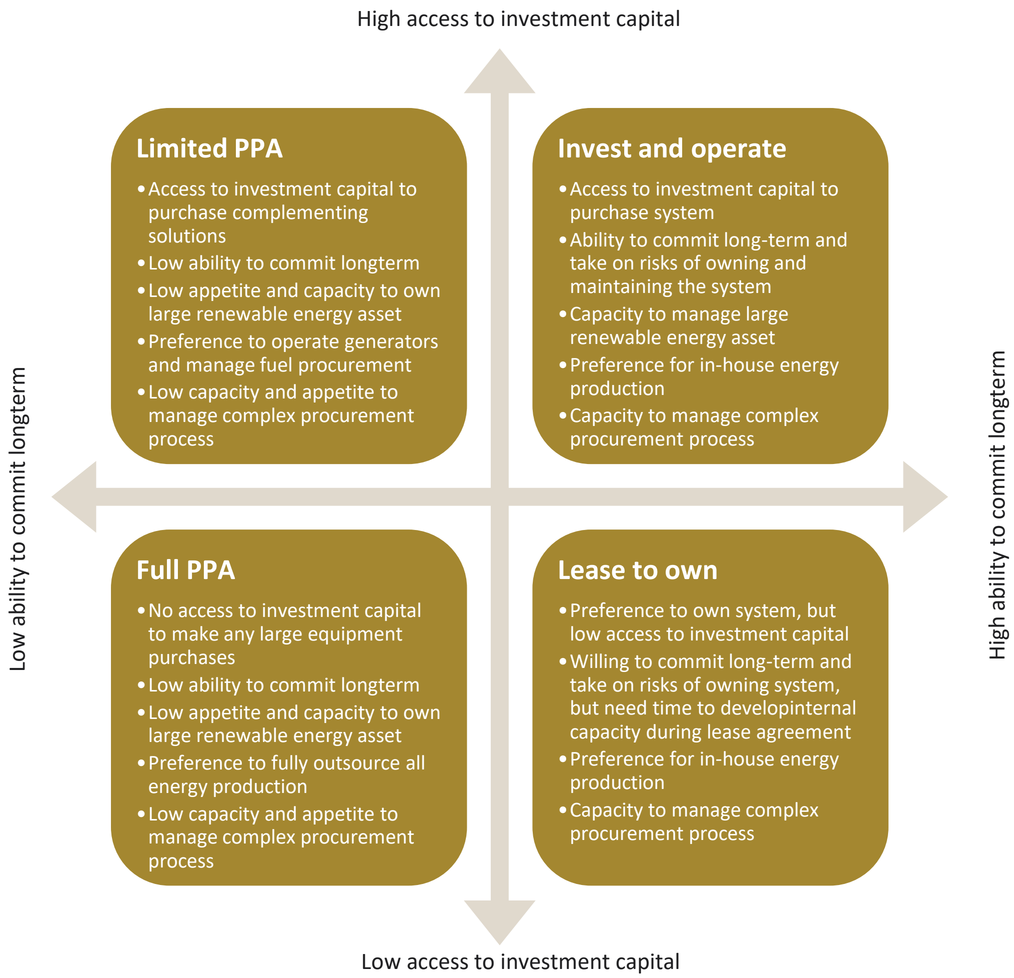
11.1.3 Individual household financing solutions – Keeping it simple

Individual household small-scale energy supply systems that can be owned or leased by each household offers a simple solution, where O&M costs can be kept low as these systems are simple and can sometimes be maintained by the refugees themselves or skilled persons in the camp. Leasing has advantages as it doesn't allocate capital from Sida and incentivises the investor to prioritise quality and low lifetime

[45] *Adopting a Market-based Approach to Boost Energy Access in Displaced Contexts, Chatham House (2020)*

cost rather than a low one-time selling price. It is also advantageous from many aspects not to permanent the localisation of the energy supply. With individual household solutions each household can easily disassemble and bring their own small-scale energy supply system to another location or terminate the lease and hand the equipment in. To decrease risk of theft or careless handling a substantial deposit is advisable if possible. With portable small-scale energy supply systems, the risk of the energy supply becoming obsolete as a refugee camp is closed or re-localised can thus be eliminated. A refugee camp that is not seen as a permanent installation may have benefits including less resistance from local residents.

Figure 19 Overview of available business models for solar procurements[46]



A complete individual household electricity supply system doesn't incentivise to keep energy usage lower than the maximum of what each system can deliver. On one hand this will cause a less efficient usage of energy, on the other hand it will give more incentives to productive use of energy than what would have been the case if the household pays per used kWh.

