Pre-Feasibility Studies for Mini- Grid and Energy Centres in Thaba-Tseka District

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Content

1. Summary

The following table provides an overview on the features and feasibility of mini-grids and energy centres in four selected villages within the Thaba-Tseka district. Please note that the electricity demand recorded for the years 2019 and 2030 is only the electricity suitable to be supplied through the mini-grid and energy centre respectively. We assume, that energy centres will not supply well-off households as well as health centres, government institutions and retail facilities as these entities usually already have own power supply.

Table 1: Overview selected features of energisation solutions in Thaba-Tseka

Village	**Sehong-hong**	**Mashai**	**Linakeng**	**Ha Mokoto**
Solution	**Mini-grid**	**Mini-grid**	**Energy centre**	**Energy centre**
Number of Households	250	200	180	200
Anchor customers	1 health centre, 2 school, 4 government institutions, 10 commercial retailers, 2 crafts	1 health centre, 3 schools, 2 government institutions, 8 retailers, 1 craft	1 health centre, 1 school, 5 retail facilities	1 health centre, 1 school, 4 retail facilities
Present annual demand kWh	36,200	43,750	20,720	35,050
2019 annual demand kWh	123,200	113,800	5,300	5,840
2030 annual demand kWh	491,400	437,000	-	-
Size PV plant kW 2019 / 2030	161/361	151/327	10.9	9.23
Size storage kWh 2019 / 2030	444/881	406/770	26	28
Additional future power source	Hydro	Hydro	-	-
Length power lines km 2019 / 2030	11.92/13.30	10.79/12.04	-	-
Size of energy centre	-	-	Medium	Medium
Initial investment Maloti 2019 / 2030	5,567,364/ 17,066,860	5,334,424/ 16,174,884	1,201,363	1,178,508
Internal Rate of Return (with national tariff) 2019 / 2030	-15%/-10%	-15%/-11%	-	-
Required tariff 2019 / 2030	9.49/6.67	9.67/6.98	-	-

2. Thaba-Tseka district

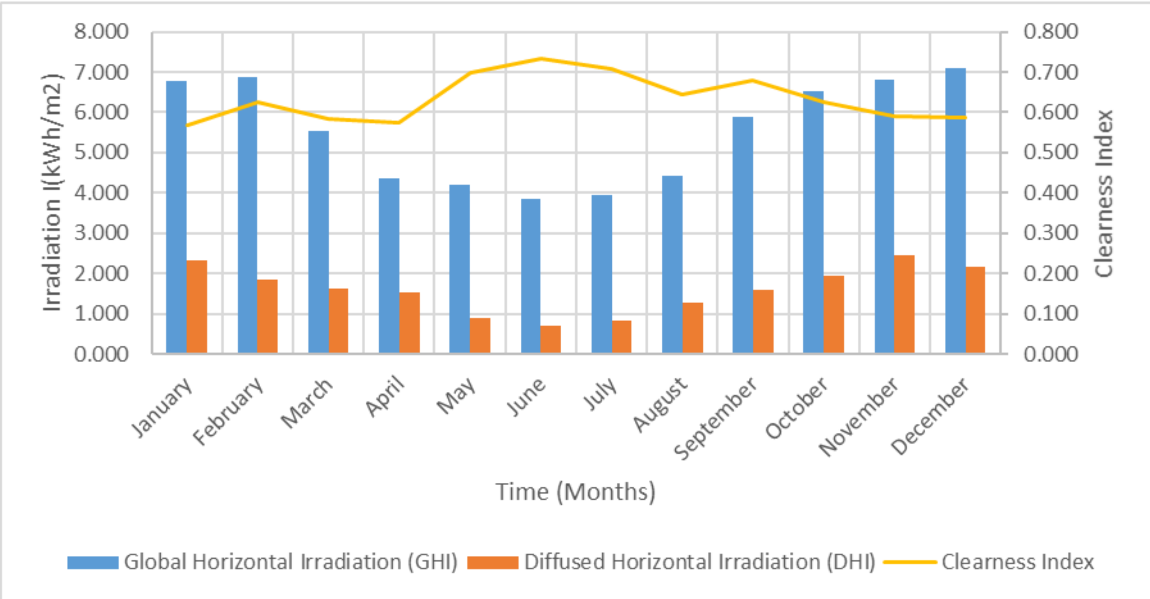
The Thaba-Tseka district takes the area of 4,270 km^2, which accounts for about 14% of the total area of. Thaba-Tseka is the 6th largest district in Lesotho with the total population of 135,00, accounting for 6.7% of the country's total population (Census 2016 estimates). According to the 2016 census estimates, the number of households within the district is around 33,556, where approximately 66% of the total households are male-headed and 34% are female-headed.

Figure 1: Location of Thaba-Tseka in Lesotho

2.1 Renewable energy potential

Thaba-Tseka (-29.54 (29°32'24"S) +28.6 (28°36'00"E) is located in the eastern part of Lesotho. Average insolation of Thaba-Tseka as given by the NASA climatologic database ranges from a minimum of 3.849 kWh/m^2/day in June to a maximum of 7.11 kWh/m^2/day in December with an annual average of 5.52 kWh/m^2/day. This is considered good for the development of solar technologies. Furthermore, Thaba-Tseka and all villages considered for mini-grids projects are located in mountainous regions, where the average clearness index is 0.63. The clearness index is a measure of the clearness of the atmosphere which is the fraction of the solar radiation that is transmitted through the atmosphere to strike the surface of the earth.

The global horizontal irradiation in the district on the monthly basis is depicted on the Figure 2 below. The underlying data set can be referred to in the Table 2. Our assessment of the potential of solar PV, wind power and micro-hydro has led us to the decision of focusing mainly on solar PV. The main arguments for each technology are below.



Source: Photovoltaic Geographical Information System (PVGIS), European Commission

Figure 2: Average solar irradiation in Thaba-Tseka over the year

Table 2: Daily global horizontal irradiation data in Thaba-Tseka (source: Photovoltaic Geographical Information System (PVGIS), European Commission)

Month	Clearness index	Daily GHI (kWh/m^2/day)
January	0.567	6.772
February	0.626	6.878
March	0.583	5.536
April	0.573	4.355
May	0.700	4.197
June	0.734	3.849
July	0.709	3.941
August	0.645	4.426
September	0.679	5.896
October	0.627	6.535
November	0.590	6.809
December	0.586	7.111
Average	0.600	5.5

Wind: Contrary to solar irradiation, the wind source is highly site specific, depending on the topography of a specific site. Average annual wind speed is approximately 4.71 m/s, which is greater than the 4 m/s rule of thumb to consider the technology viable. However, the village locations in mountainous regions may result in a high variability in wind speed. The interest in wind power is low among the private sectors, with skepticism related to costs and fluctuations in supply. Despite the potential to be one of the world's highest wind farms, Lesotho is susceptible to one of the highest rates of localised lightning strikes.

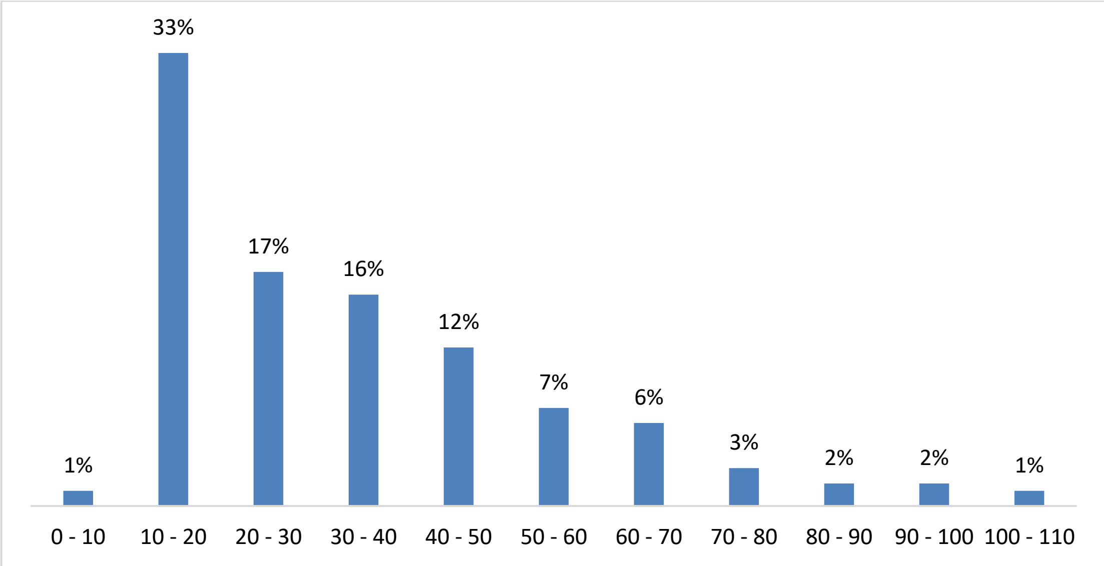
Hydro: Mini-hydropower is a very promising technology in the hilly parts of Thaba-Tseka. Thaba-Tseka has many areas with rivers and streams a sufficient water flow and drop in height to be able to continuously generate electricity. It is considered one of the richest districts in hydroelectricity resources, being the home to two hydropower dams: Katse Dam, the mains source of water to the 72 MW Muela Hydro Power Plant, and the 2 MW run-off-river hydropower plant at Mant'sonyane. There are also two main rivers (Sehong-hong and Mashai) near the project targeted communities which nearly runs throughout the year, and have good heads for run-off river mini-hydro power plant development. Feasibility Study for hydropower development of Sehong-hong River was conducted in early 1980s by SOGREAH Consulting of France.

2.2 Household characteristics

For the data analysis we extracted the results of the BOS Household Study 2017 for the Thaba-Tseka district. The total number of households in the Thaba-Tseka district is 38,937. The average household size accounts for 5 persons.

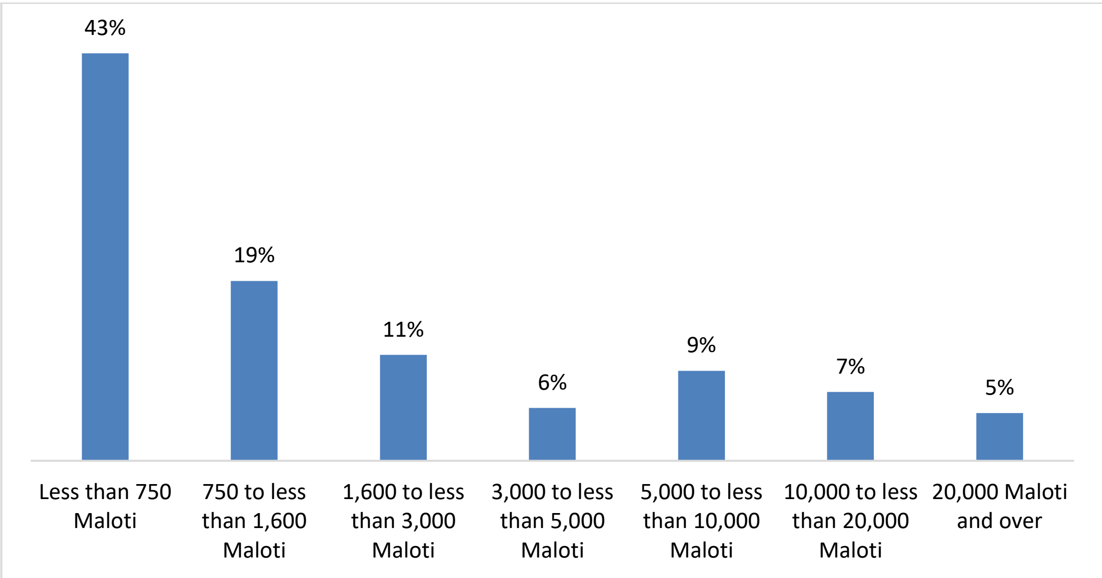
The age distribution of the residents in the households surveyed in Thaba-Tseka is slightly weighted toward the older age classes. Approximately 57% of the residents were under 25, while 13% were between 40 to 59 years of age. Only around 9% of the residents were over 60 years of age. Based on the age distribution, with more than half of the population under the age of 40 years, it is highly likely that a stable consumer base will be maintained over the next twenty years.

The majority of Thaba-Tseka' inhabitants interviewed within the BOS survey own at least two housing units, about 15 % have at least three units while 3% have four units. The population of Thaba-Tseka live mostly within a limited housing space (this is also confirmed by the BOS National Energy Survey). More than half of the total households live in the usable area of less than 40 square meters. Slightly more than 20% use more than 50 m^2 (Figure 3), which is an indication of a relative well-being of these households.



Source: BOS National Energy Survey 2017.

Figure 3: Distribution of household's usable area size in Thaba-Tseka



Source: BOS National Energy Survey 2017.

Figure 4: Distribution of household income in Thaba-Tseka

Regarding the disposable income per household, the data show that 73% of households in the district earn less than M3,000 and almost half of the Thaba-Tseka population (43%) earn less than M750 per month (see Figure 4). This implies that Thaba-Tseka has the lowest household income among the other four sampled districts. The majority of the households live from direct barter and self-sustained farming. Only 27% receive more than M3,000 per month, mainly obtained through remittances.

There are five main energy supply sources used in the Thaba-Tseka district. These are animal dung, wood and wood wastes, crop waste, straw/shrubs/grass, as well as charcoal (BOS National Energy Survey 2017). Energy consumption in summer is about 50-70% lower than in winter, indicating that heating is a very important energy service for most of the households. Households in the district are forced to take significant efforts to get to the source of fuel wood. The travelling time to reach the source of fuel wood is quite long in the district, with the majority of households travelling between 1.5 and 2 hours (29%). 23% travel more than two hours. Collection time of fuel wood is also quite long and accounts for more than one hour for almost 70% of Thaba-Tseka inhabitants. At the same time, about 20% need to spend less than one hour for this activity. In view of limited household budgets and restrictions of using electrical energy for space and water heating it is assumed that present biomass collection might be not substituted even in the presence of a modern energy supply.

In Thaba-Tseka access to electricity is very limited, even in comparison with the four other sampled districts: only 12% of households in Thaba-Tseka have electricity in their homes while 10% of households own a solar PV (BOS Energy Survey 2017).

Cooking is one of the most energy-intensive activities of the households. The main energy sources for cooking in Lesotho are biogas (22%), paraffin/kerosene (19%), LPG (17%), animal dung (17%).

Domestic space heating is another energy-intensive thermal application. In general, the majority (64%) of households living in Thaba-Tseka use energy for heating during cold months. In non-electrified households, wood and wood waste are the main energy sources for space heating.

For lighting, the majority of the households use paraffin and candles as the main energy sources respectively.

3. Sehong-hong Mini-Grid

The village is situated South East of of Thaba Tseka town and is about 50 km from the town. Its geographical coordinates are 29° 48' 0" South, 28° 49' 0" East. The site is located in a rock-shelter that is 86 m long by 19 m deep. Sehonghong is approximately 1,800 m above sea level, and it is part of a sandstone outcrop about 20 m above a tributary of the Orange River, which has a good head for run-off-river mini hydro and runs throughout the year. There are marked seasonal and daily temperature oscillations. Rain falls in the summer, while snow typically falls in the winter months. Sehong-hong is situated between Taung and Matebeng on the Senqu River. The village is very close to the Sehong-hong and Senqu rivers which contains the largest assemblage of Pleistocene freshwater fish remains in southern Africa (Plug and Mitchell, 2008; cf. data in Marean, 2016).

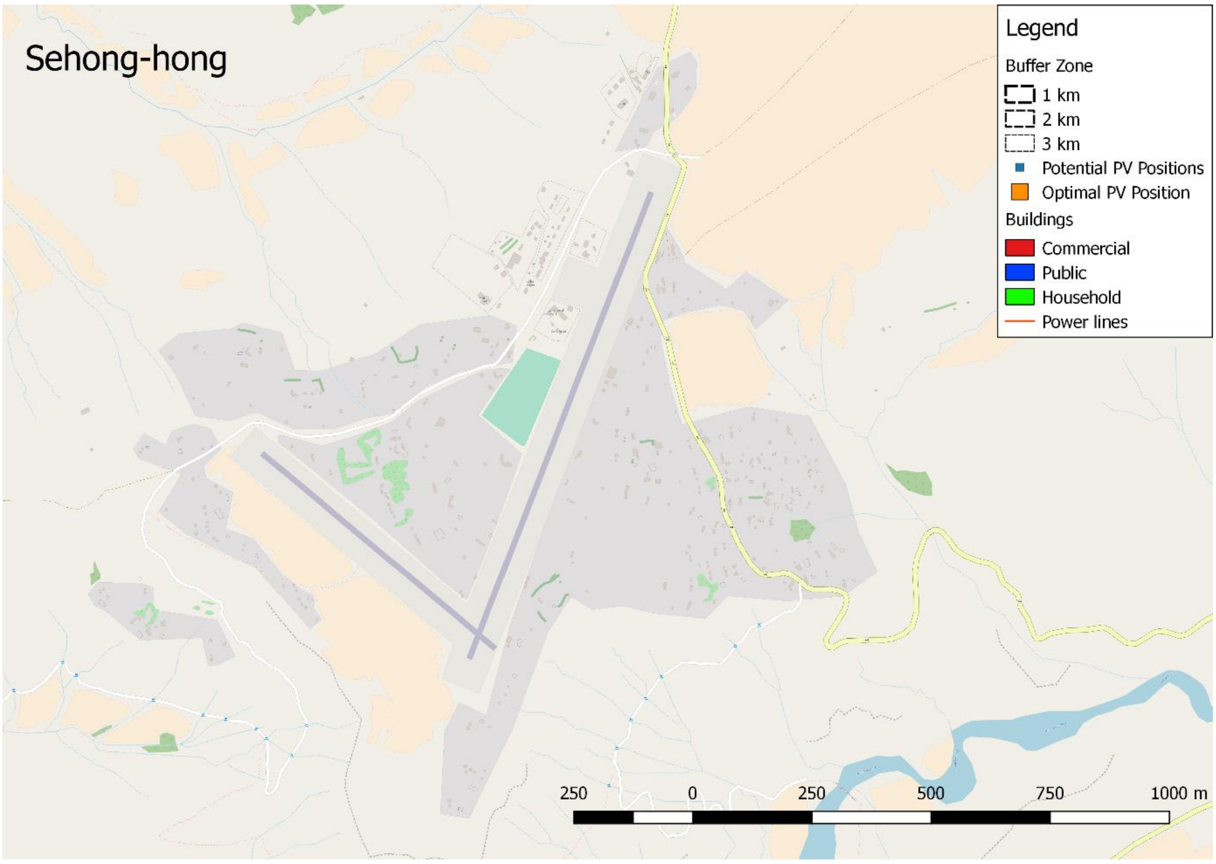


Figure 5: Map of Sehong-hong

3.1 Customer Base

Sehong-hong has more than 250 households. Main income sources in the village in order of descending importance are small-scale farming in crops and livestock, wool and mohair, self-employment, old-age pension, migrant labor income, self-employment, old-age pension and small-scale retailing. The nearest service centre is the Thaba-Tseka Town which, according to the local councilor, is about 72 km or three hours from Sehong-hong. According to the interviewed households, the village has high potential for income-generating activities such as Petrol station and medium–scale retail shops that could improve the livelihoods of the local residents and beyond.

