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

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Content

1. Summary

The following Table 1 provides an overview on the features and feasibility of mini-grids and energy centres in selected villages in Mokhotlong district. Please note that the electricity demand listed here for the years 2019 and 2030 is only the electricity viewed as apt to be supplied by the mini-grid and energy centre respectively. We assume, that, the energy centres will not supply affluent households as these households usually already feature an own power supply; and the same applies to those anchor customers who already have their own generation facilities.

Table 1: Overview of selected features of energisation solutions in Mokhotlong

Village	Matsoaing	Tlhanyaku	Linakaneng	Malingoaneng
Solution	Mini-grid	Mini-grid	Energy centre	Energy centre
Number of Households	200	200	450	250
Anchor customers	1 health centre, 2 schools, 1 government institution, 8 commercial retailers, 2 crafts	1 health centre, 1 school, 1 government institution, 11 retailers, 3 crafts	1 health centre, 1 school, local court, church, 5 commercial retail organizations, 2 crafts	1 primary school, 1 government institution, 5 retailers, 1 craft
Present annual demand kWh	25,000	27,000	34,250	30,400
2019 annual demand kWh	93,830	98,370	12,660	7,200
2030 annual demand kWh	381,800	399,420	-	-
Size PV plant kW 2019 / 2030	114/286	129/291	23	11.8
Size storage kWh 2019 / 2030	339/730	352/696	55	33
Additional future power source	Hydro	Hydro	-	-
Length power lines km 2019 / 2030	7.15/7.98	3.21/3.58	-	-
Size of energy centre	-	-	Large	Medium
Initial investment Maloti 2019 / 2030	3,805,375/ 14,443,505	4,009,115/ 14,426,245	2,231,846	1,255,343
Internal Rate of Return (with national tariff) 2019 / 2030	-16%/-13%	-17%/-12%	-	-
Required tariff 2019 / 2030	9.00/7.32	8.99/6.91	-	-

2. Mokhotlong district

The Mokhotlong district has a geographical area of 4,075 km^2, which accounts for about 13% of the total area of Lesotho. It is the 6th largest district in the country; and it has a population of about 135,000; accounting for 6.7% of the country's total population (Census 2016 estimates). The total number of households in the district is around 24,362. According to the 2016 census estimates, approximately 65% of the district's households are male-headed while 35% are female-headed.

Figure 1: Location of Mokhotlong in Lesotho

2.1. Renewable energy potential

Mokhotlong (-29.29 (29°17'24"S), +29.07 (29°04'12"E) is located in the mountainous north-eastern part of Lesotho. Average insolation of Mokhotlong as given by the NASA climatologic database ranges from a minimum of 3.43 kWh/m^2/day in June to a maximum of 6.25 kWh/m^2/day in December with an annual average of 4.91 kWh/m^2/day and an average clearness index of 0.57. 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 shiniest days of the year are within a three months period- November to January (with monthly daily averages of 5.91, 6.22 and 6.25 kWh/m^2/day, respectively) (Figure 2, Table 2).
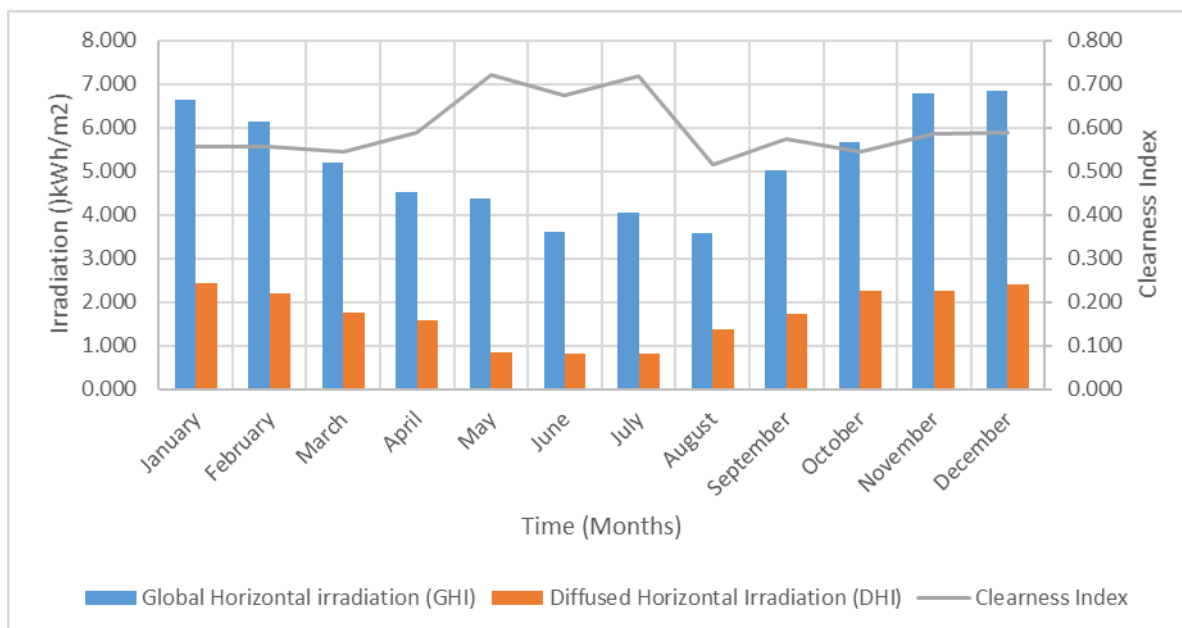
Figure 2: Average solar irradiation in Mokhotlong over the year (source: Photovoltaic Geographical Information System (PVGIS), European Commission)