Small-scale energy supply units for individual households are often not efficient for higher tier electricity usage. For low tier electricity usage, small scale power supply solutions such as individual solar panels combined with a simple cooking device is often efficient. In these cases, a different form of small-scale financing is required, where each household can be provided individual household financing solutions. Sida can sign a contract with a private actor to supply a large number of different small scale power supply solutions (lease or buy) relevant for the circumstances to a low price, at the same time

[46] Kube Energy (2020), *The Solar Energy Handbook: A guide to institutional solar for organizations working in humanitarian settings*

as the refugees are offered coupons that they may use to buy these devices or other energy/food articles of choice. This solution gives the refugees a market-based opportunity to prioritise, doesn't require any O&M commitment from the humanitarian actor and doesn't create any lock-in effects as these supply units are easy for the owner to move. Leasing of small-scale energy supply units for individual households can be advantageous to combine with a large-scale solution for host community energy supply.

11.1.4 Financing overview

There are many aspects that affect the choice of financing model. The first question is if high tier electricity usage requires a larger centralized energy production. If a larger centralized electricity production is required, two of the most important factors are high/low access to investment capital and high/low ability to commit to a project. Figure 19 illustrates when different financing alternatives can be advisable depending on access to investment capital and commitment.

11.1.5 Other financing solutions

In additional to the above-mentioned solutions, there are different loan structures constructed to reduce investor risk in order to attract capital to projects that would otherwise not be able to get financing. These loan structures are often results-based. An example of such a setup is *impact bonds*. Impact bonds are outcome-based bonds. They use private funding from investors to cover the upfront capital required for a provider to set up and deliver a service. The service is designed to achieve measurable outcomes specified by the commissioner. The investor is repaid only if these outcomes are achieved. For example, in areas where it is expensive to serve customers and local operating and maintenance capacity takes time and money to establish, a *results-based financing* may be of interest to attract different innovative solutions to create a cost-efficient solution under the circumstances.

11.1.6 Specific conditions in refugee camps

A large hurdle for private sector investors is often a lack of knowledge regarding refugee camps and their surroundings.[47] Humanitarian actors may get better financing if they can inform private companies about life in these camps and settlements, and help them navigate all the operational, legal, and regulatory difficulties that come with it.

Electrification makes cooking a lot more time efficient. If the time saved on cooking can be used for productive purposes, there is an opportunity to finance the electrification with money from productive work during the time that is saved from cooking. The refuges can thus find themselves a meaningful employment that pays them credits that may be used to procure electricity. With global e-commerce companies targeting Sub-Saharan Africa offering simple and cheap platforms to sell goods around the world, there may be a commercial opportunity to create and sell goods to create a household income, based on the time saved on electrical cooking and access to electricity. A potential problem for this solution is that refugees are not allowed to work outside the camp, set up their own businesses, own land or access microfinance in all countries. There may also be limits to their monthly income – even for work inside the camps.

Financing models that create an opportunity of a gradual upscale enables practitioners to pre-empt potential sustainability challenges and to take pre-emptive action to 'tweak' interventions to address sustainability issues. Figure 20 illustrates a useful tool that may help predict the sustainability and scalability of the interventions is the 'adopt, adapt, expand, respond' framework used in development contexts.[48] The first steps may be ease as there are already many pilot projects to learn from.

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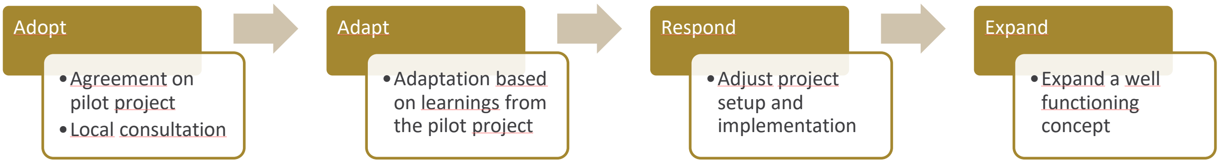
[47] Shell (2020)

[48] The Springfield Centre (2015)

Figure 20 The 'adopt, adapt, expand, respond' framework



11.2 Market based approach

The provision of energy through a market-based approach offers an alternative that facilitates the inclusion and empowerment of refugee and host communities to develop markets and solutions that meet local needs.[49] A market-based approach to meeting refugee needs also supports the UNHCR 2017–21 strategic plan to deliver the Comprehensive Refugee Response Framework, in which the agency aims to bring together development and private-sector actors to address 'immediate and longer-term needs of refugees and host communities, and in supporting them to become resilient and self-reliant'.[50]

At present, on average a refugee is displaced for 10 years and the average age of an inhabitant in a refugee camp is 18 years.[51] There are risks associated with undermining institutional recovery if these individuals spend such a large share of their youth under aid dependency and without normal society market functions present. To be part of a market-based system in the refugee camp eases the transition back to normal society.