3.1.1 Households

Sociodemographic characteristics

The survey interviewed nine households (HH) from the Sehong-hong village where an average household has five members (Q B1[1]). The demand for energy is highly dependent on the consumer base. As a results, large households become more reliable energy purchasers, due to their strong attachment to the place of residence as well as high and stable energy demand.

[1] In brackets reference to the corresponding question in the questionnaire. For questionnaire refer to the Annex.

All nine surveyed households own between one and three housing units, which is two on average (Q C1). Eight households live in a Rontabole house, which is the most common housing type in the district of Thaba-Tseka. One household lives in an optaka house, which is also popular in Thaba-Tseka. On average there are slightly less than two rooms in one house, where within each room live 4-5 people on average (Q C2). Of the total rooms occupied by an typical household, the average usable area is 52 m^2 (ranging from 9 and 105 m^2) or 11 m^2 per household member (Q C2).

Income provides the ability to pay for electricity for households. The interviewed households are characterized by very low income earnings. Three households do not earn any income, two earn about M150 per month while the other two households earn M750 income per month. Only two households earn about M7,500 on average per month, who also receive remittances of M300 per month (Q C3-C4).

In order to predict future demand for electricity, households were asked whether they had intentions of moving in the near future. None of the households indicated of moving away from the village in the next five years (Q I1).

Energy supply

The study also analyses the extend to which supply of energy sources are accessible and available to households in Sehong-hong. Out of the total households surveyed, seven households indicated that they use fuel wood, two use crop waste, one use animal waste while one uses shrubs as the only source of biomass. Most (four) households that use fuel wood collect it from the local community source while three households collect it in their backyards. Only two households indicated that they purchase fuel wood at an amount between M120 and M700. The quantity of wood used also vary by households. In general, Households used on average 760 kg in a year, which is equivalent to 3,740 kWh (Q D1). Crop waste is also important source of fuel for households in Sehong-hong. In general households consume 150 sacks (or 520 bundles), which is collected by household members. This is equivalent to 3000 kWh (or 10,400 kWh) per year. Similarly, households also use animal dung for fuel consumption. Generally, these households use about 250 sacks (or 510 bags), which is equivalent to 5,875 kWh (or 7,190 kWh) per year. Only one household use shrubs for fuel, 250 bundles or 6,125 kWh in a year.

Travelling time to the main source of fuel can determine demand and consumption of fuel. The respondents indicated that they have to travel 30–90 minutes with two HH having to travel more than 120 minutes. The majority of the households spend between 60 and 90 minutes to collect wood while two households indicated that it takes more than 120 minutes to collect wood. In general, the average time spent for travelling and collecting wood per month is between 0.5 hours and 20 hours, which is 6 hours on average. Total travelling and collection time is between 6 and 240 hours, which is 73 hours on average per year. If we compute the costs of collecting wood, we find that the total travel time converts into M584 per annum. (Q D4-D6).

The household decision to allocate labour roles for collecting fuel wood also differ across the households. Out of the total households interviewed, six indicated that women assume the responsibility of collecting fuel wood. In three households, men assume this responsibility. No children are involved in this activity (Q D7). It is clear from this distribution that fuel wood and wood waste collection is mostly female-related activity. Six households do not spend anything on biomass while three households expend less than M50 per month (Q D9). Those households who buy fuel indicated that they usually pay cash (Q D10) and would prefer to pay using cash even in the future (Q D11).

Cooking is an important household activity that requires a significant amount of fuel by households. Out of the total interviewed households in Sehong-hong, five indicated that they use LPG as a main source for cooking, three use wood while only one household uses straw/shrubs/grass (Q F1). All households in the sample also indicated that they use an alternative source of fuel for cooking in a case where their first choice is not available. Three households use LPG, two use wood while two other households use paraffin and only one household use crop waste and another charcoal.

Willingness to pay is an important indicator of consumer base for potential providers of energy sources. In general, households in Sehong-hong are willing to pay between M60 to 500 for electricity for cooking, on average of M208 per month (Q F3, Table 7). Thus can be be translated to 1-4% of the month income of a household.

Table 3: Household use of energy sources for cooking in Sehong-hong

HH No.	Use of energy sources	Annual energy consumption	Annual expenses
1	Paraffin, 0.5 litre per day, straw/shrubs, 4.5 kg per day	9,940 kWh/a	M2,373/a
2	LPG, 0.7 kg per day, Crop waste, 6.5 kg per day	14,898 kWh/a	M4,380/a
3	LPG, 0.3 kg per day	1,402 kWh/a	M2,190/a
4	LPG, 0.23 kg per day	1,075 kWh/a	M1,858/a
5	LPG, 0.3 kg per day	1,402 kWh/a	M2,190/a
6	LPG, 0.4 kg per day, paraffin, 1 litre per day	5,647 kWh/a	M7,811/a
7	LPG, 0.3 kg per day	1,402 kWh/a	M2,555/a
8	LPG, 0.3 kg per day	1,402 kWh/a	M2,190/a
9	LPG, 0.3 kg per day, Wood, 5.6 kg per day	11,417 kWh/a	M2,070/a
Average		5,398 kWh/a	M3,069/a

Lighting is also important for the majority of Sehong-hong residents. Eight out of nine interviewed households heat their houses (Q G1). Most households use paola (six households) while other households use paraffin heaters (three households) (Q G2). These require the Households to use wood (3 HH), paraffin (2 HH), and animal dung (2 HH), as a main energy source (Q G3). One household also uses LPG as an alternative energy source (Q G4).

As for willingness to pay, the interviewed households are willing to pay between M50 and M500 for electricity for space heating per month, which is M200 on average (Q G5, Table 7). The average heating area of interviewed households lies between 9 and 16 m^2, where the majority of these households (six) have between 13 and 16 m^2 of space for heating (Q G6).

For water heating, the majority of the interviewed households use wood as a main energy source. Some households also consume LPG (three households), paraffin (two households), animal dung and crop waste (one household) as alternative sources (Q G7).

Table 4: Household use of energy sources for space and water heating in Sehong-hong

HH No.	Use of energy sources	Annual energy consumption	Annual expenses
1	Paraffin, 80 litres per year, straw, 120 kg per year	1,416 kWh/a	M960/a
2	Animal dung, 530 kg per year	2,491 kWh/a	Free
3	Wood, 850 kg per year, LPG, 27 kg per year	4,511 kWh/a	M660/a
4	Paraffin, 40 litres per year, wood, 880 kg per year	4,726 kWh/a	M480/a
5	Wood, 1,390 kg per year	6,811 kWh/a	Free
6	Paraffin, 60 litres per year, animal dung, 270 kg per year, LPG, 9 kg per year, crop waste, 270 kg per year	3,085 kWh/a	M970/a
7	LPG, 27 kg per year	346 kWh/a	M630/a
8	Wood, 1,960 kg per year, paraffin, 25 litres per year	9,863 kWh/a	M300/a
9	Wood, 350 kg per year, animal dung, 230 kg per year, LPG, 36 kg per year	3,257 kWh/a	M680/a
Average		4,056 kWh/a	M520/a

Table 5: Household use of energy sources for lighting in Sehong-hong

HH No.	Use of energy sources	Annual energy consumption	Annual expenses
1	Paraffin, 48 litres per year	497 kWh/a	M576/a
2	Electricity (SHS) of 715 W	53 kWh/a	M800/a
3	Paraffin, 48 litres per year	497 kWh/a	M624/a
4	Paraffin, 24 litres per year	248 kWh/a	M336/a
5	Solar Lantern of 3 W	4 kWh/a	M500/a
6	Solar Lantern of 3 W	7 kWh/a	M500/a
7	Paraffin, 24 litres per year	248 kWh/a	M288/a
8	Paraffin, 48 litres per year	497 kWh/a	M576/a
9	Paraffin, 36 litres per year	373 kWh/a	M432/a
Average		269 kWh/a	M515/a

Four households in Sehong-hong use candles, two HH use solar lantern (3 W capacity), one uses electricity (solar home system of 715 W) for lighting purposes. Expenditure for solar lanterns were M500 per lantern, for the solar home system M800 for 715 W SHS. Paraffin is also used (Q H1). Please note that the energy consumption we calculated is on the basis of the energy content of the fuels used. It cannot be directly translated into demand for electrical power because conversion of power into light is much more efficient than conversion of fuels resulting in either a better energy service with the same energy input in terms of kWh or to a lower power demand in kWh terms with the same quality of energy service. In average, the households spent M515/a, so the equivalent budget would be at least available for purchasing power for lighting purposes.

Interviewed households in Sehong-hong use energy saver (compact fluorescent) light bulbs: a household with solar home system uses four bulbs of 12 W three hours per day, households with solar lanterns use one lamp of 3 W each for four or six hours per day (Q H3). Households were willing to pay between M30 and M300 for electricity for lighting per month. Realistic values are about 1% of the month income (Q H4, Table 7). Seven HH are willing to pay for electricity with Mpesa, and two would prefer Ecocash (Q E10).

Of the total interviewed households in Sehong-hong, three use electrical appliances at home and generate their own electricity with solar panel and solar lanterns, which they purchased for M500-M800 (Q E1-E5). All these households use electricity for lighting and phone charging while one household which has SHS at home uses it also for TV and radio (Q E6). For these reasons, all households want electricity in their houses (Q E7). Considering plans to purchase electrical appliances in the next five years, all households plan to obtain refrigerators, electric stoves, eight households want to have electric kettle/element, seven HH plan to buy television (flat screen) and microwave, six households plan to obtain an iron, three households plan to buy electric heaters, and one HH plans to buy washing machine, television LCD, laptop, bread maker (Q I3) (Table 6).

Table 6: Households desired future uses of electricity in Sehong-hong, ranked starting from the most popular ones

Electricity uses	HH 1	HH 2	HH 3	HH 4	HH 5	HH 6	HH 7	HH 8	HH 9	Total
Cooking/ re-heating	X	X	X	X	X	X	X	X	X	9
Radio	X	X	X	X	X	X	X	X	X	9
Ironing	X	X	X	X	X	X	X	X	X	9
Lighting	X	X	X	X	X	X	X		X	8
Refrigeration	X	X	X	X	X		X	X	X	8
TV	X	X		X	X	X	X	X	X	8
Phone charging	X	X		X		X		X	X	6
Water heating		X								1
Space heating						X				1
Charging (other than phone)					X					1
Air-conditioning								X		1
Laundry										0
Dishwashing										0
Sewing										0
Computer										0
Water pumping										0
Workshop										0
Total	7	8	5	7	7	7	6	7	7	-

In general, the interviewed households indicated willingness to pay for electricity, ranging between M60 and M500, an average of M250 (Q E9, Table 7). Out of these household seven households preferred Mpesa, one preferred cash while the other household preferred Ecocash (Q E10).

Similarly, all the nine interviewed households are expressed their willingness to pay for electricity for lighting, though it does not seem realistic, considering their earnings (Q H4, Table 7). In a first step, we asked for the general willingness to pay for power (responses in 3rd column). In a second step we refined the question on the willingness to individual purposes (columns 4 – 6), where the sum of individual specific willingness's to pay do not necessarily sum up to the same amount as the general willingness to pay. Also, the willingness to pay deviates substantially from the actual expenses for e.g. lighting. In summary, it seems appropriate to assume some demand for power for lighting but not for heating or cooking. Further, it seems reasonable to assume some demand for power for additional applications like phone charging, radio, television and refrigerators confirming what is described in the General Part of the report. This is also reflected in the average willingness to pay for electricity in general of monthly 575 Maloti.

Table 7: Ability and willingness to pay for electricity in general and for different applications of households in Sehong-hong

HH #	Earnings per month (ability to pay)	Willingness to pay for electricity (Maloti and % of earnings)				Plans to buy electric appliances
		In general	For cooking	For space heating	For lighting	
1	M150	M500 (333%)	M500 (333%)	M200 (133%)	M50 (33%)	Refrigerator, electric stove, TV LCD, iron, electric kettle
2	M7,792	M60 (1%)	M60 (1%)	M60 (1%)	M50 (1%)	Refrigerator, electric stove, TV flatscreen, electric kettle, microwave
3	0	M150 (-)	M250 (-)	M200 (-)	M30 (-)	Refrigerator, electric stove, TV flatscreen, electric kettle, microwave
4	M750	M500 (67%)	M100 (13%)	M300 (40%)	M100 (13%)	Refrigerator, electric stove, electric heater, washing machine, TV flatscreen, iron, electric kettle, bread maker, microwave
5	M750	M100 (13%)	M100 (13%)	M200 (27%)	M200 (27%)	Refrigerator, electric stove, TV flatscreen, electric kettle, microwave
6	M7,500	M500 (7%)	M300 (4%)	M500 (7%)	M50 (1%)	Refrigerator, electric stove, electric heater, TV flatscreen, laptop, iron, microwave
7	0	M100 (-)	M210 (-)	M100 (-)	M100 (-)	Refrigerator, electric stove, TV flatscreen, iron, electric kettle, microwave
8	0	M100 (-)	M200 (-)	M200 (-)	M300 (-)	Refrigerator, electric stove, electric heater, TV flatscreen, iron, electric kettle, microwave
9	M150	M250 (167%)	M150 (100%)	M50 (33%)	-	Refrigerator, electric stove, TV flatscreen, iron, electric kettle
	Average	M250	M208	M201	M110	

Regarding the plans for the households to purchase electric appliances in the next five years, none of the households plans to buy a solar PV, a generator running on gas, or a car battery in the next five years (Q I4).

Energy demand forecast

Three households interviewed in Sehong-hong belong to the affluent type, considering their energy generation facilities (solar panels and lanterns), current electricity usage for lighting and phone charging and even television and radio, as well as relatively high income. Other households from the village sample are typical representatives of the basic type with low income and no electrical appliances at the moment. For the entire village, we assume a distribution of household types as described in the General Part. For forecasting, we assume that the number of households equally over all household types increase by 1% per year. Further the specific demand of all household types is expected to increase once electricity is available due to more electrical appliances. The answers given on planned purchases of appliances confirms this trend. However, experiences in other countries showed that household demand for power remained stable even five years after power supply arrived (Blog World Bank 2017). In any case, it gets clear that returns from power supply rely mainly on the medium and affluent households (Table 8). From the commercial point of view, the less endowed households are less interesting, however they are those who would most benefit from enhancing their living conditions through the supply of power.

Table 8: Present and future power demand by households in Sehong-hong

Household type	No. of HH in Sehong-hong			Total power demand, kWh/year		
	Present	2019	2030	Present	2019	2030
Basic	163	165	184	0	4,950	110,400
Medium	62	63	70	3,100	31,500	189,000
Affluent	25	25	28	7,500	45,000	81,200
Total	**250**	**253**	**282**	**10,600**	**81,450**	**380,600**

3.1.2 Anchor customers

Main characteristics

Potential anchor loads in the village are the Sehong-hong Health Clinic, a post office, a police post, a primary school, a high school, the office of the community council, two supermarkets, five medium size shops, a church, Agriculture Extension, bars, a hammer mill, and a woolshed.

In Sehong-hong we interviewed eight anchor customers: one health facility, police station and five retail representatives (general dealer, grocery shop, two clothing shops, post office, pharmacy) (Q B1). Public institutions are in terms of cooperative ownership and commercial facilities are in individual ownership (Q B2). Government institutions have from three (post office) to 13 employees (health centre and police station). Commercial users employ between one and three workers (Q B3).

Regarding earnings, three commercial companies generate some income, where both grocery shops earn M750 per month, and the clothing stores has a little lower with M250 to M750. The pharmacy earns relatively more, with M3,500 per month and a post office receives M30,000 per month (Q B4). The school receives subsidies from the state accounting for M5,000 to M10,000 last year, close to M600 per month (Q B6).

Most anchor customers operates for seven days a week, except for the health clinic which operates for 5 days per week, post office for 6 days and pharmacy for 6 days (Q D1). Commercial users operate between 8 and 13 hours per day over the whole year, the police station operates 24 hours a day over the whole year, health centre and post office both operate 8 hours per day (Q D2, Q D3).

Commercial users occupy one to three buildings, police station ten buildings, health centre seven buildings while the post office occupy two buildings (Q D4). Most buildings were constructed in the period of 2006 and 2015. Some buildings are as old as before 1966 and 1975. The total building area ranges between 12 m^2 and 90 m^2 among commercial facilities, 40 m^2 on average, and 375 m^2 for the health clinic, post office and the police station. Three buildings heat their buildings. But only one building is insulated (Q D5).

Energy supply

Hard coal and biomass energy sources, namely wood, were used only by public facilities (post office, police station)(Table 9). Post and police used 2,500 or 4,000 kg hard coal (21,750 or 34,800 kWh) for space heating. Post office additionally used 1,500 kg of wood for space heating. The prices amounted to M2 per kg wood and M3-5 per kg hard coal (Q C1).

Table 9: Consumption of energy resources and electricity generation of anchor customers in Sehong-hong

Anchor customer	Hard coal		Wood		LPG		Solar PV	
	kg	Purpose	kg	Purpose	kg	Purpose	System size	Purpose
Sehong-Hong Health Clinic					288 kg	Heating	1,000 W	Lighting, water heating
Post Office	2,500	Space heating	1,500	Space heating				
Lesotho Mounted Police	4,000	Space heating	540	Heating				
Clothing								
MM Pharmacy							2,000 W	Lighting, printing, photocopy
Imameleng General Dealer							1,000 W	Lighting
Hillside							715 W	Lighting, phone charging
Clothing								
Total quantity	**6,500**		**2,040**					
Unit costs	M4.8/kg		M2/kg					
Total costs	**M24,000**		**M4,080**					

Four anchor customers (health centre, three retailers) consumed solar electricity last year, generated by solar panels of 715, 1,000 and 2,000 W capacity. Solar electricity was used for lighting, phone charging, printing, photocopying, and water heating. Anchor customers generated electricity with solar panels over the whole year for 3 to 13 hours per day (Q C3). All respondents want to have electricity in their facilities and think that it is important for companies and institutions from their branches to have (Q C4, Q C5). At the same time, none of the users perceive electricity as expensive (Q C6).

Respondents, with the exception of police station, stated that their company/institution is ready to pay for electricity between M250 and M2,000 per month, on average M864, which is a share of their month income of between 1 and 200% (Q C7).

Preferred methods to pay for electricity were via mobile phone (all commercial users) or by cash (health centre and post) (Q C8).

No anchor customer uses any central air-conditioning systems (Q D6), as well as independent heating/cooling systems (Q D8). Only the health clinic uses the LPG heating system, which operates 8 hours in a day for 5 days in a week, over 6 months in a year. For heating 288 kg of LPG were used over the last year. Police uses wood for heating, 540 kg per year, for four months in a year. Post consumes hard coal, 2,500 kg last year for heating over the whole year (Q D7).

All anchor customers are willing to pay for electricity for heating/cooling purposes. Commercial enterprises (cafes, clothing and food retailer) have a willingness to pay between M50 and M300 (6 40 % of their monthly income). Ability to pay of public institutions is more difficult to define, since we are mostly not aware of the level of subsidies which they get from the state and/or district council. The health centre and Lesotho Mounted Police are ready to pay M2,000 and M10,000 each respectively, but it is questionable if the state will accept these expenditures. Willingness to pay for electricity for heating/cooling purposes of the post office (M500) and pharmacy (M200) looks somehow feasible but the question of the expenditure approval by the competent authorities remains (Q D9, Table 11).