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

Month	Clearness index	Daily GHI (kWh/m^2/day)
January	0.557	6.644
February	0.558	6.136
March	0.544	5.192
April	0.59	4.527
May	0.721	4.383
June	0.674	3.595
July	0.72	4.063
August	0.515	3.571
September	0.575	5.027
October	0.544	5.684
November	0.585	6.801
December	0.588	6.843
Average	0.6	5.2

Wind: Contrary to solar irradiation, the wind resource is highly site specific with a high dependence on the topography of a specific site. Overall, the average annual wind speed is approximately 4.32 m/s, which is greater than the 4 m/s rule of thumb to consider the technology viable. However, being located in the mountainous part of the country, a high variability in wind speeds from site to site (or village to village) is almost an obvious feature. This highlights the need for comprehensive and site-specific feasibility studies as far as wind power generation in the district is concerned. Notably. a comprehensive pre-feasibility study on the potential for using wind power to generate electricity has been undertaken in two sites in Mokhotlong (Lets'eng-la-

Terae and Sani Top) and two sites in Quthing (Lebelonyane Lets'eng-la-Letsie - Lesotho's only Ramsar wetland). The analysis of the one-year measurement results showed potential of electricity generation from wind at both Letseng-la-Terae (commercial-scale electricity generation in the order of hundreds of Megawatts) and Sani Top (hybrid community electricity generation). In fact, in 2008, the Government of Lesotho and NetGroup signed a memorandum of understanding (MOU) for an additional feasibility study at Let'seng-la-Terae focusing on a longer time period.

It is also worth noting that, wind energy development technology, especially in Africa, is in its infancy and Lesotho can play a crucial role in its development. Unlike in some areas where wind farms are located onshore, near-shore and offshore, Lesotho is landlocked and mountainous. This makes Lesotho an ideal candidate for exploring this power source, since among other things, new challenges that are typical of inland countries will be explored and overcome, which will enrich knowledge about the technology.

Hydro: Like other mountainous districts in Lesotho, mini-hydropower is a very promising technology in Mokhotlong. Two of the three major sub-basin river systems in Lesotho originate from Mokhotlong: Senqu (Orange), which drains two thirds of Lesotho (24 485 km^2) originates near Tlhanyaku village; and Mohokare (or Caladon), which marks the border with South Africa, with a catchment area of 6 890 km^2 springs from Mount Aux Sources. Moreso, a number of other larger rivers, such as Sehong-hong River, which runs through Matsoaing village, also have their origins in Mokhotlong district. Generally, all these rivers have good heads for mini-hydro power plant development. In fact, some feasibility studies for hydropower development of Khubelu and Mokhotlong rivers have conducted in early 1980s by SOGREAH Consulting of France, which gave positive conclusions. That gave birth to the construction of a 670 kW mini-hydro power plant along Khubelu River within those 1980s, but the plant was mothballed in 1990s.

2.2. Households

For the data analysis, this research relied on the data from the BOS Household Study 2017 for the Mokhotlong district. The number of households in the Mokhotlong district is 21,555, with an average size of 4 persons per household. According to the BOS survey, the majority of Mokhotlong inhabitants have at least one housing unit at their disposal, while 10 % of the inhabitants have three units and 3% have four units.