Across the humanitarian community, there is a trend towards providing cash-based assistance instead of aid in kind. All major humanitarian organisations support cash-based assistance as a matter of principle, although the forms for handing out the aid must depend on local conditions.[52] Cash-based assistance is particularly well-suited to support refugees who live in urban areas, so that they can be part of the local market system. Apart from possible inflation and risks related to cash distribution, the advantages of aid-in-cash are abundant. Cash enables choice, providing displaced persons with greater purchasing power, which makes it possible for companies to provide access to energy. Cash also supports local economies. In this case a combination of aid-in-cash and a subsidised energy supply is advisable.

11.3 Customer charging

A smart customer charging may help to maximize the benefit from the electricity supply investment. Often the refugees won't be able to afford a full-cost tariff or the tariff offered by the national energy company if the refugee households is integrated with the national electricity grid. Jet there are methods of applying market-based customer charging to achieve demand response, energy efficiency and thereby minimize the cost/benefit-ratio. Figure 21 summarizes three customer charging methods for a centralized electricity supply and their advantages/disadvantages. An alternative approach is to supply individual household solutions, where the households can be charged as a one-time-cost for the installation or preferably as a leasing fee per time period (monthly for example).

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[49] Rivoal, M. and Haselip, J. A. (2018), *'Delivering market-based access to clean cooking fuel for displaced populations the Kigoma region, Tanzania: a business plan', United Nations Environment Program and Technical University of Denmark Partnership*

[50] *UNHCR's Strategic Directions 2017-2021*

[51] *Zetter, R. (2016), 'Protracted Displacement – Setting the Scene', International Organization for Migration, 21 December 2016 And Grafham and Lahn (2018), 'The Costs of Fuelling Humanitarian Aid'.*

[52] *Shell (2020)*

Figure 21 Customer charging

Customer charging	Advantages	Disadvantages
Billing by tariff in combination with electricity subsidies	• Can easily be integrated with the national power system • Differentiated tariffs can be implemented • Market based	• Credit risk if not paid in advance
Pay-as-you-go – Prepayment or prepaid meter	• Simple system common in parts of Sub-Sahara • Differentiated tariffs can be implemented • Market based	• Can be challenging in more complex market environments where providers need to adapt their payment collection methods, educate customers in the use of digital financial tools and rethink their last-mile distribution strategy
Free of charge	• Simple solution with low administrative costs	• Doesn't give any incentives for demand response or reduction • Don't promote market thinking • May be commercialised within the camp

11.3.1 Billing by tariff in combination with electricity subsidies

A market-based customer charging solution includes some sort of tariff or cost to enhance efficient use of electricity. The charged tariff can both be the tariff for the national grid or camp specific. The willingness to pay for electricity differs much from region to region and individual to individual, but in general it is so low that some subsidy will be needed. The subsidy can with advantage be given as cash or constructed so that the receiver may use it for different needs, such as electricity, food etc, thereby contributing to a market-based demand driven society. Sweco recommends a combination of aid-as-cash to promote a market-based system and low electricity tariffs to promote electricity usage to replace fossil fuels and promote commercial electricity usage.

If the refugee camps electricity supply is integrated with the national grid, the same tariffs as other customers will likely apply. The donor may the subsidise the cost by paying for the connection and part of each electricity bill. The donor may also have to serve as the ultimate guarantor for the payment of all electricity used by the refugees.

11.3.2 Pay-as-you-go (PAYG) business model

In parts of Sub-Saharan Africa, the pay-as-you-go (also known as a prepayment or prepaid meter) system is well established for electricity charging. It is an installation that allows customers to pay for their electricity as they use it.

In a pay-as-you-go business model a company usually rents consumers a solar home system consisting of a battery, a solar panel, a charge controller, LED bulbs and a mobile charger. Depending on the size of the solar system, small systems can power charging phones and lights, while bigger systems can power small appliances like radios and TVs. Consumers can use basic mobile phones to pay for the electricity, either on a daily, weekly or monthly basis, but also cash cards or scratch-cards can be used. Usually, the company offers customers different flexible payment terms and lease lengths, which reduces upfront payments and gives customers the flexibility to pay according to their budget consisting of savings or provided coupons (see Figure 22).[53] The PAYG system can also be used to give different customer categories different subsidies.