Four anchor customers use any light bulbs: health centre uses 36 fluorescent bulbs, three retailers use energy saver lights of 12 W (Q D10). Only the health clinic has a light and motion sensor controls (Q D11, Q D12). Regarding willingness to pay for electricity for lighting, the highest willingness and accordingly the need for lighting comes from the health centre (M1,500), other public institutions do not see it as such important electricity application, probably because of their operating hours mostly fall on sunshine day period. Surprisingly the police offices do not find it important to pay for lighting even though they operate 24 hours. Commercial customers are ready to pay for electricity for lighting between M50 and M500 (1-67% of their month earnings) (Q D13, Table 11).

As for small equipment like desktops, monitors, laptops, servers, printers, or household appliances, health centre has one desktop, two printers, two household appliances at its disposal. Pharmacy uses a printer, one retailer a radio (Q D14).

Three anchor customers with any cooking facilities among anchor customers in Sehong-hong were the health centre, the police station and the pharmacy (Q D15). As an energy source for cooking, these customers use LPG (Q D16). All the respondents are ready to pay for electricity for cooking and willingness to pay is between M50 and M800 per month, M319 on average (Q D17, Table 11).

The health centre, police station and one retailer have 1-3 refrigerators of 50-400 liters capacity, used mainly for food or medical uses. The health centre additionally has one vaccine refrigerator which is 90 litres of capacity (Q D18). Commercial customers showed willingness to pay for electricity for refrigeration between M100 and M800, which translates into an average of M294 (Q D20, Table 11).

Table 10: Electric equipment of anchor customers in Sehong-hong

Anchor customer	Lighting		Small equipment	Refrigerating equipment	
	Type & number	Capacity, W	Type & number	Type & number	Capacity, l
Sehong-Hong Health Clinic	36 fluorescent		1 desktop, 2 printers, 2 HH appliances	2 refrigerators; vaccine refrigerator	50 (refrigerator); 90 (vaccine refrigerator)
Post Office					
Lesotho Mounted Police				1 refrigerator	250
Clothing					
MM Pharmacy	5 energy saver	12	1 printer		
Imameleng General Dealer	1 energy saver	12	1 radio	3 refrigerators	400 (per refrigerator)
Hillside	1 energy saver	12			
Clothing					

Table 11: Ability and willingness to pay for electricity in general and for different applications of anchor customers in Sehong-hong

Anchor customer	Earnings per month ability to pay	Willingness to pay for electricity per month (Maloti)					
		Heating/ Cooling	Lighting	Cooking	Fridge	Total	
						Maloti	% of earnings
Sehong-Hong Health Clinic	M625	M2,000	M1,500	M500	M300	M4,300	688%
Post Office	M30,000	M500	M50	M700	M100	M1,350	5%
Lesotho Mounted Police	0	M10,000	M100	M250	M750	M11,100	-
Clothing	M750	M100	M50	M100	M100	M350	47%
MM Pharmacy	M3,500	M200	M50	M100	M100	M450	13%
Imameleng General Dealer	M750	M300	M500	M800	M800	M2,400	320%
Hillside	M750	M300	M50	M50	M100	M500	67%
Clothing	M250	M50	M20	M50	M100	M220	88%
Total	M36,625	M13,450	M2,320	M2,550	M2,350	M20,670	-

Four anchor customers generate electricity with solar panels (Q E1), with 1-10 panels, which is 715-7,150 W in total, and use electricity for lighting, water heating, printing and charging. Panels operate for 3 to 13 hours per day, throughout the year (Q E2). However, none of the anchor customer uses a generator to generate electricity and/or heat (Q E4).

Four anchor customers are planning to replace some appliances over the next five years (Q F1). The health clinic plans to replace LPG refrigerator and stove with the electric appliances; the police station plans to replace a refrigerator and install an air conditioner and a Wi-Fi; the pharmacy and general dealer plan to replace solar panels and install electric light bulbs. Other customers plan to install light bulbs, air conditioners, TV, electric refrigerators (Q F2-F5). They perceive these changes will increase their energy consumption (Q F8).

Five anchor customers plan to buy generator, and general dealer and clothing shop station plan to buy solar PV in the next five years (Q F9). No anchor customer plan to buy all three electrical sources.

All the anchor customers plan to upgrade buildings in the next five years: all want to replace light bulbs with LED, post office wants to insulate walls, and police post are going to fit a ceiling (Q F10-F11).

Energy demand forecast

Present power demand and supply of anchor customers in Sehong-hong are summarized in the Table 13. Future power demand of all anchor customers in the village, including non-interviewed ones, is presented in the Table 12.

Table 12: Future power demand of anchor customers in Sehong-hong

Type	Number of institutions	Power demand, kWh/year	
		2019	2030
Health	1	11,500	23,000
School	2	1,000	7,000
Government	4	7,150	14,300
Retail	10	22,000	66,000
Craft	2	100	500
Total		**41,750**	**110,800**

Table 13: Main characteristics of anchor customers in Sehong-hong

#	Name	Type	Size	Operation hours	Electrical equipment	Annual power demand	Present power supply	Willingness to pay[2], Maloti/month
1	Sehong-Hong Health Clinic	**Health**	13 employees; 7 buildings, area 375 m^2	8 h/day, 5 days/week, 12 months/year	36 fluorescent bulbs, 1 desktop, 2 printers, 2 HH appliances, 2 refrigerators, 1 vaccine refrigerator	9,461 kWh	10 solar panels, capacity of 7,150 W	4,300
2	Post Office	**Government**	3 employees; 2 buildings, area 375 m^2	8 h/day, 6 days/week, 12 months/year	None	0	None	1,350
3	Lesotho Mounted Police	**Government**	13 employees; 10 buildings, area 375 m^2	24 h/day, 7 days/week, 12 months/year	Refrigerator	2,453 kWh	None	11,100
4	Clothing	**Retail**	1 employee; 3 buildings, area 12 m^2	9 h/day, 7 days/week, 12 months/year	None	0	None	350
5	MM Pharmacy	**Retail**	3 employees; 1 building, area 90 m^2	8 h/day, 6 days/week, 12 months/year	5 energy savers of 12 W, 1 printer	250 kWh	2 solar panels, capacity of 2,000 W	450
6	Imameleng General Dealer	**Retail**	3 employees; 3 buildings, area 40 m^2	13 h/day, 7 days/week, 12 months/year	Energy saver of 12 W, refrigerator, radio	2,723 kWh	1 solar panel, capacity of 1,000 W	2,400
7	Hillside	**Retail**	1 employee; 1 building, area 32 m^2	11 h/day, 7 days/week, 12 months/year	Energy saver of 12 W	48 kWh	1 solar panel, capacity of 715 W	500
8	Clothing	**Retail**	2 employees; 2 buildings, area 24 m^2	9 h/day, 7 days/week, 12 months/year	None	0	None	220
					Total	14,934 kWh		20,670

[2] Sum of willingness to pay for electricity for heating/cooling, lighting, cooking, and refrigeration (Table above).

The power demand distributes spatially as depicted in the Table 14.

Table 14: Development of power demand in Sehong-hong by distance from power plant site

Customer	Annual Power Demand MWh											
	Present				2019				2030			
	1km	**2km**	**3km**	**total**	**1km**	**2km**	**3km**	**total**	**1km**	**2km**	**3km**	**total**
Households	7.7	1.1	0.0	8.8	58.7	8.4	0.0	67.2	245.3	35.2	0.0	280.5
Anchor customers	31.2	0.0	0.0	31.2	47.2	0.0	0.0	47.2	137.6	0.0	0.0	137.6
Total	38.8	1.1	0.0	**39.9**	105.9	8.4	0.0	**114.4**	382.9	35.2	0.0	**418.1**

3.2 Set-up for Mini-Grid

Like with most villages, the land ownership in Sehong-hong is communal where the community elders and area leaders give authority for use of land for development either for domestic, business or institutional purposes. For the purpose of developing a mini-grid, the community seems receptive to allocate land for the project.

We designed the mini-grid by using HOMER Pro software. For dimensioning the generation plants we used the consumption pattern as derived in previous sections of this report.

HOMER analysis shows that for the electricity supply under conditions in present, the combination of PV power plant and storage is the most optimal and least-cost solution. Capacity of battery storage should exceed maximum hourly output of solar panels in about 2.5 times, but this ratio depends to large extent on relative costs of solar panels and battery. In this combination the unmet load accounts for about 2%, and excess electricity produced 48.3% which makes possible to connect further loads. The levelized cost of electricity is quite high for this setup: M11.5/kWh, that points out the need of additional studies before making a decision about mini-grid design.

Table 15: Elements of mini-grid setup in Sehong-hong in present conditions

Element	Size	CAPEX (Maloti)	Replacement costs (Maloti)	OPEX (Maloti/year)
PV Power Plant	47.7 kW	806,130	0	9,302
Battery	127 kWh	495,300	1,981,200	16,510
System converter	13.3 kW	34,580	34,580	0
Power lines	11.81 km	247,905	0	4,958
Power meters	225 units	720,000	0	14,400
Total	-	**2,303,915**	**2,015,780**	**1,129,250**

Regarding the expected demand increase, the modular characteristics of pv allow for an easy stepwise adaption of generation. In this regard, developers may further install lines in order to be able to accommodate higher loads than the expected future loads. For expected demand increase in 2019 after commissioning of a mini-grid the most optimal option remains a combination of solar power plant and storage. Significant enlargement of PV and battery size leads to a nearly threefold higher investment need.

Table 16: Elements of mini-grid setup in Sehong-hong in 2019

Element	Size	CAPEX (Maloti)	Replacement costs (Maloti)	OPEX (Maloti/year)
PV Power Plant	161 kW	2,720,900	0	31,395
Battery	444 kWh	1,731,600	6,926,400	57,720
System converter	52.8 kW	137,280	137,280	0
Power lines	11.92 km	250,384	0	5,008
Power meters	227 units	727,200	0	14,544
Total	**-**	**5,567,364**	**7,063,680**	**2,716,675**

Figure 6 presents the distribution of capital costs between different components of a mini-grid. It shows that power grid components (lines and meters) have a significant share of 17% of the capital costs in the case of Sehong-hong.

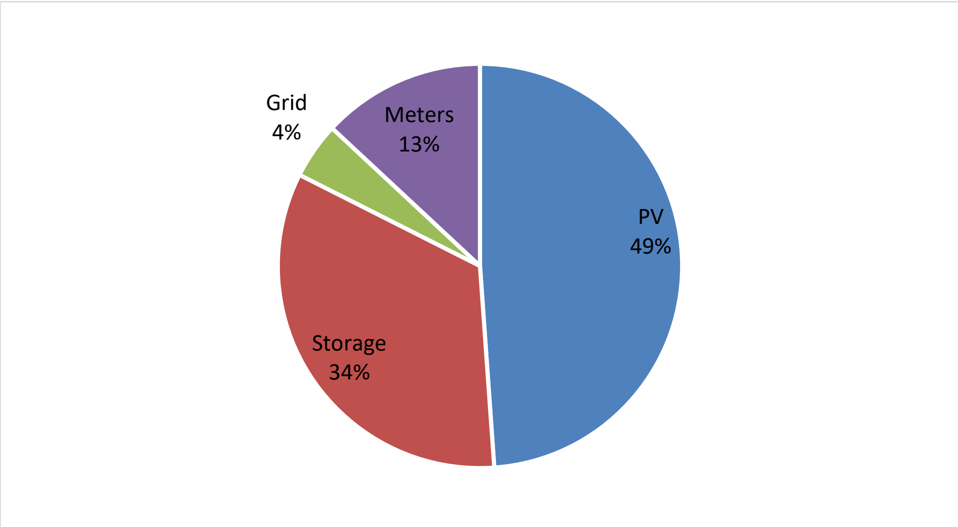


Figure 6: Distribution of capital costs of a mini-grid in Sehong-hong in 2019

For the Mini Grid, three feasible sites were identified. Two sites, which are marked blue on the Figure 7, were chosen according to physical criteria like direction to the sun, area size and availability of space. The yellow marked optimal site was determined according to the calculation algorithm of the geometrical mean of all buildings in the radius 1-3 km in the village. So, it is the location that has the minimum sum of distances to all existing potential residential, public and business customers. In the case of Sehong-hong, the theoretically chosen potential site for a mini-grid coincided with the site chosen as a result of field research. This particularly suitable site is presented on the following map as two squares, blue and yellow, inscribed in each other.

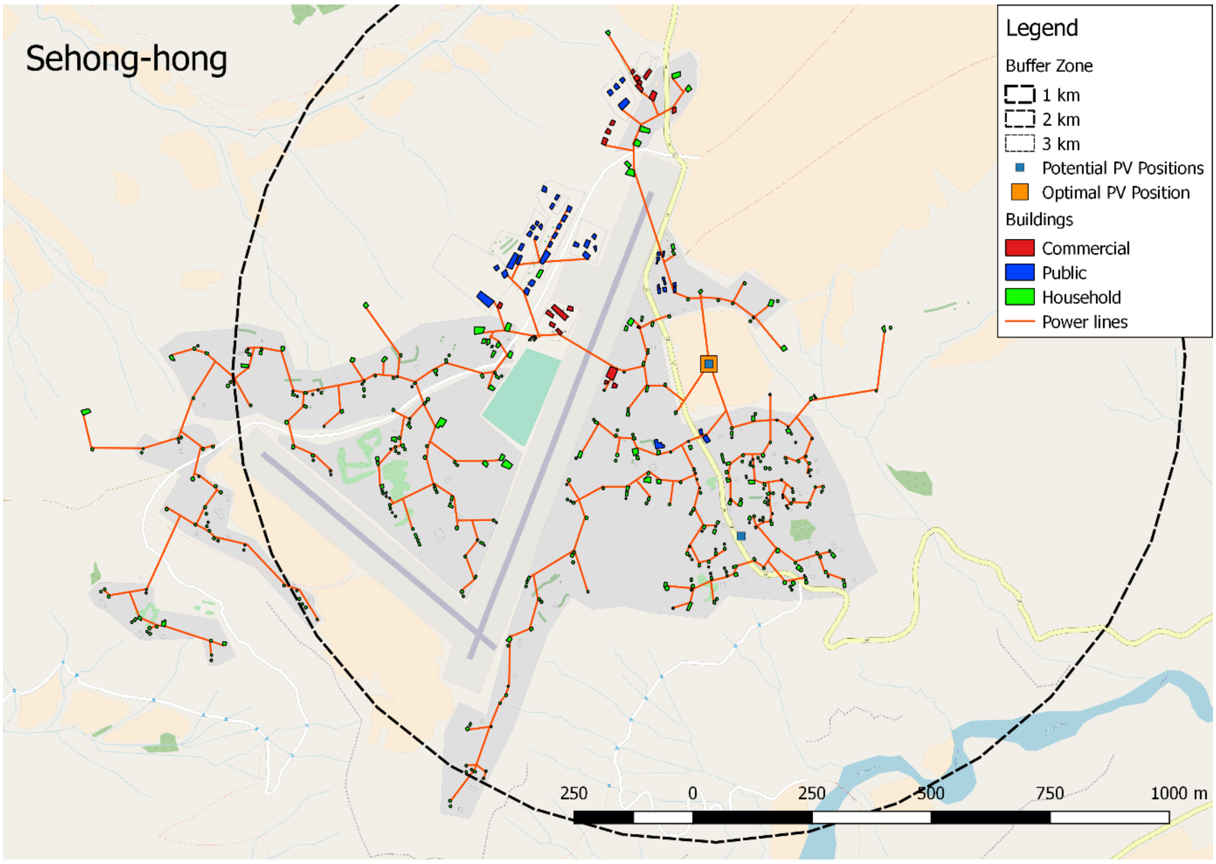


Figure 7: Map of the mini-grid set-up in Sehong-hong

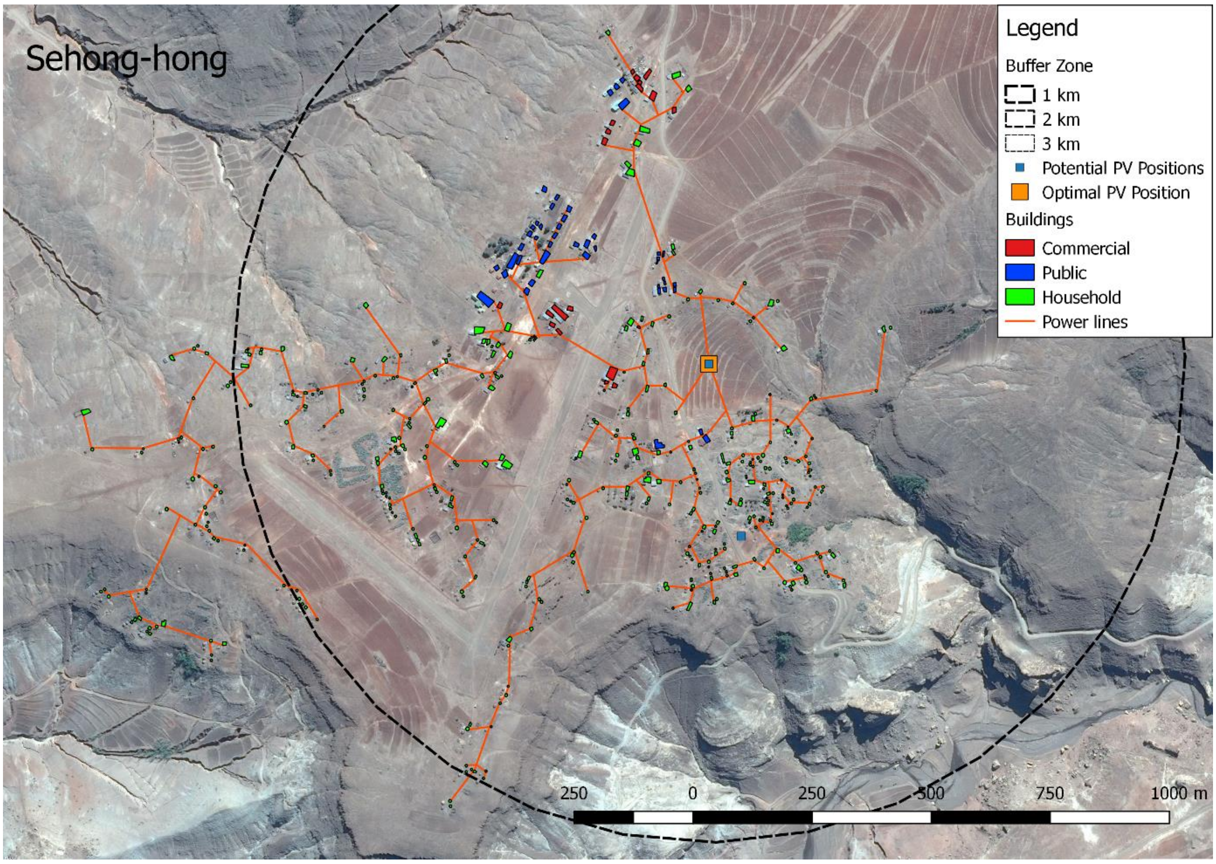


Figure 8: Satellite map of the mini-grid set-up in Sehong-hong

For the long-term period till 2030, additional to the solar power plant generation sites can be considered, like hydro power plant. The option with PV, storage and hydro is cited as a least-cost by HOMER software. Until then, it is due to carry out extensive research of river flow rates and conditions throughout the year to define hydro energy potential. Besides, in the long-term period of more than ten years further reductions of PV and battery costs are foreseen, whereas the hydropower costs would most probably remain the same, as the technology is already well-advanced, and the cost reduction potential is quite exhausted.