Also, according to the BOS National Energy Survey the results. Fig. 3, shows the household usable area patterns (or distribution) among the population in the district. Notably, . just over half (53%) of the total households are cooped up on the area less than 30 sqm. Thus, a majority of the population of Mokhotlong lives in reduced circumstances regarding house area; which also suggests that a majority of the district's population is generally poor.
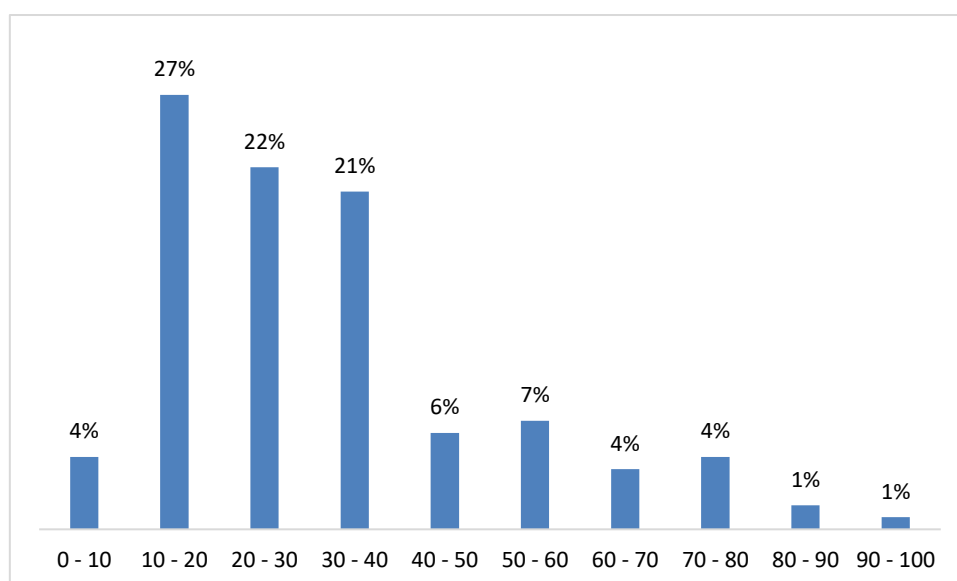
Source: BOS National Energy Survey 2017

Figure 3: Distribution of household's usable area size in Mokhotlong, m^2
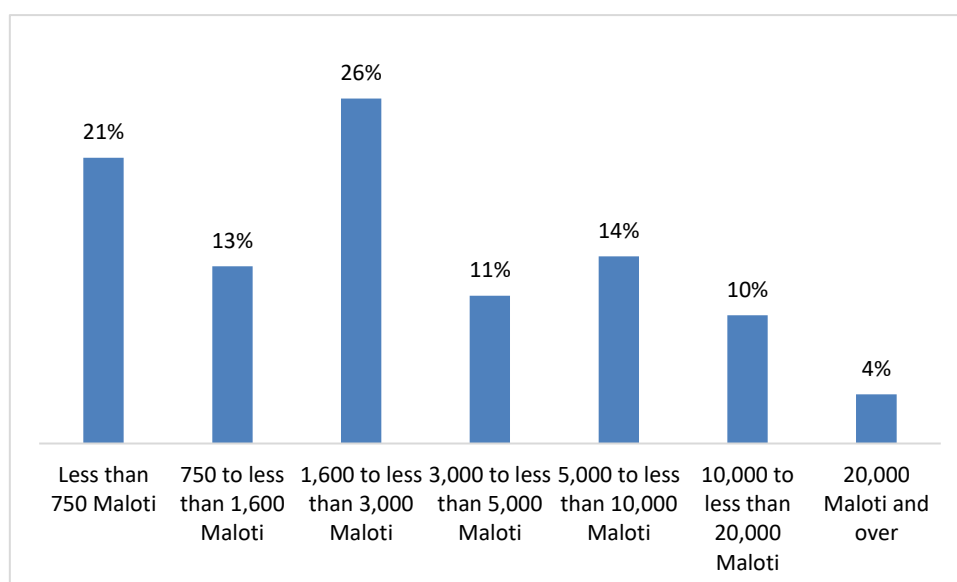
Source: BOS National Energy Survey 2017.

Figure 4: Distribution of household income in Mokhotlong

The age distribution of the residents in the households surveyed in Mokhotlong is slightly weighted toward the older age classes. Approximately 57% of residents were under 25, while 13% were from 40 to 59 years of age. Only about 8% of residents were over 60 years old. So, judging by the age distribution, with more than half of the population under the age of 40, it is quite likely that a stable consumer base will remain over the course of the next twenty years.

2.2.1. Present energy supply

The three main energy sources in the district are animal dung, wood and wood wastes and shrubs. Another interesting observation from the survey data are the huge seasonal variations in energy demand. The energy consumption in summer is about 40-90% lower than in winter.