[53] *Science Po 2018*

GSMA conducted a case study[54] on a pay-as-you-go solar home systems in Kakuma Refugee Camp in Kenya in 2019. The study states that the PAYG business model enables the use of renewable energy in refugee camps efficiently but encounters challenges in terms of developing the business model and structure which are financially sustainable for the companies. If the PAYG solar provider works with a humanitarian organisation on this, this risk can be reduced.

Figure 22: Three different PAYG-subscriptions by three different solar companies[54]

11.3.3 Free of charge

An administratively simple solution is to give all inhabitants in the refugee camp limited access to free electricity. This will not incentives energy efficiency, demand response or promote a market-based thinking that may smoothen the transition back to normal society. The cost of administrating measuring and a payment system for electricity, should be compared with the decreased efficiency and other positive effects that a market-based system adds. The environmental aspect of the increased electricity usage that a free of charge system can be assumed to cause, is also an important aspect. If the increased electricity usage comes from renewable options and replaces fossil fuels it is likely to have a positive environmental impact. Another important aspect is the risk of mis usage of the free electricity for commercial purposes. The amount of supplied electricity can be limited through either a limited effect or a limited energy usage per time unit (i e 50 kWh/month).

In many parts of the world energy companies have started to offer free off-peak electricity in some tariff models, this may be an interesting model that increases demand response and gives all households access to some free electricity every day.

11.4 Cooperation with host community

Social tensions between host and refugee communities can be decreased by electrification if electric cooking replaces firewood stoves and decreases deforestation caused by refugees in need of firewood. On the other hand, tensions can increase if free/cheap electricity supplied to the refugee camp creates business opportunities for the refugees that cannibalizes on local businesses.

To decrease tensions, it is important to ensure that the host community also benefits from the electrification of the refugee camp, something that can be achieved by procuring local products and aid-in-cash that creates demand on the local market.[55] A possible solution may be to base the whole technical and administrative apparatus in the hands of the host population. The refugee camp would then be seen as its major customer, at least initially, and it would create possibilities for further development in the host community, for instance by improved services, possibilities for production and processing of local resources (agriculture, forest, minerals, etc.).

54 *GSMA 2019*

55 *Adopting a Market-based Approach to Boost Energy Access in Displaced Contexts, Chatham House (2020)*

Another possible solution may be to tap into existing local markets and integrate existing supply chains in the distribution of solar cooking devices for households. It can be important to include existing fuel traders into renewable alternatives as this is an important source of income, particularly for the local community, and any disruption of this business may face resistance.

Sida requests that the provided electricity source for the refugee camp is built so that it can provide the host population with electricity, if the geographical circumstances enables this to a reasonable cost. A connection to both the refugee camp and the host village will provide the host village with opportunities and thus reduce tension between the host village and the refugees. A connection may also create a better business opportunity for an external investor, with a possibility to sell to more customers and a security that some income opportunity will remain even if or when the refugee camp closes or reduced in size.

11.5 Suggested financing for centralized solar, batteries and back-up diesel in combination with household solar systems

Different technical solutions may be suitable for electrification of different sites. However, as suggested in chapter 9 a centralized electricity supply based on solar together with batteries and diesel as back-up in combination with small scale solar cooking systems for each household, is an attractive solution in many cases. Such a system would require two different financial setups, one for the centralized electricity supply and one for the solar cooking household systems.

In this case Sweco recommends subsidised leasing of solar cooking systems for households. The subsidy makes electricity cheap enough to be attractive for the refugees to lease and replace firewood stoves and possibly use electricity for commercial activities. The leasing setup also gives the owner of the solar cooking systems incentives to focus on lifecycle costs rather than the procurement price and develop better products/offerings. The subsidised solar cooking leasing must likely be combined with cash aid to the refugees.

For the centralised mini-grid electricity supply it is key to reduce risk for a private investor, in order to be able to keep costs low. A long-term commitment from Sida is often essential to guarantee the investor revenues over the whole lifetime of the electricity supply units. If the legal and technical situation is favourable, Sweco suggests an electricity supply solution integrated with the national grid, where electricity is procured through a long-term PPA with a private investor. The PPA should be on the form pay-as-consumed, where Sida guarantees the procurement of the electricity used by the refugees. The PPA cost can be lowered through the possibility for the investor to sell additional electricity to the national grid when the refugee camp demands less than produced or is closed down.