Table 17: Elements of mini-grid setup in Sehong-hong in 2030

Element	Size	CAPEX (Maloti)	Replacement costs (Maloti)	OPEX (Maloti/year)
PV Power Plant	361 kW	6,100,900	0	70,395
Battery	881 kWh	3,435,900	13,743,600	114,530
Hydro Power Plant	100 kW	6,000,000	0	180,000
System converter	169 kW	439,400	439,400	0
Power lines	13.30 km	279,346	0	5,587
Power meters	254 units	811,314	0	16,226
Total	-	**17,066,860**	**14,183,000**	**9,668,450**

The expected growth in demand allows for lower generating costs in the future (Table 18). Thereby we have not considered, that due to technology advancements some elements to be added in the future will have very likely lower specific CAPEX than presently. There is a high rate of excess power to allow for a generation entirely based on renewable energies. This waste of energy could be avoided in two ways: Either one would allow a minor share of fossil based generation which would run during winter, when PV generation is low, leading also to lower overall generation costs. Or additional seasonal usage of the excess power is created, e.g. refrigeration and cooling which both would perfectly match the generation patterns of solar generation.

Table 18: Characteristics of mini-grid setup in Sehong-hong in present and future

Time horizon	Unmet load, %	Excess electricity, %	LCOE, M/kWh
Present	2.13	48.3	11.486
2019	2.11	47.5	9.492
2030	2.27	65.4	6.666

3.3 Economic Viability

For the assessment of economic viability of a mini-grid setup, we calculated the internal rate of return (IRR) with revenues on the basis of the present national electricity tariffs. This calculation allows to assess the economic viability under the present framework conditions. Additionally, we calculated a uniform tariff for all customers allowing for an IRR of 8%, equivalent to levelized costs of electricity (LCOE). The difference between the LCOE tariff and the national tariff indicates the amount of public support needed to keep tariffs in the mini-grid at the level of LEC tariffs in the national grid. For the calculation, we assume two different scenarios. The first scenario assumes that the energy demand will remain stable on the level of 2019 over the entire project lifetime of 25 years. In that case, the IRR with revenues on the level of national tariffs will be negative, -15%.

Under these conditions, the project is not economic viable without public support. The difference between revenue from national tariffs and annualized costs, consisting of capital costs including replacement, and operation and maintenance costs, accounted for M9,212,713 over 25 years, or M368,509 per year. Converted into electricity demand, the subvention need would be M2.98/kWh. Regarding allowance need in terms of customers, some M1,357 should be additionally paid per year for one customer.

The second scenario earmarks the increase of electricity demand between 2019 and 2030 according to the load forecast and stable demand after 2030. Under these circumstances, the difference between tariff revenue and total project expenditure amounts M21,408,564 over whole project lifetime, and M856,343 per year. Subvention need per kWh would be somewhat lower than in the first scenario: M2.12/kWh. Due to significant annual increase of energy demand, allowance needs per customer would also increase more than twofold, accounting for M2,815 per customer per year.

3.4 Summary

Sehong-hong represents a relatively large village in our sample, with 250 households and several important anchor loads. Current electricity demand is about 36,200 kWh per year (for 71% of demand anchor customers are responsible, for 29% households). In the future, growth in electricity demand is expected: in 2019, when mini-grid will be commissioned, we expect an annual consumption of 123,200 kWh (66% by households, 34% by commercial and public customers). Power demand shares will drastically grow, because when households receive grid electricity, they will purchase electric appliances, for example, switching from ineffective paraffine lamps and candles to LED lights and acquiring long desired refrigerators, irons, radios and hair clippers. The forecasted long-term demand for the year 2030 is 491,400 kWh in a year with an increased share of households in total energy consumption (77%).

In order to cover this constantly increasing power demand, a highly scalable modular energy system is required. The most optimal renewable energy technology for this is solar combined with storage. It can be commissioned and expanded in a short period of time. Besides, in that field further cost reductions in both PV solar panels and battery storage are expected. Closer to the end of considered period till 2030, it can be necessary to integrate other RES technologies, like hydro or wind power, but it will require detailed study of demand forecast and potential of these technologies in the region.

4. Mashai Mini-Grid

Mashai (29°38'42.3"S 28°48'35.8"E) is located 47.7 km South East of Thaba-Tseka Town. Orange River flows nearby this village, which has a good head for run-off-river mini hydro and runs throughout the year. It is about 10.48 km from A3 main road. The nearest service centre is Thaba-Tseka Town, with distance of about 48 km, or 2.5 hours. Mashai is situated between Taung and Sehong-hong on the Senqu River. According to interviewed residents, the village has high potential for income-generating activities such as Petrol station and medium –scale retail shops.

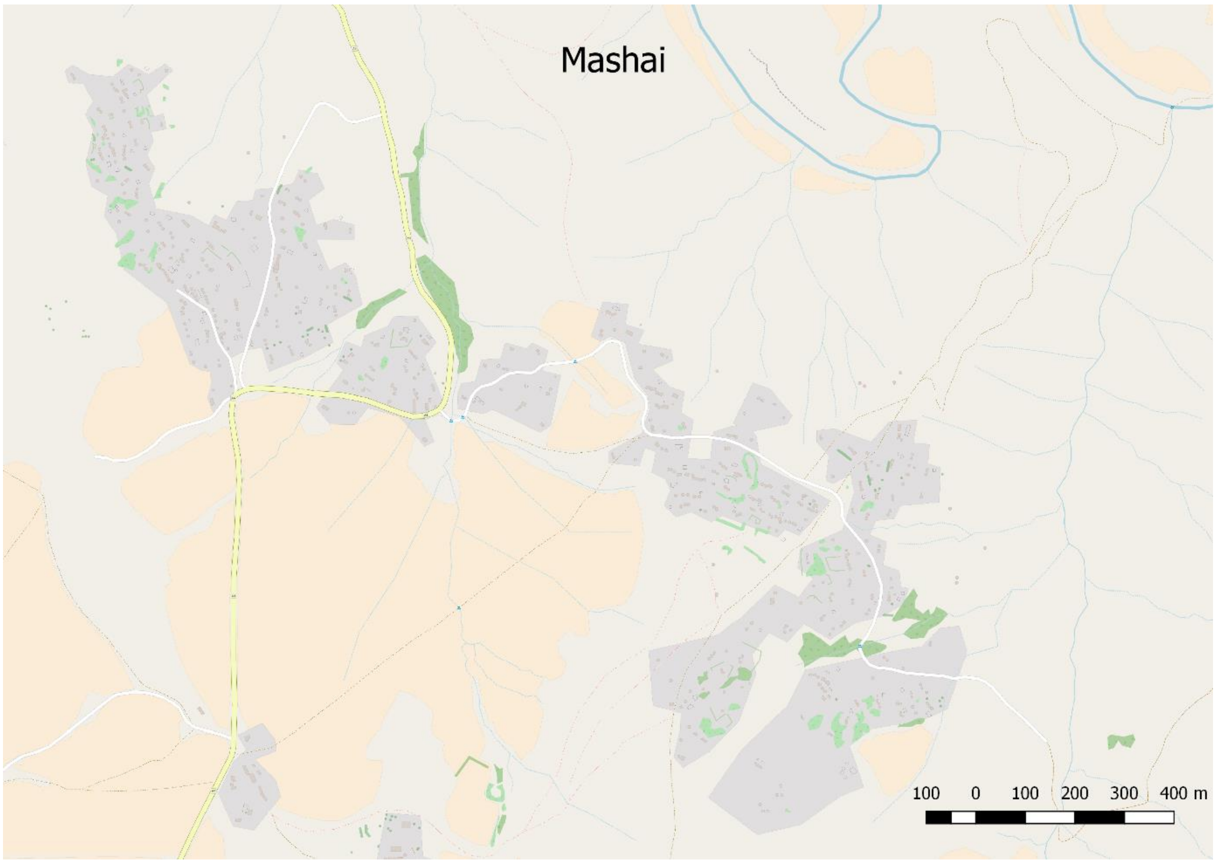


Figure 9: Map of Mashai

4.1 Customer Base

According to the local counsellor, the main sources of income in the village are retailing, farming in crops and in livestock.

4.1.1 Households

Sociodemographic characteristics

Mashai accommodates more than 200 households. In the survey, ten households (HH) were interviewed from the village. The interviewed households in Mashai have two to seven members, which is four persons on average (Q B1[3]). Large households are more reliable energy consumers, due to their strong attachment to the place of residence as well as high and stable energy demand.

The surveyed households have varying number of housing units at their disposal, from one to five housing units, which is three units on average (Q C1). Six households live in a house of Rontabole type, which is the most common housing type in the district of Thaba-Tseka. Two households live in a polata and the other two in optaka house, which is also popular in the area. On average, there are varying number of rooms in one house, ranging from one room to six rooms per house, where within a room live 4-5 people on average (Q C2).

The usable area of all disposable buildings per household ranges from 8 and 122 m^2, 55 m^2 on average (about 14 m^2 per household member) (Q C2). The interviewed households are characterized by relatively high income earnings. Only one household does not have any income in cash or remittances. The other nine households earn between M750 and M7,500 per month, which is M1,663 on average. One household out of the ten receives remittances of M1,500 per year, what corresponds to about M125 per month (Q C3-C4).

None of the households are going to move away from the village in the next five years (Q I1).

Energy supply

Five households of the total interviewed in Mashai use fuel wood, two use wood waste and one uses crop waste as the only biomass source. Households used between 450 and 1,850 kg of wood per year, equivalent to 2,200-9,065 kWh. Fuel wood was either purchased (for M200-M1,440, about M0.2-0.8 per kg) or self-produced. Wood waste was obtained by self-production or collection, it was 530 or 880 kg used (equivalent to 2,600-4,300 kWh). 980 kg crop waste were collected by one household (3,920 kWh) (Q D1). To obtain wood, households either purchase it (three households), collect it from communal forest (three households) or from their backyard (two households) (Q D3).

Respondents from Mashai indicated that they have to travel 30 – 90 minutes towards the wood collection area and back, with only one household having to travel less than 30 minutes. Majority of households take 30 – 90 minutes to collect wood, and only one household takes less than 30 minutes to collect. In general, it results in average time spent for travelling and collecting wood per month between one and 12.5 hours, which is on average, 5.5 hours. Total travelling and collection time per year accounts for 12-150 hours, with an average time of 66 hours. Based on an hourly wage of 8 Maloti, this converts into annual costs of approx. 528 Maloti (Q D4-D6).

In most of the interviewed households, it is women who are mostly involved in fuel wood collection. In five households, women assume the responsibility of collecting fuel wood while men

[3] In brackets reference to the corresponding question in the questionnaire. For questionnaire refer to the Annex.

collect wood in three households. No children are involved in this activity (Q D7). It is clear from this distribution that fuel wood and wood waste collection shared among female and males between households. No household has an improved fuel wood stove, one household uses a magic stove (Q D8).

For purchasing biomass, five households spend nothing while three households expend M25-400 per month (Q D9). All of these household normally pay in cash for commercial fuels (Q D10) and would prefer to pay using cash even in the future (Q D11).

Five households in Mashai use wood, four use LPG and one uses crop waste as a main energy source for cooking (Q F1). Household consume paraffin LPG and wood as alternative sources.

Table 19: Household use of energy sources for cooking in Mashai

HH No.	Use of energy sources	Annual energy consumption	Annual expenses
1	Wood, 850 kg per year	4,165 kWh/a	Free
2	Biogas, 0.95 kg per day	1,942 kWh/a	M14,600/a
3	LPG, 0.3 kg per day Wood, 550 kg per year	4,097 kWh/a	M2,446/a
4	LPG, 0.3 kg per day	1,402 kWh/a	M2,446/a
5	Wood, 650 kg per year	3,185 kWh/a	Free
6	LPG, 0.3 kg per day Wood, 12 kg per day	22,864 kWh/a	M4,892/a
7	LPG, 0.3 kg per day Paraffin, 0.5 litres per day Crop waste, 3.5 kg per day	8,400 kWh/a	M4,198/a
8	LPG, 0.3 kg per day Paraffin, 0.5 litres per day	3,290 kWh/a	M4,636/a
9	LPG, 0.3 kg per day Paraffin, 0.5 litres per day	3,290 kWh/a	M4,636/a
10	Paraffin, 0.5 litres per day, wood, 4.5 kg per day	9,937 kWh/a	M2,190/a
Average		6,257 kWh/a	M2,827/a

Households in Mashai are ready to pay between M30 to 200 for electricity for cooking per month, M103 on average (Q F3, Table 23). No household has a wonder box (Q F4).

Eight households out of ten in Mashai heat their houses (Q G1). For space heating, eight households use paraffin heater and six households use paola, (Q G2) and paraffin and wood as energy sources, often in combination (Q G3). As for willingness to pay, households in Sehong-hong are ready to pay between M100 and M200 for electricity for space heating per month, on average M138 (Q G5, Table 23).

The heating area of interviewed households ranges between 6 and 18 m^2, which is 10 m^2 on average (Q G6).

Households use wood, paraffin and LPG as main and alternative energy sources for water heating, often used in combination (Q G7).

Table 20: Household use of energy sources for space and water heating in Mashai

HH No.	Use of energy sources	Annual energy consumption	Annual expenses
1	Wood, 1,850 kg per year	9,065 kWh/a	Free
2	Paraffin, 20 litres per year Wood, 550 kg per year	2,902 kWh/a	M490/a
3	Paraffin, 20 litres per year Wood, 1,110 kg per year	5,646 kWh/a	M240/a
4	Paraffin, 40 litres per year Wood, 590 kg per year	3,305 kWh/a	M960/a
5	Wood, 1,430 kg per year	7,007 kWh/a	Free
6	Paraffin, 20 litres per year, wood, 1,080 kg per year, LPG, 18 kg per year	5,729 kWh/a	M1,240/a
7	Paraffin, 70 litres per year, wood, 250 kg per year	1,950 kWh/a	M840/a
8	Paraffin, 70 litres per year	725 kWh/a	M840/a
9	Paraffin, 60 litres per year, LPG, 9 kg per year	736 kWh/a	M920/a
10	Paraffin, 90 litres per year, wood, 240 kg per year	2,108 kWh/a	M1,080/a
Average		3,917 kWh/a	M661/a

Eight households in Mashai use paraffin, two HH use solar lanterns as main energy source for lighting (Q H1). As an alternative lighting source, four households use solar lanterns and one uses candles. Please note that the energy consumption we calculated is on the basis of the energy content of the fuels used cannot be directly translated into demand for electrical power because conversion of power into light is much more efficient than conversion of fuels resulting in either a better energy service with the same energy input in terms of kWh or to a lower power demand in kWh terms with the same quality of energy service. On average, the households spent M352/a, so the equivalent budget would be at least available for purchasing power for lighting purposes (Q H2).

Six of the ten interviewed households in Mashai who own solar lanterns use LED light bulbs of 3 W capacity for one to six hours per day (Q H3). Households are willing to pay between M30 and M250 for electricity for lighting per month. More representative values would be 1-10% of the household's monthly income (Q H4, Table 23).

Table 21: Household use of energy sources for lighting of households in Mashai

HH No.	Annual use of energy sources	Annual energy consumption	Annual expenses
1	Paraffin, 48 litres per year	497 kWh/a	M576/a
2	Paraffin, 48 litres per year	497 kWh/a	M576/a
3	Solar lantern, 3 W Paraffin, 24 litres per year	252 kWh/a	M288/a
4	Solar lantern Paraffin, 36 litres per year	375 kWh/a	M432/a
5	Paraffin, 48 litres per year	497 kWh/a	M576/a
6	Solar lantern	7 kWh/a	NA
7	Paraffin, 15 litres per year	155 kWh/a	M180/a
8	Solar lantern, 1 W Paraffin, 20 litres per year	214 kWh/a	M240/a
9	Solar lantern, 1 W Paraffin, 15 litres per year	162 kWh/a	M180/a
10	Solar lantern, 1 W Paraffin, 10 litres per year	105 kWh/a	M120/a
Average		276 kWh/a	M352/a

Table 22: Households desired future uses of electricity in Mashai, ranked starting from the most popular ones

Electricity uses	HH 1	HH 2	HH 3	HH 4	HH 5	HH 6	HH 7	HH 8	HH 9	HH 10	Total
Lighting	X	X	X	X	X	X	X	X	X	X	10
Cooking/ re-heating	X	X	X	X	X	X	X	X	X	X	10
Radio	X	X	X	X	X	X	X	X	X	X	10
Refrigeration	X	X	X	X	X	X	X	X	X	X	10
TV		X	X	X	X	X	X	X	X	X	9
Ironing	X	X	X	X	X		X	X	X	X	9
Phone charging	X	X	X	X			X	X	X	X	8
Laundry		X				X				X	3
Air-conditioning				X	X						2
Computer									X		1
Dishwashing										X	1
Water heating											0
Space heating											0
Charging (other than phone)											0
Sewing											0
Water pumping											0
Workshop											0
Total	6	8	7	8	7	6	7	7	8	9	-

Three interviewed households in Mashai use electrical appliances at home and generate their own electricity with 36-715W solar panels, spending M500 (two households) and M2,000 in one household (Q E1-E5). Now they all are using electricity for phone charging, and two use it for lighting and one for charging other than phone (Q E6). As a result, all households want electricity in their houses (Q E7). Interviewed households expressed their willingness to pay for electricity for the amount between M20 and M400, which is on average M187. This translates into 5-29% share of their month income (Q E9, Table 23).

As a preferred way to pay for electricity six respondents from Mashai chose Mpesa and four respondents chose cash (Q E10).

Concerning the plans to purchase electrical appliances in the next five years, all households intend to buy electric stoves and iron, nine of the interviewed households want to obtain refrigerators, eight want to purchase electric kettle/element, seven households are willing to have microwave, six households want to buy washing machine, bread maker, while five households want to buy electric heaters, television flat-screen. Three households want to purchase toaster, electric pot, two households are planning to buy television LCD, air-conditioner. Electric geyser, dishwasher, television CRT, laptop, electric hair clipper, phone charger is planned to be obtained by one household. Not relevant electric appliances were chest/deep freezer, tumble dryer, hoover, hair dryer, computer (Q I3).

One household wants to buy a solar PV in the next five years (Q I4).