Another striking feature of the district is the amount of time spent towards accessing wood fuel. The travelling time to reach the source of fuel wood is generally very long in this district, with 33% of the households travelling between half an hour and one hour; 20% travelling for more than two hours; and 7% having to travel for between one and two hours for that activity (Fig. 6). Overall, only 47% of Mokhotlong inhabitants spend time less than one hour collecting fuel wood; while about 15% spend more than one and a half hours, and 9% spend more than two hours. The timeframes for the collection of the wood were separated reported and also vary from less than half an hour to over two hours (Fig. 7). This scenario clearly deprives a large number of community members of a huge amount of time to engage in economically productive activities such tending their fields and animals (which are critical economic activities in that part of Lesotho).
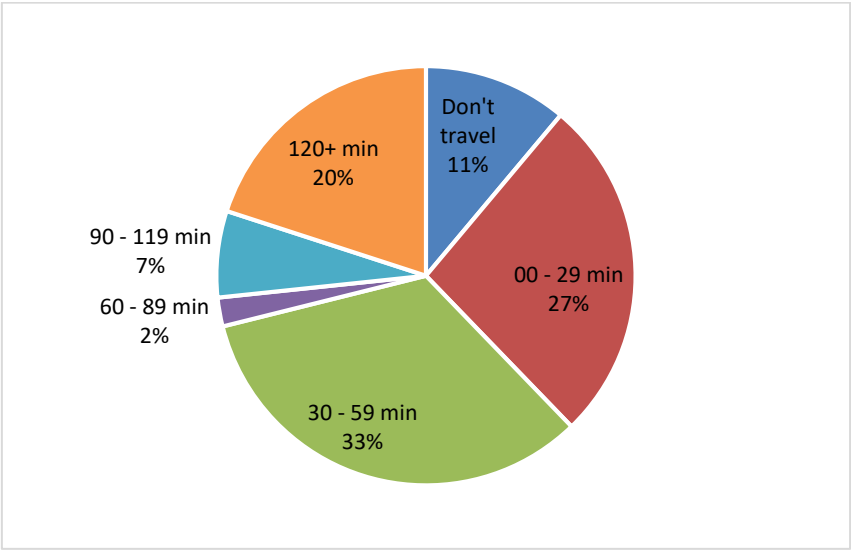
Source: BOS National Energy Survey 2017.

Figure 5: Travel time to the source of fuel wood in Mokhotlong.
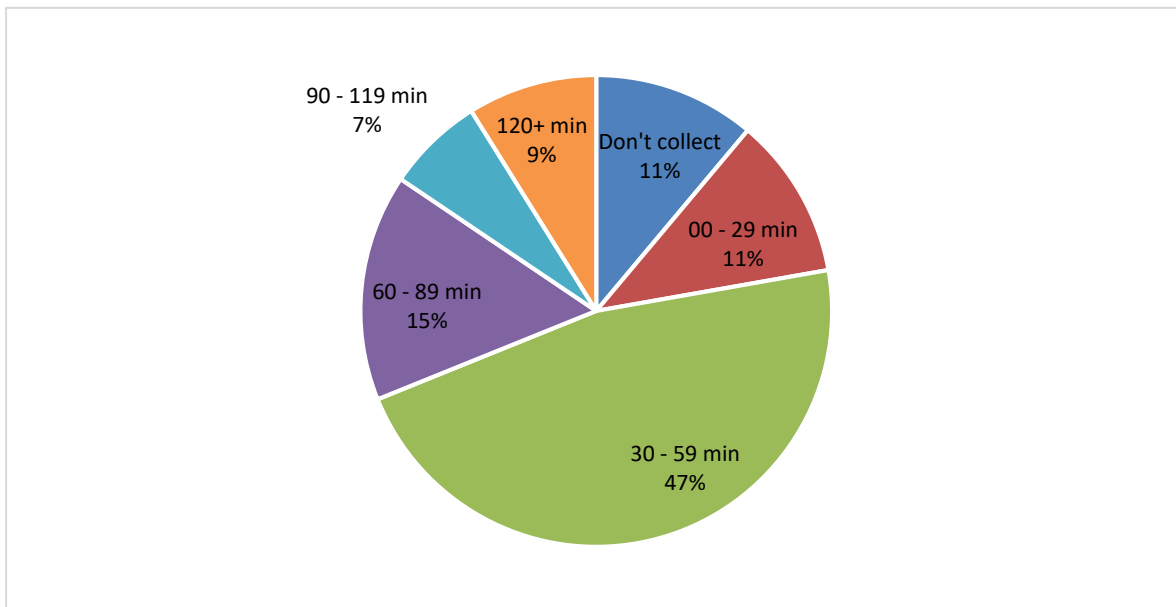
Source: BOS National Energy Survey 2017.

Figure 6: Collection time of fuel wood in Mokhotlong.

Electricity

According to the BOS Energy Survey about 16% of households have electricity in their homes, and approximately 12% of households own a solar PV in Mokhotlong district. By merely considering these low percentages of households with access to some form of electricity supply, one gets a picture of a district in dire need of electricity supplies.