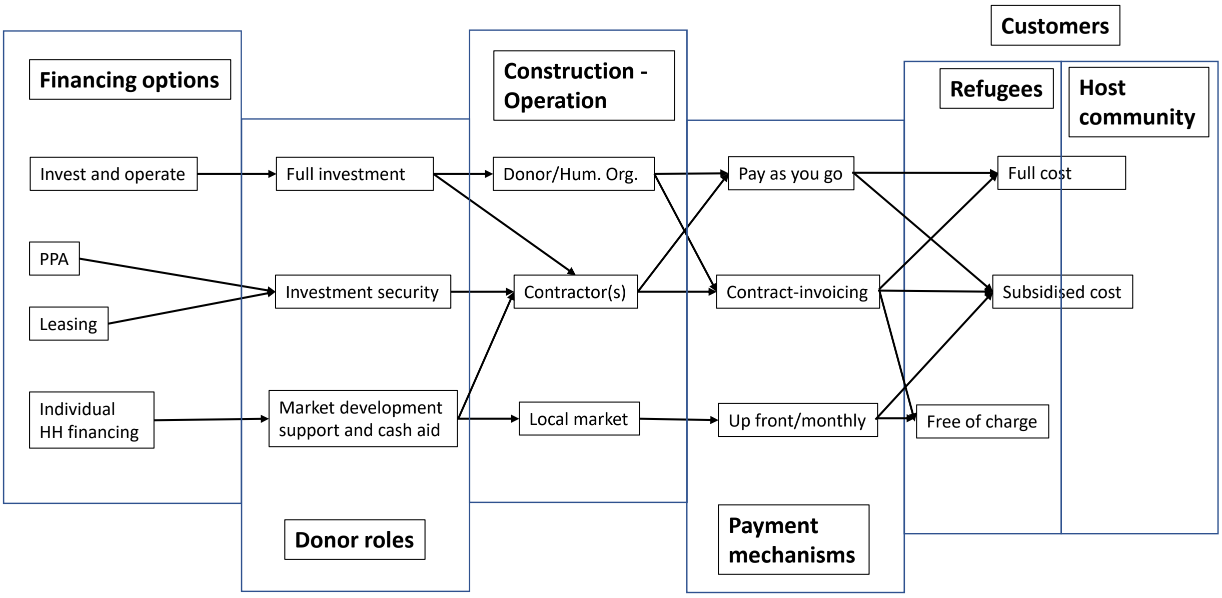
A challenge is that Sida may have difficulties to commit to long term financing due to its annual government financing. Long-term commitment is key to keep costs low, to be able to guarantee private investors long term revenues. The investor will preferably want a PPA contract with a duration that matches the lifetime of the technical assets as good as possible. Inability to commit to long term agreements possess a challenge to most financing forms.

An alternative could be that Sida pays fully or partially for the installation up front but leaves the technical procurement and O&M and necessary re-investments to a private investor. The produced electricity can still be procured through a PPA with the private investor. A private investor is chosen on the basis of how low the private investors are able to sell electricity under these conditions during a given period of time. The private investor then sells the electricity at a low PPA-price to the refugees in the first place and secondly to the national energy company over a duration of time that matches the lifetime of the assets. This solution releases Sida from any long-term financial commitment and takes benefit of private investors expertise in the technical procurement and operating the system.

11.6 Summary of financing, roles and payment options

There are numerous different combinations of financing options and payment mechanisms, which enables several different solutions. The donor (investor) role can be anything from providing a fully financed technical solution, to supporting open market initiatives. The operator can be a humanitarian organisation with some technical and operational know-how, a local or international contractor, or the local open market. The customers can be the refugees only, or also a host community. Including the host community among the users (customers) will reduce the risk for investors or operators in case the refugee camp is reduced in size or abandoned completely.

Figure 23: Summary of financing, roles and payment options



It is necessary to be clear of the difference between financing options and payment mechanisms, as these are not necessarily directly linked to one another. Also, the role of the operator/contractor is important. It is obviously an advantage if the operator can accommodate some financial risk, but this reduces the likelihood of local or small operators to be able to compete for contracts. Some operators have their own ideas on how to recover the investment costs. Pesitho, for instance, has a subsidised deferred payment scheme with option for buy-out, while Solar Bora has a scheme for leasing the equipment. LPG distributors rely largely on market mechanisms but may need risk-reducing measures in setting up the systems. Subsidies at different levels can most feasibly be introduced in pay-as-you-go systems but may also be introduced using other mechanisms.

Most likely, any system providing electricity through a mini-grid to larger consumers and individual options to household users would need to have more than one payment mechanism. Probably there will also be need for more than one contractor, as contractors will be specialised depending on the energy sources established. For the mini-grid, it is by no means certain that the contactor building the systems (energy generation, network) will have an interest in operating the system after completion. Then a separate contract will have to be made with an operator.

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