Table 23: Ability and willingness to pay for electricity in general and for different applications of households in Mashai

HH #	Earnings per month (ability to pay)	Willingness to pay for electricity (Maloti and % of earnings)				Plans to buy electric appliances
		In general	For cooking	For space heating	For lighting	
1	None	M100 (-)	M30 (-)	M100 (-)	M100 (-)	Refrigerator, electric stove, washing machine TV CRT, iron, electric kettle, bread maker toaster, microwave
2	M750	M100 (13%)	M100 (13%)	M150 (20%)	M50 (7%)	Refrigerator, electric stove, electric heater washing machine, air conditioner, iron electric kettle, bread maker, toaster microwave, electric pot, phone charger
3	M1,500	M100 (7%)	M100 (7%)	M100 (7%)	M100 (7%)	Refrigerator, electric stove, electric heater, TV flat-screen, iron, electric kettle, bread maker microwave
4	M750	M200 (27%)	M100 (13%)	M180 (24%)	M100 (13%)	Refrigerator, electric stove, electric heater washing machine, TV LCD, air conditioner iron, electric kettle, bread maker, microwave
5	M750	M20 (3%)	0	M100 (13%)	M20 (3%)	Refrigerator, electric geyser, electric stove electric heater, washing machine, iron, electric kettle, microwave
6	M1,500	M400 (27%)	M100 (6%)	M200 (13%)	M150 (10%)	Refrigerator, electric stove, washing machine TV flat-screen, laptop, iron
7	M1,500	M200 (13%)	M100 (6%)	M100 (7%)	M250 (17%)	Refrigerator, electric stove, TV LCD, iron electric kettle
8	M7,500	M350 (5%)	M100 (1%)	M100 (1%)	M30 (0%)	Electric stove, TV flat-screen, iron, microwave
9	M1,500	M150 (10%)	M200 (13%)	M200 (13%)	M150 (10%)	Refrigerator, electric stove, TV flat-screen iron, electric kettle, bread maker, toaster electric pot, hair clipper
10	M875	M250 (29%)	M100 (11%)	M150 (17%)	M50 (6%)	Refrigerator, electric stove, electric heater washing machine, dishwasher, TV flat-screen iron, electric kettle, bread maker, microwave electric pot
Average		M187	M103	M138	M100	

Energy demand forecast

Three households interviewed in Mashai can be placed among representatives of the medium type, regarding usage of electric appliances, solar lanterns and relatively high income. Other households rather belong to the basic type, with low income and no electrical appliances at the moment. For the entire village, we assume a distribution of household types as described in the General Part. For forecasting, we assume that the number of households equally over all household types increase by 1% per year. Further, the specific demand of all household types is expected to increase once electricity is available due to more electrical appliances. The answers given on planned purchases of appliances confirms this trend. However, experiences in other countries showed that household demand for power remained stable even five years after power supply arrived (Blog World Bank 2017). In any case, it gets clear that returns from power supply rely mainly on the medium and affluent households (Table 24). From the commercial point of view, the less endowed households are less interesting, however they are those who would most benefit from enhancing their living conditions through the supply of power.

Table 24: Present and future power demand by households in Mashai

Household type	No. of HH in Mashai			Total power demand, kWh/year		
	Present	**2019**	**2030**	**Present**	**2019**	**2030**
Basic	130	131	146	0	3,930	87,600
Medium	50	51	56	2,500	25,500	151,200
Affluent	20	20	23	6,000	36,000	66,700
Total	**200**	**202**	**225**	**8,500**	**65,430**	**305,500**

4.1.2 Anchor customers

Main characteristics

Potential anchor loads in the village are the Mashai Health Clinic, two primary schools and a high school, the offices of the local government, the community council office, six medium size retail shops, a church, a guest house, bars and a hammer mill. In Mashai, we interviewed ten anchor customers: one health facility, one school, two government facilities (local government and community council) and six commercial users (two general dealers, catering and tavern, two taverns, clothing shop) (Q B1). Public institutions are in terms of state ownership and commercial facilities are in individual ownership (Q B2). The health centre has the most employees with 34 employees. Community council employs 16 persons, local government has four employees, school seven. Commercial facilities have between two and five employees, three on average (Q B3).

Regarding earnings, six commercial companies generate some income, where both grocery shops earn between M3,500 and M30,000per month, and the clothing stores earns a little higher with M30,000per month. The taverns also earn about M3,500 per month (Q B4). The school receives subsidies from the state accounting for M750 per month. On average, anchor customers have M7,200 per month at their disposal (Q B6).

Most anchor customers work seven days a week, except for the local government offices and school (5 days/week) and one retailer (also 5 days/week) (Q D1). Government institutions operate 7-8 hours per day, commercial users 5-17 hours, health centre 24 hours per day. All anchor customers, with the exception of school, operate the whole year round while school operate over 11 months (Q D2, Q D3).

Anchor customers cover one to seven buildings. School has seven buildings, health centre six, community council five and local government two. Commercial users have 1-4 buildings, three on average (Q D4). Most buildings were constructed during the period between 2006 and 2015. Some buildings are as old as before 1966 and 1975. The total building area ranges from 16 m^2 to 56 m^2 among commercial facilities, on average 34 m^2, and 24-210 m^2 for the state institutions (health centre and school have 200-210 m^2, council 104 m^2, local government 24 m^2). Five anchor customers heat their buildings and two buildings are insulated (Q D5).

Energy supply

Energy sources, such as wood, were used only by public facilities (school and the local government offices), where 56 or 1,500 kg was used for space heating by government and for cooking by the school. Hard coal was mainly used by the local clinic and one commercial customer (50 or 250 kg used for space heating) (Q C1). Energy sources were paid in cash (Q C2).

Table 25: Consumption of energy resources and electricity generation of anchor customers in Mashai

Anchor customer	Hard coal		Wood		LPG		Solar PV		Generator	
	kg	Purpose	kg	Purpose	kg	Purpose	System size	Purpose	Size	Purpose
Mashai Local government			56	Space heating	48	Heating				
Mashai Primary School			1,500	Space heating, cooking						
Motsekuoa General Dealers										
Mashai Catering and Tavern							2 panels of 36 W	Lighting	1 generator	Lighting
Maluti Tavern							3 W	Charging	1 generator	Other uses
Basia General Dealer										
Makholokoe Textiles										
Maikutlong Tavern	50	Space heating					1 panel of ?? W	Lighting, radio, TV	1 generator	Heating, other uses
Linakeng Council							8 panels of 1,500 W	Lighting, printing	1 generator	Other uses
St. Theresa Health Clinic	250				48	Heating	18 panels of 715 W	Lighting	1 generator	Lighting
Total quantity	**300**		**1,556**		**144**					
Unit costs	M2/kg		M0.8/kg							
Total costs	**M105**[4]		**M1,200**[5]							

[4] Health centre as a government institution does not pay for energy sources.
[5] The local government does not pay for energy supply.

Five anchor customers (health centre, council, three commercial retailers) use solar electricity. Commercial users have 3-20 W capacity, community council 1,500 W, clinic 715 W. Solar electricity is used for lighting by all anchor customers, for charging, radio and printing by one customer in each case (Q C3).

All respondents intend to have electricity in their facilities and presumes that electricity is important for companies and institutions from their branches to have (Q C4, Q C5). However, one respondent perceives electricity as expensive (Q C6).

Respondents stated that their company/institution is ready to pay for electricity between M100 and M4,000 per month, M890 on average (Q C7). Preferred methods to pay for electricity were via mobile phone (eight respondents) or by using cash (two respondents) (Q C8).

No anchor customer uses any central air-conditioning systems (Q D6). Two customers (local government and health centre) have LPG heating systems, which run the operating time of the companies over two months in a year. 48 or 96 kg LPG were consumed over year (Q D7). No independent heating/cooling systems were used by anchor customers in Mashai (Q D8).

All anchor customers expressed their willingness to pay for electricity for heating/cooling purposes, between M200 and M1,400, M430 on average. Ability to pay of public institutions is sometimes more difficult to define, since we are mostly not aware of the level of subsidies which they get from the state and/or district council. The health centre is ready to pay M300, which is reasonable for the state will accept these expenditures (Q D9, Table 27).

Six retail anchor customers use any type of light bulbs: three retailers use LED lights of 3 W, one or three units, health centre and community council use 22 or 24 fluorescent light bulbs, one retailer uses solar lamp. Additionally, two customers have paraffin lamps (Q D10). No customer has a light and motion sensor controls (Q D11, Q D12). Regarding willingness to pay for electricity for lighting, it lies between M100 and M1,200. The highest willingness and accordingly the need for lighting comes from the textile company (M1,200), while other public institutions do not see it as such important electricity application, probably because of their operating hours mostly fall on sunshine day period. Other commercial customers are ready to pay for electricity for lighting between M100 and M500 (Q D13, Table 27).

The community council and the health center have small equipment like desktops, and printers (Q D14).

Six anchor customers with any cooking facilities in Mashai were the health centre, the school, four commercial users (Q D15). As an energy source for cooking, these customers use LPG or wood (Q D16). Six respondents are ready to pay for electricity for cooking and willingness to pay is between M100 and M1,000 per month, M517 on average (Q D17, Table 27).

Five anchor customers: a health centre and four commercial users have any refrigerating equipment for food or medical uses: from one to three refrigerators of 200, 250 or 2,500 litres (Q D18). Six customers (those with refrigerating equipment) show any willingness to pay for electricity for refrigeration, between M100 and M800, on average M520 (Q D20, Table 27).

Table 26: Electric equipment of anchor customers in Mashai

Anchor customer	**Lighting**		**Small equipment**	**Refrigerating equipment**	
	Type & number	Capacity, W	Type & number	Type & number	Capacity, l
Mashai Local government					
Mashai Primary School					
Motsekuoa General Dealers	1paraffin lamp	200ml per day		1 refrigerator	250
Mashai Catering and Tavern	1 LED	3 W		3 refrigerators	250
Maluti Tavern	3 LEDs	3 W		2 refrigerators	250
Basia General Dealer	1 LED	3 W			
Makholokoe Textiles	1paraffin lamp	1L per day			
Maikutlong Tavern	1 solar			1 refrigerator	200
Linakeng Council	22 fluorescent		2 desktops		
St. Theresa Health Clinic	24 fluorescent		1 desktop, 3 printers	2 refrigerators	250

Four anchor customers (health centre, council, two retailers) generate electricity with solar panels (Q E1), with 1-18 panels of 36 or 715 W, and use electricity for lighting (all customers), printing, radio and TV. Panels operate for 8-24 hours (whole operating hours of the organizations) per day all year long (Q E2). Five anchor customers (health centre, community council, three retailers) use generators to generate electricity and/or heat for lighting, heating and other processes, fuelled by unleaded petrol. Generators are in use over 5 to 24 hours per day over two months or the whole year (Q E4).

Table 27: Ability and willingness to pay for electricity in general and for different applications of anchor customers in Mashai

Anchor customer	Earnings per month ability to pay	Willingness to pay for electricity per month (Maloti)					
		Heating/ Cooling	Lighting	Cooking	Fridge	Total	
						Maloti	% of earnings
Mashai Local government	M0	M 500	M100	-	-	M600	-
Mashai Primary School	M750	M200	M100	M100	-	M400	53%
Motsekuoa General Dealers	M30,000	M300	M200	-	M600	M1,100	4%
Mashai Catering and Tavern	M3,500	M500	M400	M1,000	M500	M2,400	69%
Maluti Tavern	M750	M400	M300	M400	M800	M1,900	253%
Basia General Dealer	M3,500	M200	M100	-	-	M300	9%
Makholokoe Textiles	M30,000	M300	M1,200	M900	-	M2,400	8%
Maikutlong Tavern	M3,500	M200	M100	M200	M100	M600	17%
Linakeng Council	M0	M1,400	M500	-	-	M1,900	-
St. Theresa Health Clinic	M0	M300	M500	M500	M600	M1,900	-

Total	M72,000	M4,300	M3,500	M3,100	M2,600	M13,500	-

All anchor customers are planning to replace some units in the next five years (Q F1). The health clinic plans to replace the refrigerator with an electric one; the school plans to replace use of wood and install computer, air conditioner, TV, microwave; the community council is willing to replace solar panels and install air conditioner; local government plans to replace LPG and install computer and air-conditioner. Commercial users want to replace paraffin lamps, heater, generators, solar panels, LPG, LED lights and install electric light bulbs, electric heater, air-conditioner, electric mill, cold room, microwave, computer, electric refrigerator. It will in most cases increase their energy consumption (Q F2-F8).

One anchor customer is planning to buy a solar PV, five plan to buy a generator, two plan to buy a car battery in the next five years (Q F9). None of the customers want to buy all three electrical sources.

All the anchor customers plan to upgrade buildings in the next five years: all want to replace light bulbs, other two to install solar water heaters, one respondent wants to insulate walls (Q F10-F11).

Energy demand forecast

Present power demand and supply of anchor customers in Mashai are summarized in the Table 28. Future power demand of all anchor customers in the village, including non-interviewed ones, is presented in the

Table 29.

Table 28: Main characteristics of anchor customers in Mashai

#	Name	Type	Size	Operation hours	Electrical equipment	Annual power demand	Present power supply	Willingness to pay[6], Maloti/month
1	St. Theresa Health Clinic	**Health**	34 employees; 6 buildings, area 210 m^2	24 h/day, 7 days/week, 12 months/year	24 fluorescent lights, 1 desktop, 2 refrigerators	13,140 kWh	18 solar panels, capacity of 715 W, 1 generator	1,900
2	Mashai Primary School	**School**	7 employees; 7 buildings, area 200 m^2	7 h/day, 5 days/week, 11 months/year	None	0	None	400
3	Mashai Local government	**Government**	4 employees; 2 buildings, area 24 m^2	8 h/day, 5 days/week, 12 months/year	None	0	None	600
4	Linakeng Council	**Government**	16 employees; 5 buildings, area 104 m^2	8 h/day, 5 days/week, 12 months/year	22 fluorescent lights, 2 desktops, 3 printers	2,954 kWh	8 solar panels of 1,500 W, 1 generator	1,900
5	Motsekuoa General Dealers	**Retail**	2 employees; 1 building, area 16 m^2	5 h/day, 7 days/week, 12 months/year	1 refrigerator	2,453 kWh		1,100
6	Mashai Catering and Tavern	**Retail**	5 employees; 2 buildings, area 21 m^2	17 h/day, 7 days/week, 12 months/year	1 LED of 3 W, 3 refrigerators	7,377 kWh	2 solar panels, capacity of 36 W, 1 generator	2,400
7	Maluti Tavern	**Retail**	5 employees; 3 buildings, area 40 m^2	11 h/day, days/week, 12 months/yea7	3 LED of 3 W, 2 refrigerators	1,788 kWh	Solar panel(s) of 3 W, 1 generator	1,900
8	Basia General Dealer	**Retail**	2 employees; 3 buildings, area 36 m^2	9 h/day, 7 days/week, 12 months/year	1 LED of 3 W	10 kWh	None	300
9	Maikutlong Tavern	**Retail**	3 employees; 4 buildings, area 56 m^2	14 h/day, 7 days/week, 12 months/year	1 solar lamp, 1 refrigerator	2,124 kWh	1 solar panel, 1 generator	600
10	Makholokoe Textiles	**Craft**	2 employees; 3 buildings, area 32 m^2	9 h/day, 5 days/week, 12 months/year	None	0	None	2,400
					Total	29,846 kWh		13,500

[6] Sum of willingness to pay for electricity for heating/cooling, lighting, cooking, and refrigeration (Table above).

Table 29: Future power demand of anchor customers in Mashai

Type	Number of institutions	Power demand, kWh/year	
		2019	2030
Health	1	15,200	30,400
School	3	1,500	10,500
Government	2	4,450	8,900
Retail	8	27,150	81,450
Craft	1	50	250
Total		**48,350**	**131,500**

The power demand distributes spatially as depicted in the Table 30.

Table 30: Development of power demand in Mashai by distance from power plant site

Customer	Annual Power Demand MWh											
	Present				2019				2030			
	1km	2km	3km	total	1km	2km	3km	total	1km	2km	3km	total
Households	9.0	2.0	0.0	11.0	68.8	15.3	0.0	84.0	287.3	63.7	0.0	350.9
Anchor customers	20.8	0.0	0.0	20.8	28.7	0.0	0.0	28.7	56.6	0.0	0.0	56.6
Total	29.8	2.0	0.0	**31.8**	97.4	15.3	0.0	**112.7**	343.8	63.7	0.0	407.5

4.2 Set-up for Mini-Grid

Like with most villages, the land ownership in Mashai is communal where the community elders and area leaders give authority for use of land for development either for domestic, business or institutional purposes. For the purpose of developing a mini-grid, the community seems receptive to allocate land for the project.

We designed the mini-grid by using HOMER Pro software. For dimensioning the generation plants we used the consumption pattern as derived in previous sections of this report.

HOMER analysis showed that for the electricity supply under conditions in present, the combination of PV power plant and storage is the most optimal and least-cost solution. Capacity of battery storage should exceed maximum hourly output of solar panels in about 2.5 times, but this ratio depends to large extent on relative costs of solar panels and battery. In this combination the unmet load accounts for about 2%, and excess electricity produced 49% which makes possible to connect further loads. The levelized cost of electricity is quite high for this setup: M11.3/kWh, that points out the need of additional studies before making a decision about mini-grid design.

Table 31: Elements of mini-grid setup in Mashai in present conditions

Element	Size	CAPEX (Maloti)	Replacement costs (Maloti)	OPEX (Maloti/year)
PV Power Plant	58.1 kW	981,890	0	11,330
Battery	153 kWh	596,700	2,386,800	19,890
System converter	14.6 kW	37,960	37,960	0
Power lines	10.68 km	224,364	0	4,487
Power meters	268 units	857,600	0	17,152
Total	-	**2,698,514**	**2,424,760**	**1,321,475**

Regarding the expected demand increase, the modular characteristics of pv allow for an easy stepwise adaptation of generation. In this regard, developers may further install lines able to accommodate higher loads than the expected near future loads. For expected demand increase in 2019 after commissioning of a mini-grid the most optimal option remains a combination of solar power plant and storage. Significant enlargement of PV and battery size leads to more than twofold higher investment need.

Table 32: Elements of mini-grid setup in Mashai in 2019

Element	Size	CAPEX (Maloti)	Replacement costs (Maloti)	OPEX (Maloti/year)
PV Power Plant	151 kW	2,551,900	0	29,445
Battery	406 kWh	1,583,400	6,333,600	52,780
System converter	40.9 kW	106,340	106,340	0
Power lines	10.79 km	226,608	0	4,532
Power meters	271 units	866,176	0	17,324
Total	-	**5,334,424**	**6,439,940**	**2,602,025**

Figure 10 presents the distribution of capital costs between different components of a mini-grid. It shows that power grid components (lines and meters) have a significant share of one quarter of the capital costs in the case of Mashai.

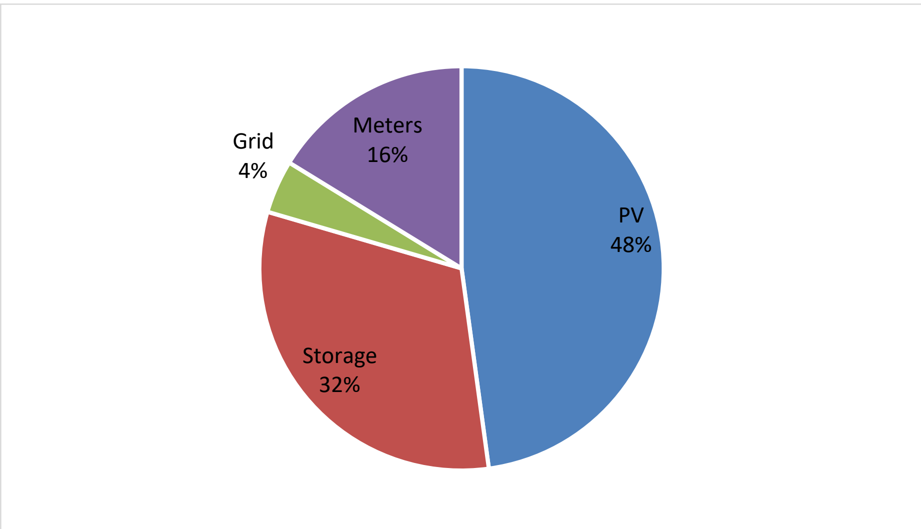


Figure 10: Distribution of capital costs of a mini-grid in Mashai in 2019

For the Mini Grid, three feasible sites were identified. Two of them, the sites which are marked blue on the Figure 11, were chosen according to physical criteria like direction to the sun, area size and availability of space. The yellow marked optimal site was determined according to the calculation algorithm of the geometrical mean of all buildings in the radius 1-3 km in the village. So, it is the location that has the minimum sum of distances to all existing potential residential, public and business customers. In the case of Mashai the theoretically chosen potential site for a mini-grid coincided with the site chosen as a result of field research. This particularly suitable site is presented on the following map as two squares, blue and yellow, inscribed in each other.