Cooking

Cooking is one of the most energy-intensive activities of households. The main energy sources for cooking in Lesotho are biogas (22%), paraffin/kerosene (19%), LPG (17%), animal dung (17%).
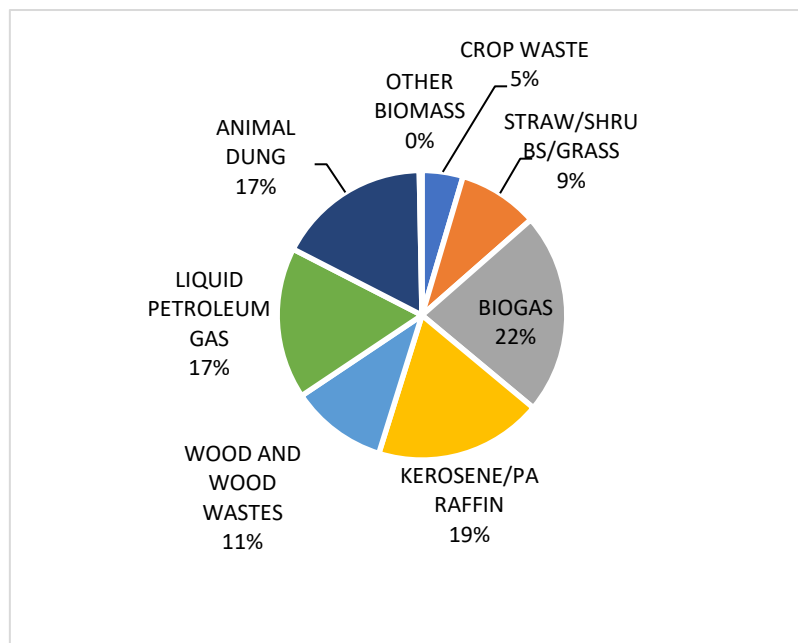
Figure 7: Households energy source consumption for cooking in 2017 (except electricity) in Lesotho.

Heating

Domestic space heating is another energy-intensive thermal application. In non-electrified households, wood and wood waste are the main energy sources for space heating. In general, about 87% of inhabitants of Mokhotlong use energy for heating during cold months.

Lighting

For lighting, paraffin and candles are used. Most of the non-electrified households in Lesotho rely on candles as a main energy source for lighting, with paraffin accounting for the predominant source for this purpose for most of remaining households.

3. Matsoaing Mini-Grid
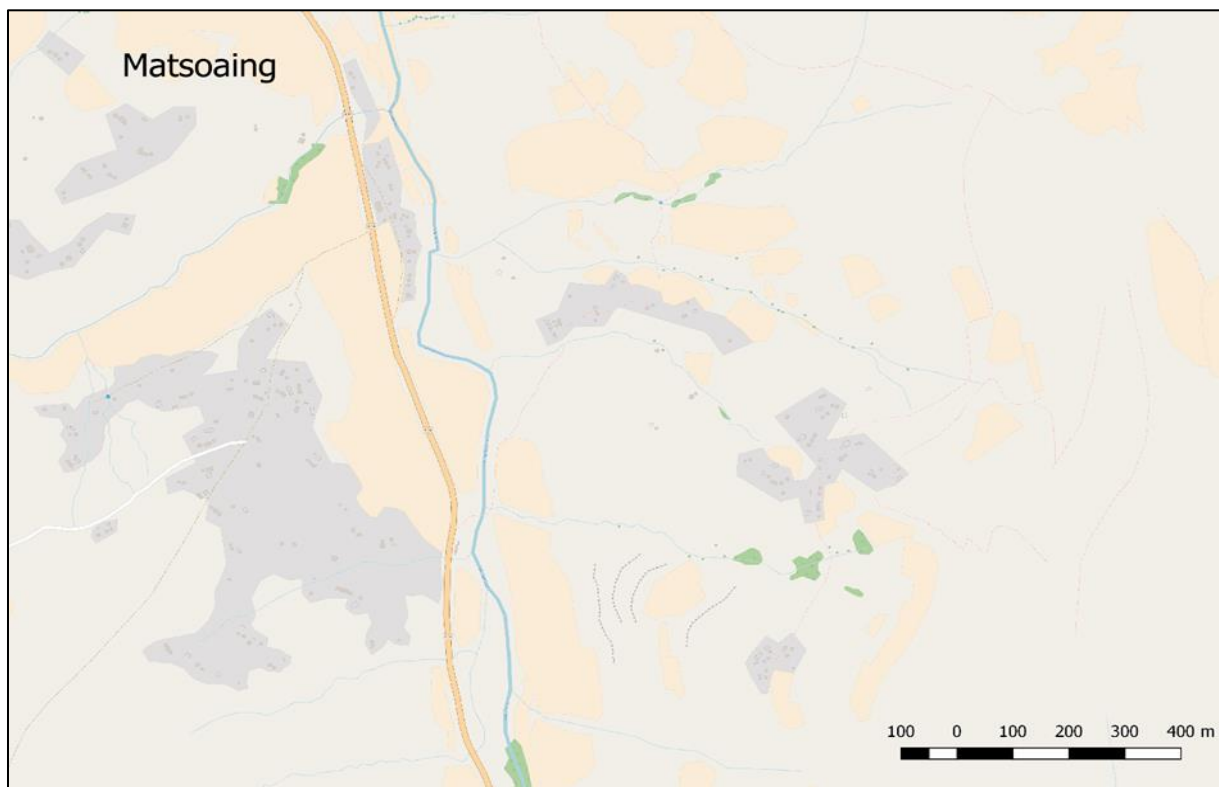
Figure 8: Map of Matsoaing

Figure 9: Pictures from field visits in Matsoaing

The village is close to Sehong-hong and Matsoaing rivers. The nearest grid distribution is approximately 7 km.