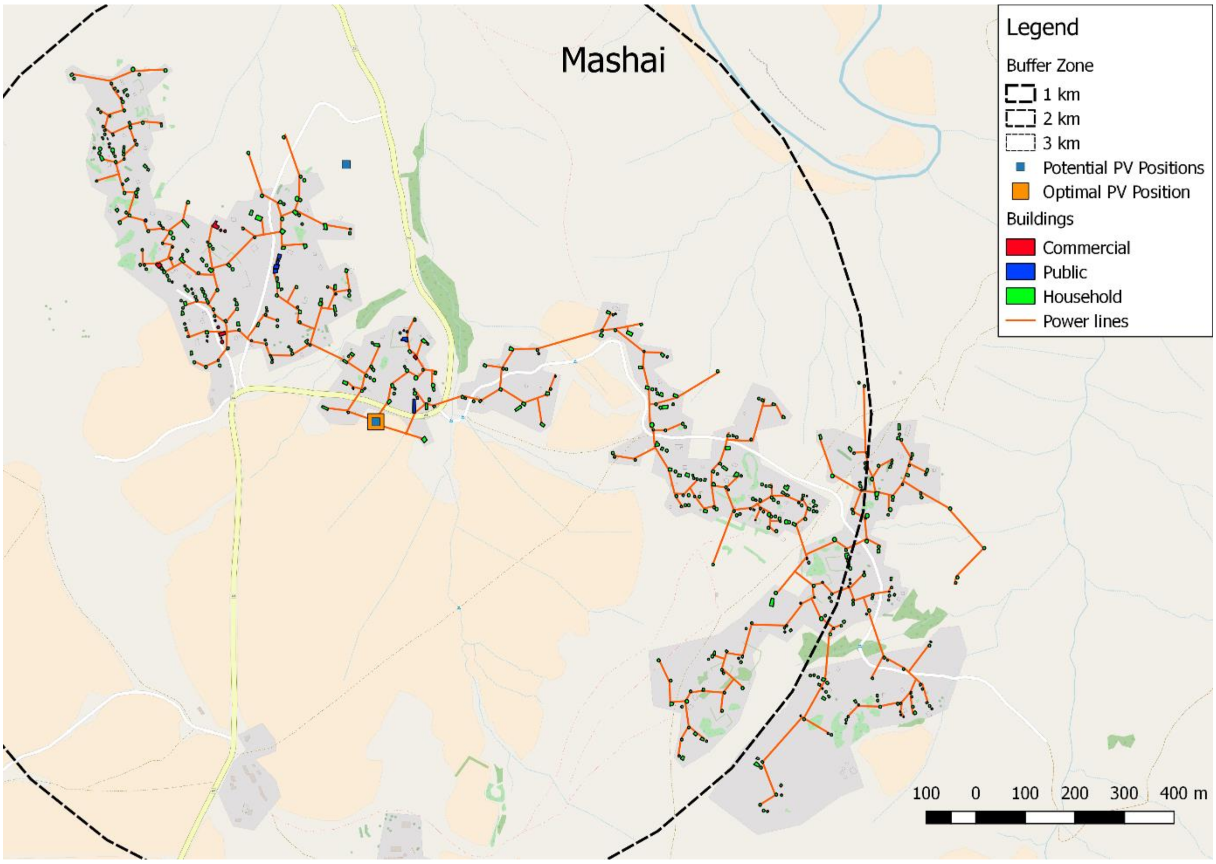


Figure 11: Map of the mini-grid set-up in Mashai

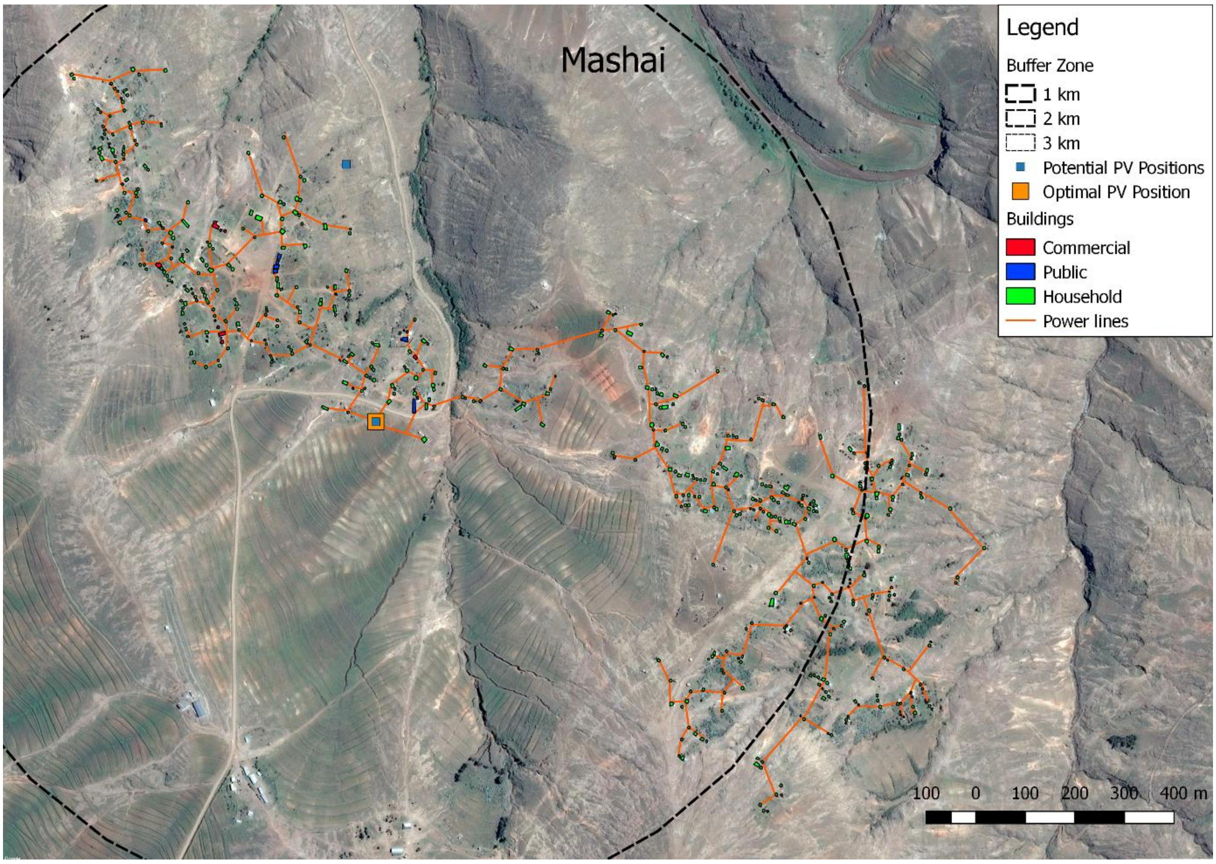


Figure 12: Satellite map of the mini-grid set-up in Mashai

For the long-term period, from the current period to 2030, additional to the solar power plant generation sites can be considered, like hydro power plant. The option with PV, storage and hydro is found to be the least-cost by HOMER software. Further research can be carried out on river flow rates and conditions throughout the year to define hydro energy potential. Besides, in the long-term period of more than ten years further reductions of PV and battery costs are foreseen, whereas the hydropower costs would most probably remain the same, as the technology is already well-advanced, and the cost reduction potential is quite exhausted.

Table 33: Elements of mini-grid setup in Mashai in 2030

Element	Size	CAPEX (Maloti)	Replacement costs (Maloti)	OPEX (Maloti/year)
PV Power Plant	327 kW	5,526,300	0	63,765
Battery	770 kWh	3,003,000	12,012,000	100,100
Hydro Power Plant	100 kW	6,000,000	0	180,000
System converter	164 kW	426,400	426,400	0
Power lines	12.04 km	252,819	0	5,056
Power meters	302 units	966,365	0	19,327
Total	-	**16,174,884**	**12,438,400**	**9,206,225**

The expected growth of demand allows for lower generating costs in the future (Table 34). Thereby we have not considered, that due to technology advancements some elements to be added in the future will have very likely lower specific CAPEX than presently. There is a high rate of excess power to allow for a generation entirely based on renewable energies. This waste of energy could be avoided in two ways. One would be to allow a minor share of fossil based generation which would run during winter, when PV generation is low, leading also to lower overall generation costs. Alternatively, seasonal usage of the excess power could be created, e.g. refrigeration and cooling which both would perfectly match the generation patterns of solar generation.

Table 34: Characteristics of mini-grid setup in Mashai in present and future

Time horizon	Unmet load, %	Excess electricity, %	LCOE, M/kWh
Present	2.11	48.8	11.268
2019	2.09	48.4	9.666
2030	2.28	68.2	6.977

4.3 Economic Viability

For the assessment of economic viability of a mini-grid setup, we calculated the internal rate of return (IRR) with revenues on the basis of the present national electricity tariffs. This calculation allows to assess the economic viability under the present framework conditions. Additionally, we calculated a uniform tariff for all customers allowing for an IRR of 8%, equivalent to levelized costs of electricity (LCOE). The difference between the LCOE tariff and the national tariff indicates the amount of public support needed to keep tariffs in the mini-grid at the level of LEC tariffs in the national grid. For the calculation, we assume two different scenarios. The first scenario assumes that the energy demand will remain stable on the level of 2019 over the entire project lifetime of 25 years. In that case, the IRR with revenues on the level of national tariffs will be negative, -15%. Under these conditions, the project is not economically viable without public support. The difference between revenue from national tariffs and annualized costs, consisting of capital costs including replacement, and operation and maintenance costs, accounted for M8,613,454 over 25 years, or M344,538 per year. Converted into electricity demand, the subvention need would be M3.03/kWh. Regarding allowance need in terms of customers, some M1,588 should be additionally paid per year for one customer.

The second scenario earmarks the increase of electricity demand between 2019 and 2030 according to the load forecast and stable demand after 2030. Under these circumstances, the difference between tariff revenue and total project expenditure amounts M20,448,064 over whole project lifetime, and M817,923 per year. Subvention need per kWh would be somewhat lower than in the first scenario: M2.28/kWh. Due to significant annual increase of energy demand, allowance needs per customer would also increase more than twofold, accounting for M3,363 per customer per year.

4.4 Summary

Mashai is a middle-sized village with 200 households and some important anchor loads. Current electricity demand amounts about 43,750 kWh per year, where about 81% is consumed by anchor customers, and less than 20% by households. This uneven distribution of shares in total energy consumption is a rather typical situation for settlements which are at the moment yet not electrified. Since the commissioning of a mini-grid this relation is expected to change fundamentally. Residential customers will consume 58% of electricity delivered and public and commercial customers about 42%. Annual electricity demand will grow from 113,800 kWh in 2019 to approx. 437,000 kWh in 2030.

In order to cover this demand, first PV power plant and storage solutions would be sufficient. In the long-term, additional energy resources should be attracted. It can be hydro power plant, or wind mill. The decision should be made upon study of a potential of these RE technologies in the region and further development of relative costs of the technologies.

5. Linakeng Energy Centre

Linakeng (29°31'46.8"S 28°47'10.1"E) is a village situated 45.1 km east of Thaba Tseka Town. It has the elevation of 2,033 m and a total population of 4,347. It is located about 1 km from A3 main road. The community of Linakeng includes the villages of Ha Firi, Matebeng, Sehonghong, Mashai (Moreneng), Hloahloeng (Ha Teke), Taung, Khotsong, Ha Rampeoane, Phahameng, Ha Motjolopane, Ha Theko, Pontseng, Ha Mankereu, Kolebere, Ha Khanyetsi, Ha Setala, Khochaneng, Ha Seroala-Nkhoana, Linakeng, Ha Makunyapane, Ha Shoaepane, Taung, Ha Khoali, Ha Khatho, Matlatseng, Lekhalong, Ha Makoko, Pitseng, Makhanyaneng, Bokhoase, Thaba-Bosiu, Ha Korotla, Lulang, Ha Mapheelle, Tiping, Ha Chakatsa, Moriting. The nearest service centre is Thaba-Tseka Town, with distance of about 46 km, or two hours. Linakeng is situated between Ha Mokoto and Ha Makunyapane.

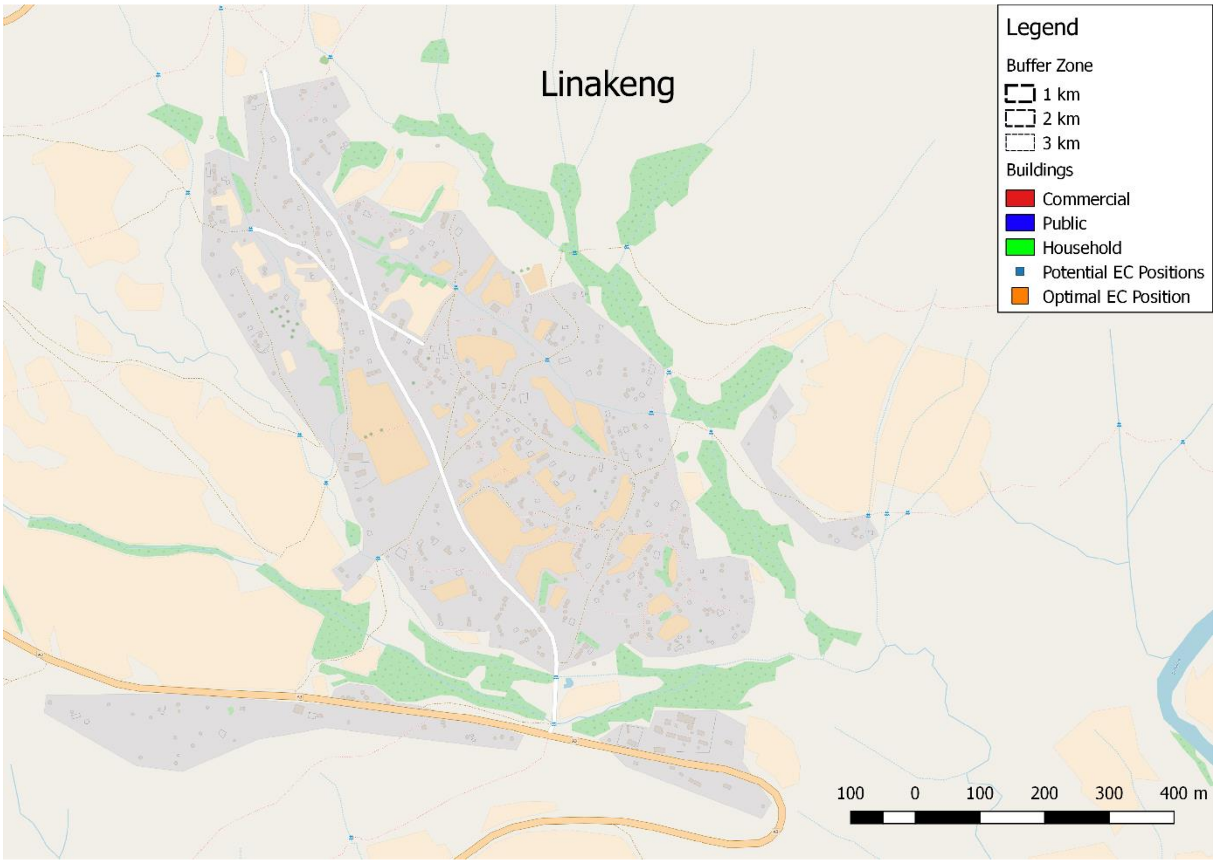


Figure 13: Map of Linakeng

5.1 Customer Base

The main income sources for Linakeng households, according to the village counsellor, are retailing local beer and farming in crops and in livestock.

5.1.1 Households

Energy demand forecast

Approximately 180 households live in Linakeng. We calculated key parameters for the village based on the assumptions on current and future energy demand. Power demand in 2019 reflects only the share of the total demand of households which will be covered by the Energy Centre. Therefore, affluent households were not considered in the calculation for 2019, since they already cover their own energy needs using solar home systems, solar lanterns and rechargeable batteries.

Table 35: Present and future power demand by households in Linakeng

Household type	No. of HH in Linakeng	Total power demand, kWh/year	
		Present	2019
Basic	117	0	1,520
Medium	45	2,250	3,285
Affluent	18	5,400	0
Total	**180**	**7,650**	**4,805**

5.1.2 Anchor customers

Main characteristics

The community of Linakeng includes the villages of Ha Firi, Matebeng, Sehonghong, Mashai (Moreneng), Hloahloeng (Ha Teke), Taung, Khotsong, Ha Rampeoane, Phahameng, Ha Motjolopane, Ha Theko, Pontseng, Ha Mankereu, Kolebere, Ha Khanyetsi, Ha Setala, Khochaneng, Ha Seroala-Nkhoana, Linakeng, Ha Makunyapane, Ha Shoaepane, Taung, Ha Khoali, Ha Khatho, Matlatseng, Lekhalong, Ha Makoko, Pitseng, Makhanyaneng, Bokhoase, Thaba-Bosiu, Ha Korotla, Lulang, Ha Mapheelle, Tiping, Ha Chakatsa, Moriting.

Potential anchor loads in Linakeng are Linakeng Health Clinic, one primary school and five medium-sized retail shops.

In Linakeng, five anchor customers were interviewed: one health facility, school, and three commercial users (dress-making, catering, food retail shop) (Q B1). Public institutions are in terms of state ownership and commercial facilities are in individual ownership (Q B2). The health centre has nine employees, school seven workers, all commercial users have each one employee (Q B3).

Regarding earnings, three of the five anchor customers generate some income between M750 and M1,500 per month (Q B6).

Energy sources in terms of hard coal were mainly used by the local clinic (2,000 kg hard coal used last year for space heating expending on it M15,000). The school used 1,850 kg of wood for cooking, costing M7,000. The price for wood is M4 per kg and of charcoal is M7.5 per kg (Q C1). Customers par for the energy sources in cash (Q C2). The health centre uses solar electricity (Q C3).

All respondents want to have electricity in their facilities and perceive that electricity is important for companies and institutions (Q C4, Q C5). At the same time, none of the users suppose electricity is expensive (Q C6).

Respondents stated that their company/institution is willing to pay for electricity at the amount between M200 and M1,500 per month, with the upper limit being by a health centre. Without health centre, all other customers are willing to pay on average M250 (Q C7). Preferred methods to pay for electricity were using cash (Q C8).

Most anchor customers work six days a week, except the primary school (5 days/week), (Q D1). Commercial users operate between nine hours per day over the whole year, school works seven hours per day over 11 months, health institution operates eight hours per day (Q D2, Q D3).

Health centre covers eight buildings, school has two buildings, commercial users one to two buildings at their disposal (Q D4). Most buildings were constructed in the period of 1966 and 1975. The total building size ranges from 20 to 36 m^2 by commercial users. Health centre has buildings of 144 m^2, school 108 m^2. Two buildings are insulated (Q D5).

No anchor customer uses any central air-conditioning systems (Q D6). Only the health centre uses hard coal for heating system, 40 units, summing up to 2,000 kg, which is in use the whole operation time of the centre (Q D7).

All anchor customers are willing to pay for electricity for heating/cooling purposes between M100 and M1,000, on average M450, with the highest willingness to pay coming from public institutions (health centre and school) (Q D9, Table 36).

The health clinic uses 24 energy saver lights of 12 W. Two commercial retailers use paraffin lamps, consuming 0.5 litres paraffin per day (Q D10). Willingness to pay for electricity for lighting is within limits with M50-M100 per month, perhaps because anchor customers do not see it as such important electricity application, since their operating hours mostly fall on sunshine day period (Q D13, Table 36).

No small equipment like desktops, monitors, laptops, household appliances were used by the anchor customers in Linakeng (Q D14). Two anchor customers with any cooking facilities were the school and the catering company (Q D15). As an energy source for cooking, these customers use LPG and wood (Q D16). Both these respondents are ready to pay for electricity for cooking and willingness to pay is M300 or M2,500 per month (Q D17, Table 36).

The health centre and the catering company have refrigerating equipment for food or medical uses (Q D18). They have one or six refrigerators at their facilities. These two anchor customers are ready to pay electricity for refrigeration M400 or M1,000 (Q D20, Table 36).

Only the health clinic generates electricity with four solar panels of 1,000 W and use electricity for lighting and space heating. Panels operate for eight hours per day all year long (Q E1-E2). None of the anchor customer uses a generator to generate electricity and/or heat (Q E4).

All anchor customers are planning to replace some units in the next five years (Q F1). The health clinic plans to replace solar; the school plans to replace use of wood; while the commercial anchor customers plan to replace LPG and use of paraffin lamps and use electrical appliances. Anchor customers in Linakeng plan to install air conditioners, computers, TV, electric refrigerators, electric stoves, light bulbs, overlock sewing machines. They think this action will increase their energy consumption (Q F2-F8).

Four anchor customers are planning to buy a generator in the next five years (Q F9).

All anchor customers plan to upgrade buildings in the next five years: replace light bulbs with CFL (all), install solar water heater (three), replace light bulbs with LED (one), and insulate walls (one) (Q F10).

Table 36: Ability and willingness to pay for electricity in general and for different applications of anchor customers in Linakeng

Anchor customer	Earnings per month ability to pay	Willingness to pay for electricity per month (Maloti)					
		Heating/ Cooling	Lighting	Cooking	Fridge	Total	
						Maloti	% of earnings
Bahlakoana Dress Making	M750	M100	M50	M0	M0	M150	20%
Linakeng Health Clinic	M0	M700	M100	M0	M1,000	M1,800	-
Linakeng Primary School	M750	M1,000	M100	M2,500	M0	M3,600	480%
Catering	M1,500	M250	M100	M300	M400	M1,050	70%
Food retail	M0	M250	M50	M0	M0	M300	-
Total	M3,000	M2,300	M400	M2,800	M1,400	M6,900	-

Energy demand forecast

Present power demand and supply of anchor customers in Linakeng are summarized in the Table 38. Future power demand of all anchor customers in the village, including non-interviewed ones, is presented in the Table 37. We derived the forecast for power demand of anchor customer on the results of the entire survey. However, only school will be supplied with energy by the energy centre whereas for the other types specific individual demand is too high to be covered by the energy centre. Moreover, the other customer types often already feature own generation facilities.

Table 37: Present and future power demand of anchor customers in Linakeng

Type	Number of institutions	Power demand, kWh/year	
		Present	2019
Health	1	6,100	6,100
School	1	0	500
Retail	5	6,970	6,970
Total		**13,070**	**13,570**

Table 38: Main characteristics of anchor customers in Linakeng

#	Name	Type	Size	Operation hours	Electrical equipment	Annual power demand	Present power supply	Willingness to pay[7], Maloti/month
1	Linakeng Health Clinic	**Health**	9 employees; 8 buildings, area 144 m^2	8 h/day, 6 days/week, 12 months/year	24 energy saver lights, 6 refrigerators	6,097 kWh	4 panels, capacity 1,000 W	1,800
2	Linakeng Primary School	**School**	7 employees; 2 buildings, area 108 m^2	7 h/day, 5 days/week, 12 months/year	None	0	None	3,600
3	Bahlakoana Dress Making	**Retail**	1 employee; 1 building, area 20 m^2	9 h/day, 6 days/week, 12 months/year	None	0	None	150
4	Catering	**Retail**	1 employee; 2 buildings, area 36 m^2	9 h/day, 6 days/week, 12 months/year	1 refrigerator	3,370 kWh	NA	1,050
5	Food retail	**Retail**	1 employee; 1 building, area 21 m^2	9 h/day, 6 days/week, 12 months/year	None	0	None	300
					Total	9,467 kWh		6,900

[7] Sum of willingness to pay for electricity for heating/cooling, lighting, cooking, and refrigeration (Table above).

The power demand distributes spatially as depicted in the Table 39. Here, also anchor customers and affluent households are included even though we do not expect them to be supplied by the energy centre.

Table 39: Development of power demand in Linakeng by distance from energy centre

Customer	Annual Power Demand MWh											
	Present				2019				2030			
	1km	**2km**	**3km**	**total**	**1km**	**2km**	**3km**	**total**	**1km**	**2km**	**3km**	**total**
Households	8.6	0.0	0.0	8.6	11.1	0.0	0.0	11.1	275.1	0.0	0.0	275.1
Anchor customers	13.1	0.0	0.0	13.1	13.6	0.0	0.0	13.6	42.7	0.0	0.0	42.7
Total	21.7	0.0	0.0	**21.7**	24.7	0.0	0.0	**24.7**	317.8	0.0	0.0	**317.8**

5.2 Set-up for Energy Center

Like with most villages, the land ownership in Linakeng is communal where the community elders and area leaders give authority for use of land for development either for domestic, business or institutional purposes.

For the Energy Centre three feasible sites were identified. Two sites, which are marked blue on the Figure 14, were chosen according to physical criteria like direction to the sun, area size and availability of space. The yellow marked optimal site was determined according to the calculation algorithm of the geometrical mean of all buildings in the radius 1-3 km in the village. So, it is the location that has the minimum sum of distances to all existing potential residential, public and business customers. In the case of Linakeng the theoretically chosen potential site for the energy centre coincided with the site chosen as a result of field research. This particularly suitable site is presented on the following map as two squares, blue and yellow, inscribed in each other.

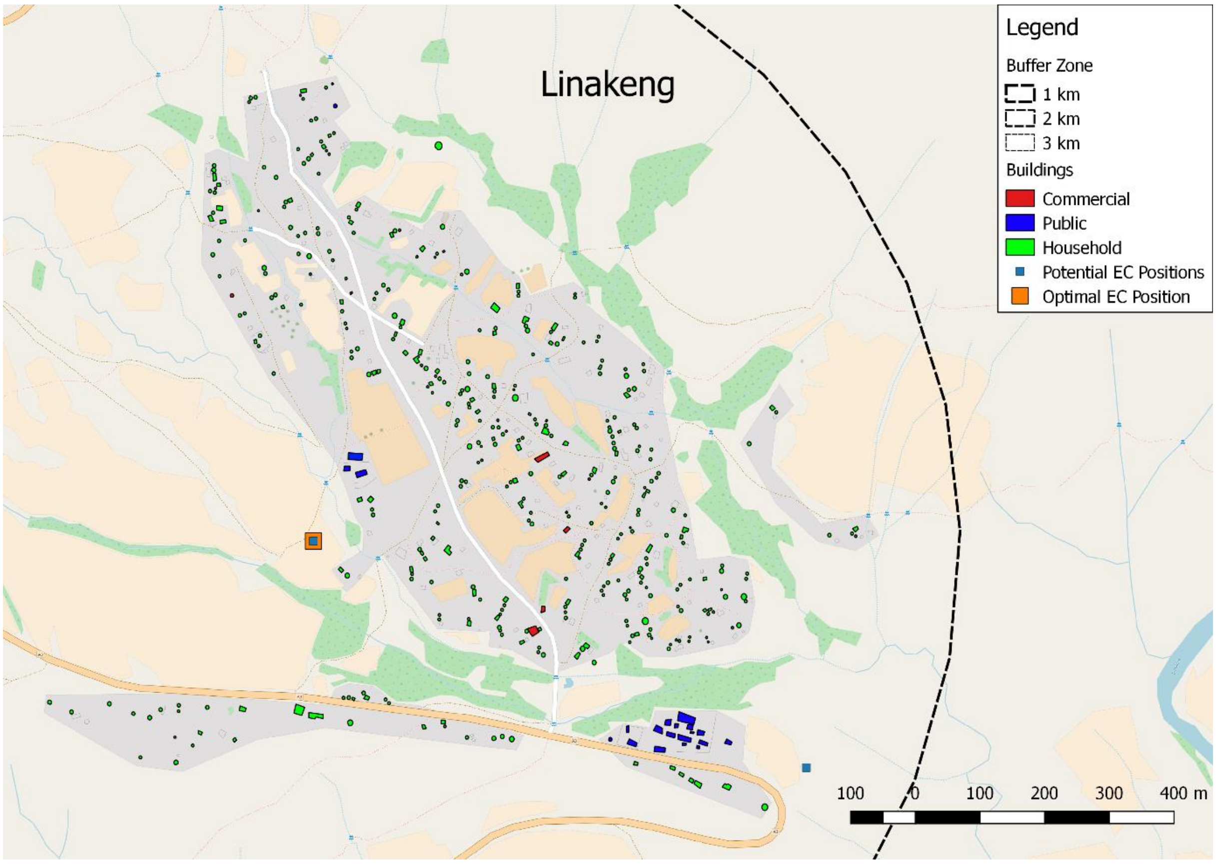


Figure 14: Spatial distribution of customers and positions of energy center in Linakeng

5.3 Economic Viability

Linakeng with its 180 households living in there and few anchor customers belongs to middle-sized villages, so the energy centre to be constructed here should be of medium size. In the Table 40 main characteristics and financials of the energy centre setup in Linakeng like initial investment, annual expenditure, replacement costs due every five years as well as residual value after 10 years of operation are cited.

In order to supply energy needs of households, business and public customers in Linakeng as well as to cover the electricity demand for the services provided through the centre, a solar power plant of 10.9 kW with battery storage facility of 26 kWh is needed. It can be taken into consideration to build up this plant in stepwise mode along the expected increase in power demand and power-related services.

We calculated the cash flow over a period of ten years after commissioning the energy centre (Figure 15). Even though most of the equipment as well as the building will be not worn out after ten years we expect that power provision through batteries will be replaced either by a mini-grid or a connection to the central grid after 2029. Besides the initial investment (we assumed 2018, i.e. the year before start of operation, for reasons of calculation) certain elements like vehicles or inverters needs to be replaced after five years. Annual revenues arise from provision of charging services (lights, phones, large batteries), equipment services (printing, calling, internet services, sales of drinks and snacks, etc.), as well as profit on equipment sales. With an internal rate of return of 8%, net present value of the project over ten years is equal to M495,950, that makes this energy centre setup economically feasible and very profitable compared to other setups (small and large).

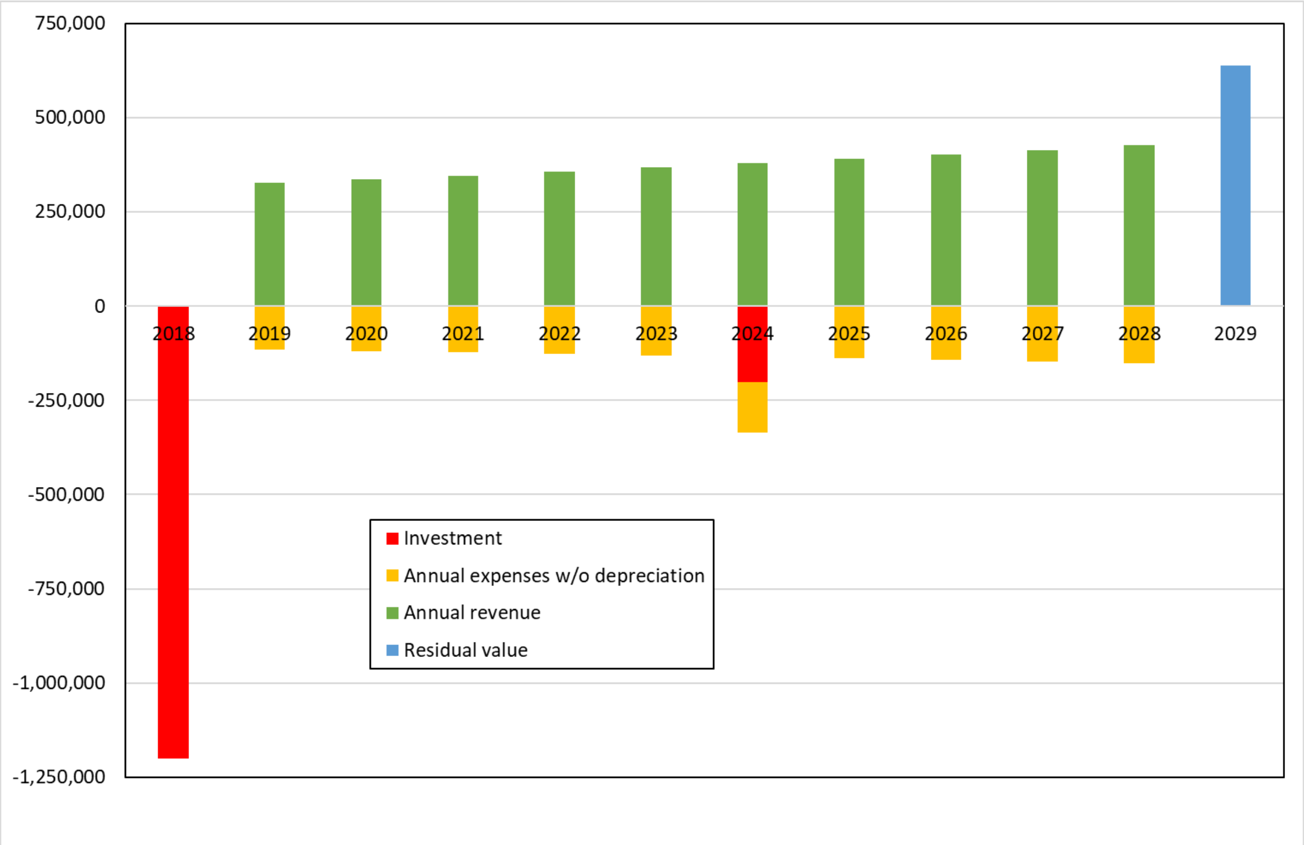


Figure 15: Cash flow of the energy centre in Linakeng in 2018-2029

Table 40: Main features and financial parameters of an energy centre in Linakeng

Features	
Number of households in the village	180
Building area, m2	80
Vehicle, #	0.5
Employees, #	3
Capacity PV, kW	10.9
Capacity storage, kWh	26
Initial investment	
Building costs, M	160,000
Vehicle, M	100,000
PV+storage, M	292,891
Initial Stockage, M	412,545
Equipment, M	30,700
Staff Training, M	5,000
Contingencies	200,227
Total initial investment	**1,201,363**
Annual costs	
Salaries, M	75,000
Maintenance PV, M	5,858
Depreciation on hardware investment	34,140
Vehicle Maintenance and fuels	10,000
Contingencies	25,000
Total annual costs	**149,997**
Replacement costs	
Inverter+ storage	101,400
Vehicle	100,000
Annual revenue	
Charging lights, phones #/yr	24,333
Charging large batteries #/yr	5,100
Charging lights, phones, M	121,667
Charging large batteries, M	51,000
Equipment services	30,000
Profit on equipment sales	123,764
Total annual revenue	**326,430**
Residual value	
Building costs, M	80,000
Vehicle, M	0
PV+storage, M	146,445
Initial Stockage, M	412,545
Equipment, M	0
Total residual value	**638,990**

5.4 Summary

Linakeng with 180 households belongs to the middle-sized villages, so the energy centre will be of medium size. The settlement is densely populated in the small radius, that makes it an attractive location for an energy centre to be easily reached on foot by potential customers. Energy centre should have a building area of about 80 m^2 to accommodate stock, display and office rooms. Three employees, two sales assistants and one maintenance agent, will support customers by choosing a right energy product, explain advantages and profits of using energy efficient products and technologies, handle small repairs and deliver products and spare parts. A vehicle will be needed for trips around the village and neighborhoods which for cost-saving purposes can be shared with another energy centre or some business located in the close proximity. Combination of PV and battery storage will cover energy needs of customers and own energy consumption of the centre. If a noticeable growth of energy demand will be observed, this PV system can be scaled up with relatively small effort. Given that stocked goods will find demand, and services of the centre like battery and phone charging will become popular, the establishment of such a facility is economically profitable with initial investment of M1,201,363 and provides a rate of return of more than 15% as a result of ten years of operation.

6. Ha Mokoto Energy Centre

Ha Mokoto (29°41'31.6"S 28°42'45.0"E) is located 42.1 km South East of Thaba Tseka town in about 11 km from A3 main road. The nearest service centre is Thaba-Tseka Town, with distance of about 46 km, or two hours. Ha Mokoto is situated between Linakeng and Ha Makunyapane.

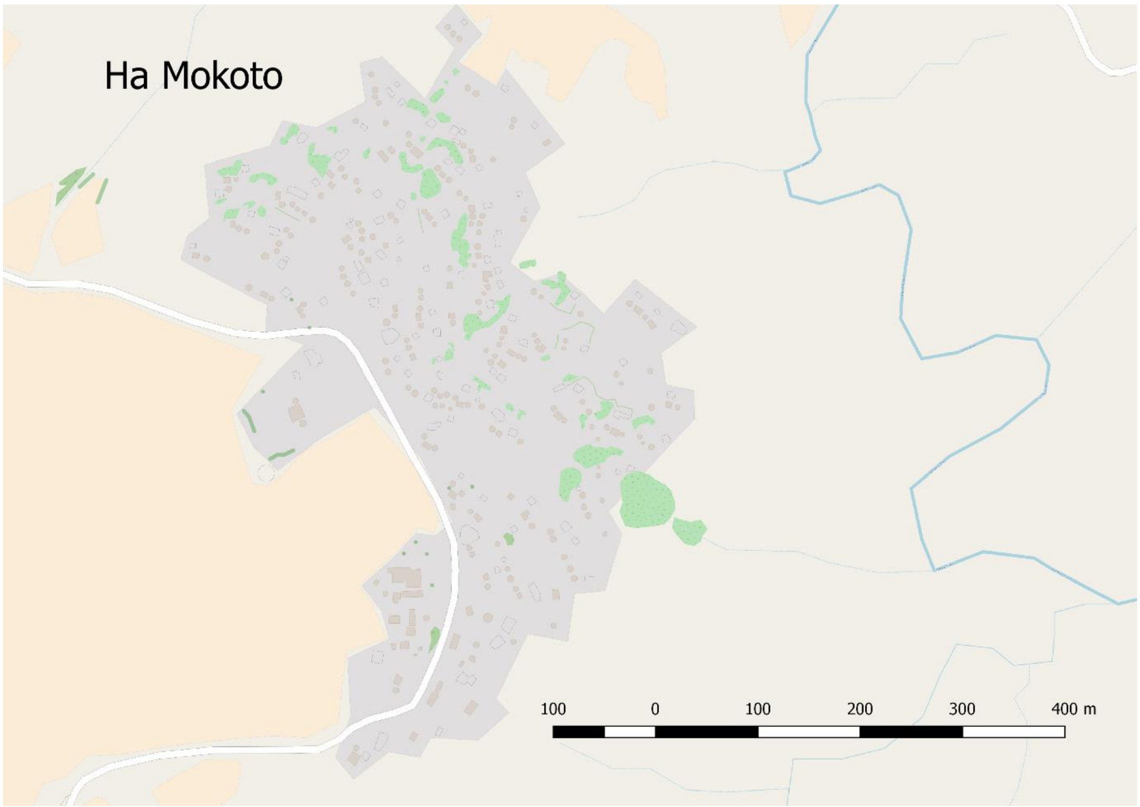


Figure 16: Map of Ha Mokoto

6.1 Customer Base

Main income sources for Ha Mokoto households are retailing local beer, farming in crops, livestock as well as hawking.