3.1. Customer Base

According to the UNDP project document, in Matsoaing there are more than 200 households. Potential anchor loads are Matsoaing clinic, Matsoaing Herdboys School and Handicraft shop, primary school, 5 medium-sized shops and grain mill. Main income sources in order of descending importance are livestock rearing, self-employment, old age pension, and small-scale retail. Pastoralism is the main mode of livestock rearing used in this area. Small-retail trading for goods, e.g. foodstuff, is also present within the village being a last stopover point for travellers plying the Mokhotlong-Sani Pass route. The nearest service centre is Mokhotlong Town and distance to it amounts to 20 km. Matsoaing is situated along the main road to two main tourist attractions, the Sani-Pass (UNESCO World Heritage Site) and Thabana-Ntlenyana (the highest mountain in Southern Africa). This site (Matsoaing) is a potential growth village due to its strategic geographical position, including proximity t and being the last village on the way to the South African Boarder, which is approximate 35 km from the village. According to interviewed residents, the village has high potential for businesses such as petrol station and medium –scale retail shops.

3.1.1. Households

Socio-demographic characteristics

As part of this study, we conducted a survey in Matsoaing village and ten village households (HH) were interviewed. The following observations were made. The number of HH members ranges from two to nine, and the average number of HH members is six (Q B1).

The surveyed households live in two to five housing units; with an average number of housing units of three. The most common type of house in this area is the Rontabole (13). As a second or third house The Polata is very popular as a second or third house. Other types of houses with a significant presence in the village are the Heisi (1), Apartments/town houses (4), and Mok'huk'hu (temporary structures) (3). Most houses have one room, the highest number of rooms for a single housing unit is 9; and on average each housing unit has 2 rooms. The usable area size ranges from 24 to 180 m^2 whereas the average usable area size is 110 m^2 (Q C2). The average area of houses owned by one HH is 110 m^2; and the mean value of disposable area per HH member in Matsoaing is 26 m^2..

The HH in Matsoaing have very different incomes per month - varying from none (2) to M7,500 (1). The average income per HH per month is about M2,400 (Q C3-C4).

Energy supply

Seven HH use animal dung, which is obtained either by self-production or collected. Four HH use between one and 208 bags of animal waste which is equal to 14-2,933 kWh per year, and one HH uses 6,084 kg animal waste (28,595 kWh), which is completely free. Half of the HH use collected shrubs, one HH also uses self-produced shrubs, which are all free. They use between one and 208

bundles, which is equal to 25-3,058 kWh. Two HH use fuel wood that they collect or produce by themselves which is completely free. A quantity of 15 kg is used by one household in a year which means 75 kwh (Q D1).

All HH have access to an area where they can collect wood (Q D2). Most HH use the communal forest, three HH use their own yard and only one household uses a private forest (Q D3). Respondents from Matsoaing indicated that they have to travel a minimum of 15 minutes to a maximum of 120 minutes plus (Q D4) and minimum time of 45 minutes to maximum of 120 plus minutes to collect wood. The overall average time to get fuel wood is 205 minutes (Q D5). It is collected from 4 to 14 times a month that means an average of 9 times per month. This gives amaximal time spent on the whole wood acquisition process of 54 hours per month (i.e., in worst case). Total travelling and collection time per year accounts for 30-714 hours, on average 173 hours. With an hourly wage of 8 Maloti this converts into annual costs of approx. 1,390 Maloti (Q D6). It is also revealed that, 15 men, 13 women and 4 children are involved in collecting fuel wood. This is, at least one woman from every HH but children are from only two HH (Q D7). None of the households used an improved fuelwood stove (Q D8).

With regard to purchase of biomass, nine HH indicate that they spend nothing on biomass while one HH spends about M25 per month (Q D9).

For the purchase of fuel, they all usually pay through cash (Q D10) although some indicate that they would prefer to pay through electronic transfer channels - Mpesa and Ecocash, others still prefer to use the cash method (Q D11).

The HH in Matsoaing use LPG (3 HH), animal dung (2 HH), straws/shrubs/grass (3 HH) and also wood (2 HH) as main energy source for cooking (Q F1). As alternative, paraffin could be used.

Table 3: Household use of energy sources for cooking in Matsoaing

HH No.	Use of energy sources	Annual energy consumption	Annual expenses
1	Straw/shrubs/grass, 1,825 kg per year	8,943 kWh/a	0
2	LPG, 89 kg per year	1,126 kWh/a	M1,734/a
3	Animal dung, 1,369 kg per year	6,433 kWh/a	0
4	LPG, 219 kg per year, animal dung, 913 kg per year	7,092 kWh/a	M4,333/a
5	LPG, 106 kg per year	1,357 kWh/a	M2,095/a
6	Straw/shrubs/grass, 1,369 kg per year	6,707 kWh/a	0
7	Paraffin, 180 litres per year, animal dung	1,863 kWh/a	M2,372/a
8	LPG, 29 kg per year, animal dung, shrubs, 608 kg per year	3,352 kWh/a	M540/a
9	LPG, 84 kg per year	1,075 kWh/a	M1,489/a
10	LPG, 55 kg per year, animal dung	704 kWh/a	M1,068/a
	Average	3,856 kWh/a	M1,363/a

The HH in Matsoaing are willing to pay between M0 and M260/month for electricity for cookinggiving an average amount of M70/month (Q F3, Table). None of the HH has a wonder box (Q F4).