6.1.1 Households

Energy demand forecast

Ha Mokoto has approximately 200 households. Based on the assumptions on current and future energy demand, we calculated key parameters for the village. Power demand in 2019 reflects only the share of the total demand of households which will be covered by the Energy Centre. Therefore, affluent households were not considered in the calculation for 2019, since they already cover their own energy needs using solar home systems, solar lanterns and rechargeable batteries.

Table 41: Present and future power demand by households in Ha Mokoto

Household type	No. of HH in Ha Mokoto	Total power demand, kWh/year	
		Present	**2019**
Basic	130	0	1,690
Medium	50	2,500	3,650
Affluent	20	6,000	0
Total	**200**	**8,500**	**5,340**

6.1.2 Anchor customers

Main characteristics

Potential anchor loads in the village are the Health Clinic, one primary school and four medium-sized retail shops. In Ha Mokoto, five anchor customers were interviewed: one health facility and four commercial users (food retail shops) (Q B1). Health centre is a state institution, and commercial facilities are in individual ownership (Q B2). The health centre has 17 employees, commercial retailers one or three workers (Q B3).

Regarding earnings, four commercial companies generate some income between M750 and M30,000 per month (Q B4). The health centre receives subsidies from the state and therefore does not earn any income (Q B6).

Energy supply

Energy sources, namely coal (10,000 kg per year for space heating) and wood (550 kg per year for space heating), were used only by the health centre (Q C1). The health centre uses also solar electricity, 715 W for lighting over the whole operating time (Q C2).

All respondents want to have electricity in their facilities and think that it is important for companies and institutions from their branches to have (Q C4, Q C5). At the same time, none of the users suppose that electricity is expensive (Q C6).

Respondents stated that their company/institution is ready to pay for electricity between M150 and M500 per month, M320 an average, which seems to be realistic with their income (Q C7). Preferred methods to pay for electricity were using cash (four answers) and via mobile phone (one answer) (Q C8).

Most anchor customers work seven days a week except one retailer which works five days a week (Q D1) and operate for 8-10 hours per day over the whole year. Health centre is open 24 hours per day the whole year (Q D2, Q D3).

Commercial customers interviewed cover one to three buildings, health centre has five buildings at its disposal (Q D4). Most buildings were constructed in the period of 2006 and 2015. Some buildings are as new as after 2015. The total building area ranges from 9 m^2 to 42 m^2 among commercial facilities, on average 26 m^2, area size of health centre buildings is 108 m^2. One building is insulated (Q D5).

No anchor customer uses any central air-conditioning systems (Q D6), as well as independent heating/cooling systems (Q D8). Only the health clinic uses the LPG heating system, 144 units of 48 kg were used over last year. System operates over the whole year (Q D7).

Four anchor customers are willing to pay for electricity for heating/cooling purposes, between M100 and M250, M163 on average (Q D9, Table 42).

Health centre uses 26 fluorescent light bulbs (Q D10). No customer uses light or motion sensor controls at their facilities (Q D11, Q D12). Regarding willingness to pay for electricity for lighting, the commercial customers are ready to pay for electricity for lighting between M50 and M250, while the health clinic is willing to pay M200 per month (Q D13, Table 42).

The health centre has one desktop in operation (Q D14).

Two anchor customers with any cooking facilities in Ha Mokoto were the health centre and the general dealer (Q D15). As an energy source for cooking, these customers use LPG (Q D16). Only these two respondents are ready to pay for electricity for cooking and willingness to pay is between M200 or M500 per month (Q D17, Table 42).

Two general dealers and a health centre have refrigerating equipment for food or medical uses: one to seven refrigerators (Q D18). Commercial customers show relatively high willingness to pay for electricity for refrigeration (more than 10% of the monthly income) (Q D20, Table 42).

The health centre generates electricity with 21 solar panels of 715 W capacity and use electricity for lighting. Panels operate for 24 hours per day all year long (Q E1-E2). Health centre additionally uses one generator to generate electricity and/or heat for lighting, fuelled by unleaded petrol, that runs round the clock all year long (Q E4).

Table 42: Ability and willingness to pay for electricity in general and for different applications of anchor customers in Ha Mokoto

Anchor customer	Earnings per month ability to pay	Willingness to pay for electricity per month (Maloti)					
		Heating/ Cooling	Lighting	Cooking	Fridge	Total	
						Maloti	% of earnings
Bahlakoana General Dealer	M750	M250	M50	-	-	M300	40%
Bafokeng General Dealer	M30,000	M100	M250	-	M1,000	M1,350	5%
Food	M1,500	-	M50	M200	-	M250	17%
Mapota General Dealer	M3,500	M100	M100	-	M200	M400	11%
Ha Mokoto Health Clinic	M0	M200	M200	M500	M500	M1,400	-
Total	M35,750	M650	M650	M700	M1,700	M3,700	-

Four anchor customers are planning to replace some units in the next five years: refrigerators, LPG, solar (Q F1). The health clinic plans to replace solar and LPG; and install electric light bulbs, Wi-Fi and TV. The three commercial anchor customers plan to replace the refrigerators and LPG and install electric appliances (light bulbs, electric refrigerators, electric stoves). They think this action will increase their energy consumption (Q F2-F8).

Four anchor customers plan to buy a generator in the next five years (Q F9).

All the anchor customers plan to upgrade buildings in the next five years: replace light bulbs with CFL (all respondents), install solar water heater (one respondent), replace windows (one), fit ceiling (one) (Q F10).

Energy demand forecast

The present power demand and supply of anchor customers in Ha Mokoto are summarized in the Table 43. Future power demand of all anchor customers in the village, including non-interviewed ones, is presented in the Table 44. We derived the forecast for power demand of anchor customer on the results of the entire survey. However, only school will be supplied with energy by the energy centre whereas for the other types specific individual demand is too high to be covered by the energy centre. Moreover, the other customer types often already feature own generation facilities.

Table 43: Main characteristics of anchor customers in Ha Mokoto

#	Name	Type	Size	Operation hours	Electrical equipment	Annual power demand	Present power supply	Willingness to pay[8], Maloti/month
1	Ha Mokoto Health Clinic	**Health**	17 employees; 5 buildings, area 108 m^2	24 h/day, 7 days/week, 12 months/year	26 fluorescent lights, desktop, 7 refrigerators	17,812 kWh	21 solar panels, capacity 715 W, 1 generator	1,400
2	Bahlakoana General Dealer	**Retail**	1 employee; 2 buildings, area 28 m^2	8 h/day, 7 days/week, 12 months/year	None	0	None	300
3	Bafokeng General Dealer	**Retail**	3 employees; 3 buildings, area 42 m^2	10 h/day, 7 days/week, 12 months/year	4 refrigerators	3,504 kWh	NA	1,350
4	Food	**Retail**	1 employee; 1 building, area 9 m^2	8 h/day, 5 days/week, 12 months/year	None	0	None	250
5	Mapota General Dealer	**Retail**	1 employee; 2 buildings, area 24 m^2	10 h/day, 7 days/week, 12 months/year	1 refrigerator	4,380 kWh	NA	400
					Total	25,696 kWh		3,700

Table 44: Present and future power demand of anchor customers in Ha Mokoto

Type	Number of institutions	Power demand, kWh/year	
		Present	2019
Health	1	17,812	17,812
School	1	0	500
Government	1	850	850
Retail	4	7,884	7,884
Total		**26,546**	**27,046**

[8] Sum of willingness to pay for electricity for heating/cooling, lighting, cooking, and refrigeration (Table above).

The power demand distributes spatially as depicted in the Table 45. Here, also anchor customers and affluent households are included even though we do not expect them to be supplied by the energy centre.

Table 45: Development of power demand in Ha Mokoto by distance from energy centre

Customer	**Annual Power Demand MWh**											
	Present				**2019**				**2030**			
	1km	**2km**	**3km**	**total**	**1km**	**2km**	**3km**	**total**	**1km**	**2km**	**3km**	**total**
Households	4.5	0.0	0.0	4.5	5.7	0.0	0.0	5.7	142.3	0.0	0.0	142.3
Anchor customers	28.3	0.0	0.0	28.3	28.8	0.0	0.0	28.8	67.7	0.0	0.0	67.7
Total	32.8	0.0	0.0	**32.8**	34.6	0.0	0.0	**34.6**	210.0	0.0	0.0	**210.0**

6.2 Set-up for Energy Center

Like with most villages, the land ownership in Ha Mokoto is communal where the community elders and area leaders give authority for use of land for development either for domestic, business or institutional purposes.

For the Energy Centre one feasible site was identified (Figure 17). The yellow marked optimal site was determined according to the calculation algorithm of the geometrical mean of all buildings in the radius 1-3 km in the village. So, it is the location that has the minimum sum of distances to all existing potential residential, public and business customers.

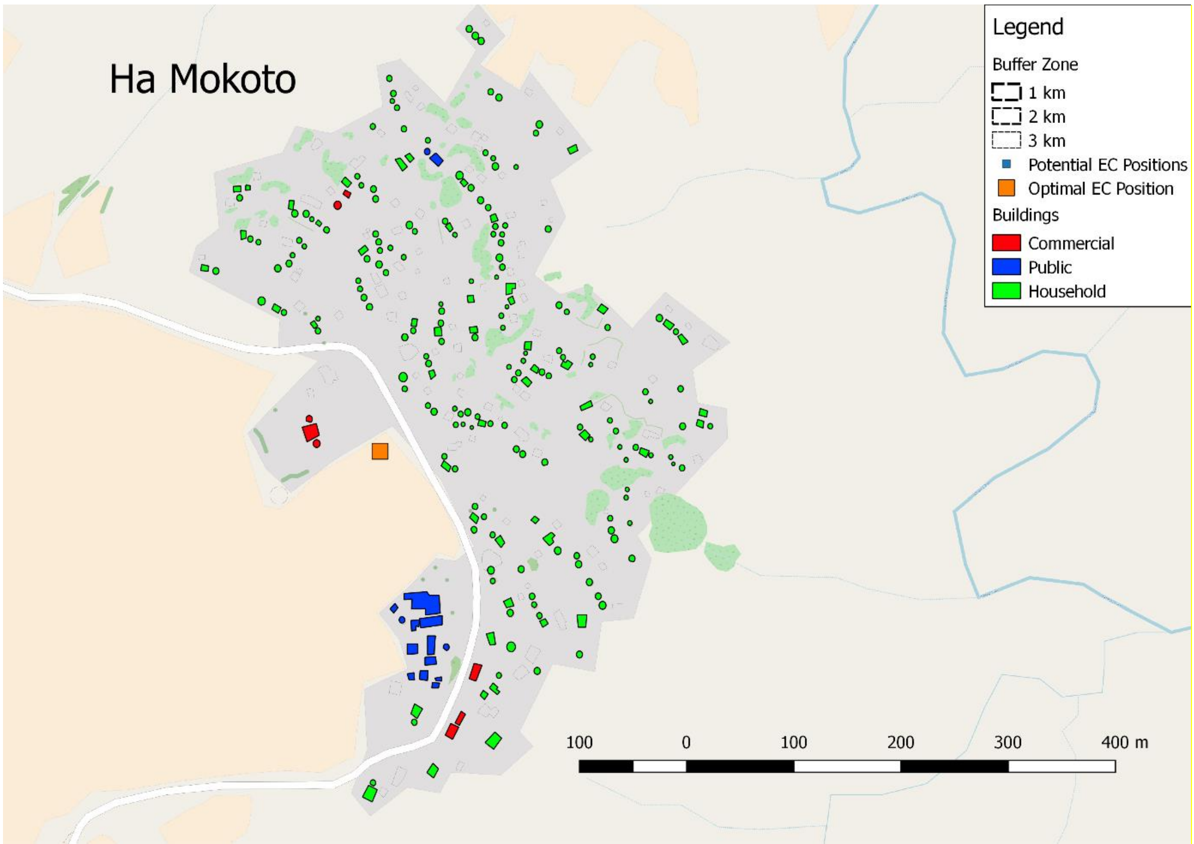


Figure 17: Spatial distribution of customers and positions of energy center in Ha Mokoto

6.3 Economic Viability

Ha Mokoto with 200 households and few anchor customers belongs to middle-sized villages, so the energy centre to be constructed here should be of medium size. In the Table 46 main characteristics and financials of the energy centre in Ha Mokoto like initial investment, annual expenditure, replacement costs due every five years as well as residual value after 10 years of operation are cited.

In order to supply energy needs of households, business and public customers in Ha Mokoto as well as to cover the electricity demand for the services provided through the centre, a solar power plant of 9.23 kW with battery storage facility of 28 kWh is needed. It can be taken into consideration to build up this plant in stepwise mode along the expected increase in power demand and power-related services.

We calculated the cash flow over a period of ten years after commissioning the energy centre (Figure 18). Even though most of the equipment as well as the building will be not worn out after ten years we expect that power provision through batteries will be replaced either by a mini-grid or a connection to the central grid after 2029. Besides the initial investment (we assumed 2018, i.e. the year before start of operation, for reasons of calculation) certain elements like vehicles or inverters needs to be replaced after five years. Annual revenues arise from provision of charging services (lights, phones, large batteries), equipment services (printing, calling, internet services, sales of drinks and snacks, etc.), as well as profit on equipment sales. With an internal rate of return of 8%, net present value of the project over ten years is equal to M511,974, that makes this energy centre setup economically feasible and very profitable compared to other setups (small and large).

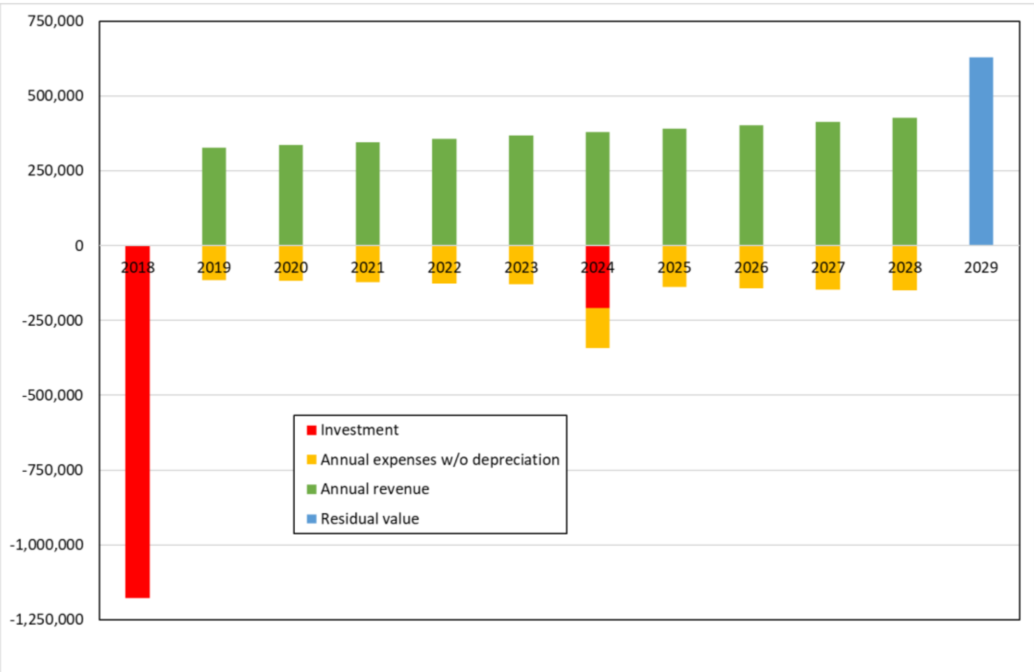


Figure 18: Cash flow of the energy centre in Ha Mokoto in 2018-2029

Table 46: Main features and financial parameters of an energy centre in Ha Mokoto

Features	
Number of households in the village	200
Building area, m2	80
Vehicle, #	0.5
Employees, #	3
Capacity PV, kW	9.23
Capacity storage, kWh	28
Initial investment	
Building costs, M	160,000
Vehicle, M	100,000
PV+storage, M	273,845
Initial Stockage, M	412,545
Equipment, M	30,700
Staff Training, M	5,000
Contingencies	196,418
Total initial investment	**1,178,508**
Annual costs	
Salaries, M	75,000
Maintenance PV, M	5,477
Depreciation on hardware investment	34,140
Vehicle Maintenance and fuels	10,000
Contingencies	24,923
Total annual costs	**149,540**
Replacement costs	
Inverter+ storage	109,200
Vehicle	100,000
Annual revenue	
Charging lights, phones #/yr	24,333
Charging large batteries #/yr	5,100
Charging lights, phones, M	121,667
Charging large batteries, M	51,000
Equipment services	30,000
Profit on equipment sales	123,764
Total annual revenue	**326,430**
Residual value	
Building costs, M	80,000
Vehicle, M	0
PV+storage, M	136,923
Initial Stockage, M	412,545
Equipment, M	0
Total residual value	**629,468**

6.4 Summary

Ha Mokoto, with 200 households living in the village, is a representative of middle-sized villages, so the energy centre will be medium. The settlement is densely populated in the small radius, that makes it an attractive location for an energy centre to be easily reached on foot by potential customers. Energy centre should have a building area of about 80 m^2 to accommodate stock, display and office rooms. Three employees, two sales assistants and one maintenance agent, will support customers by choosing a right energy product, explain advantages and profits of using energy efficient products and technologies, handle small repairs and deliver products and spare parts. A vehicle will be needed for trips around the village and neighborhoods which for cost-saving purposes can be shared with another energy centre or some business located in the close proximity. Combination of PV and battery storage will cover energy needs of customers and own energy consumption of the centre. If a noticeable growth of energy demand will be observed, this PV system can be scaled up with relatively small effort. Given that stocked goods will find demand, and services of the centre such as battery and phone charging will become popular, the establishment of such a facility is economically profitable with initial investment of M1,178,508 and provides a rate of return of almost 16% as a result of ten years of operation, which makes this energy centre particularly profitable to set up.

7. References

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