Nine of the interviewedHH in Matsoaing heat their houses,and only one does not (Q G1). For space heating, all HH use paola, two also use paraffin heaters (Q G2). Four HH use animal dung, three HH use wood, two households use straw/ shrubs and one HH uses paraffin as main energy source. As an alternative energy source for space heating, four HH use animal dung, and two HH used shrubs, and one used wood and paraffin each in the last year (Q G3). The willingness to pay for electricity for heating ranged from none to M100, and averaged M36,5 (Q G5, Table).

Table 4: Household use of energy sources for space and water heating in Matsoaing

HH No.	Use of energy sources	Annual energy consumption	Annual expenses
1	LPG, 114 kg per year, paraffin, 50 litres per year, wood, 4 trees per year, animal dung, 96 bags per year, shrubs, 12 bundles per year	23,224 kWh/a	M4,030/a
2	Animal dung, 81 bags per year, shrubs ¾ stack per year	1,160 kWh/a	0
3	Animal dung, 232 bags per year	3,271 kWh/a	0
4	Animal dung, 416 bags per year, paraffin, 20 litres per year, shrubs	6,073 kWh/a	M728/a
5	Paraffin, 36 litres per year, animal dung, 208 bags per year, LPG, 105 kg per year	4,649 kWh/a	M1,082/a
6	Shrubs, 144 bundles per year, wood	3,528 kWh/a	0
7	Animal dung, 234 bags per year	3,299 kWh/a	0
8	Animal dung, 104 bags per year, shrubs, 365 bundles per year, LPG	10,409 kWh/a	NA
9	Paraffin, 56 litres per year, wood, 1/3 stack per year, animal dung	581 kWh/a	M728/a
10	Animal dung, 208 bags per year, wood	2,933 kWh/a	0
	Average	6,244 kWh/a	M821/a

The heating area of interviewed HH lies between 16 and 124 m^2, with the area ranging between 24 and 45 m^2 for the majority of the HH; giving anaverage of 40 m^2 (Q G6).

For water heating, the majority of the HH use animal dung (4 HH), while some use wood (3 HH) and shrubs (2 HH) as a main energy source. As alternative sources, the same energy resources are used, with paraffin being another possibility. One HH has no alternative source (Q G7).

For lighting, four HH in Matsoaing use candles, four use paraffin, 1 HH uses rechargeable battery lamps and another 1 HH uses electricity (solar home system). As alternative sources, five HH use paraffin, three use candles and one rechargeable battery lamps (Q H1).

Please note that the energy consumption calculated here 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, a HH spends M593/a, so it can be assumed that the equivalent budget would be at least available for purchasing power for lighting purposes.

Table 5: Household use of energy sources for lighting in Matsoaing

HH No.	Annual use of energy sources	Annual energy consumption	Annual expenses
1	n.a.	-	-
2	Candles, 20 packets per year, paraffin	60 kWh/a	M380/a
3	Candles, 13 packets per year, paraffin, 20 litres per year	227 kWh/a	M494/a
4	Candles, 72 packets per year, paraffin, 5 litres per year	160 kWh/a	M1,361/a
5	Rechargeable battery lamp, 1 unit, paraffin, 10 litres per year	169 kWh/a	M500/a
6	Paraffin, 75 litres per year	776 kWh/a	M975/a
7	Candles, 23 packets per year, paraffin	35 kWh/a	M414/a
8	LPG, 9 kg per year, candles, 9 packets per year	129 kWh/a	M340/a
9	Electricity (SHS), paraffin, 49 litres per year	566 kWh/a	M637/a
10	Rechargeable battery lamp, 1 unit, paraffin, 3 litres per year	38 kWh/a	M239/a
	Average	240 kWh/a	M593/a

Two of the interviewed HH in Matsoaing use energy savers (compact fluorescent) of 10 W capacity (2 hours per day, 7.3 kWh per year) and of 40 W (4 hours per day, 58.4 kWh per year), one HH uses incandescent (ordinary) globes light bulbs of 60 W capacity (3 hours per day, 65.7 kWh per year). Comparatively, the HH in Matsoaing are much better equipped with lighting sources and light bulbs than inhabitants of other interviewed villages where ooverwhelming majority do not use any light bulbs, rechargeable battery lamps or solar home systems at all (Q H3).

The HH are prepared to pay between M0 and M50/month on electricity for lighting, giving an average of M18/month . Realistic values are 0% and 6% of the monthly income (Q H4, Table).

Four of the interviewed HH in Matsoaing use electrical appliances at their homes, 6 h do not use any (Q E1). Two HH generate their own electricity (Q E2). In this case they usually use solar panels, and one of them also uses a generator as an additional source (Q E3). Four HH spend nothing on electricity (Q E4), while the one using a generator spends M890/ year. In most cases electricity is used for phone charging and lighting (3 HH each). In addition it is also used for charging other things (2 HH), TV, radio, cooking and re-heating (one HH each) (Q E6).

Notably, all HH want electricity in their houses (Q E7). Primarily they need it for phone charging, lighting and cooking/re-heating (10 HH), then for radio (6 HH), water heating (6 HH), charging other than phone (5 HH), ironing (4 HH), TV (3 HH), space heating (2 HH), refrigeration (1 HH), and water

pumping (1 HH). None relevant electricity uses, according to the respondents from Matsoaing are laundry, dishwashing, sewing, air-conditioning, computer, and workshops were picked out (Q E8).

Table 6: Households desired future uses of electricity in Matsoaing, 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
Phone charging	X	X	X	X	X	X	X	X	X	X	10
Water heating	X	X	X	X	X	X	X	X		X	9
Cooking/ re-heating	X		X	X	X	X			X		6
Radio			X	X	X	X		X	X		6
Charging (other than phone)		X	X	X				X	X		5
Ironing			X		X	X			X		4
TV		X				X			X		3
Space heating						X			X		2
Water pumping	X										1
Refrigeration				X							1
Sewing											0
Air-conditioning											0
Computer											0
Dishwashing											0
Workshop											0
Laundry											0
Total	5	5	7	7	6	8	3	5	8	3	-

With regard to willingness to pay for electricity, the interviewed HH indicate amounts ranging from M0 (none) to M500. Average willingness to pay is M160/month (Q E9), with 5 HH being ready to pay above M200 per month (Q E9, Table). It is interesting to note that, in many cases high willingness to pay for electricity is reflected by HH with absent or negligible income. Therefore, this brings into question the reliability of the numbers or responses given.

As for preferred methods of paying for electricity, five respondents from Matsoaing prefer cash, while two prefer Ecocash (Q E10).

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

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	M750	M25 (3 %)	M10 (1%)	-	M0 (-)	Refrigerator, electric stove, hair dryer, television (flat screen), electrical hair clipper, phone charger
2	M2,125	M2 (0 %)	M0 (-)	-	M2 (0 %)	Electric stove
3	M3,500	M200 (6 %)	M70 (2%)	M50 (1 %)	M0 (-)	Refrigerator, electric stove, electric heater, television (flat screen), electrical pot, electrical hair clipper, phone charger
4	M163	M500 (307 %)	M200 (123%)	M100 (61 %)	M50 (31 %)	Refrigerator, electric stove, television (flat screen), phone charger
5	M7,500	M350 (5 %)	M260 (3%)	M60 (1 %)	M30 (0 %)	Refrigerator, electric stove, electric heater, television (flat screen), iron, microwave, phone charger
6	M33	M250 (758 %)	M20 (61%)	M50 (152 %)	M50 (152 %)	Refrigerator, electric stove, television (flat screen), iron, electrical pot, phone charger
7	M750	M20 (3 %)	M15 (2%)	M15 (2 %)	M5 (1 %)	Television (flat screen), phone charger
8	Nothing	M50 (-)	M0 (-)	M30 (-)	M5 (-)	Electric stove, television (flat screen), phone charger
9	M7,513	M200 (3 %)	M120 (2%)	M60 (1 %)	M20 (0 %)	Refrigerator, electric stove, television (flat screen), iron, phone charger
10	M1,500	M0 (-)	M0 (-)	-	M0 (-)	Electric stove, phone charger
	Average	M160	M70	M37	M16	

Nine HH are not planning to move away from the village in the next five years (Q I1), just one HH is looking for better economic conditions (Q I2).

Considering plans to purchase electrical appliances in the next five years, nine HH want to obtain phone chargers and electric stoves, eight HH want televisions (flat screen), six want to obtain refrigerators, three HH irons, two HH want to buy electric heaters, electric pot, and electric hair clipper, one HH wants microwave and hair dryer. So the most wanted things are electric stoves, phone chargers and TVs (Q I3).

Seven HH want to obtain a solar PV in the next five years, three HH are planning to purchase a car battery, and two HH want a generator in the next five years (Q I4).

Energy demand forecast

Three of the HH interviewed in Matsoaing belong to the affluent type, judging from their present electricity sources (solar home systems, rechargeable battery lamps), electric appliances and relatively high incomes. The rest of the interviewedHH are rather representatives of the basic type,

with the exception of one HH that has a relatively high income (M3,500/month), but no electric appliances at the moment, which can be of medium type. Now, considering 200 HH currently living in the village and 1% growth rate in HH number per year the estimate present and future energy demand is calculated to be as given below (Table 8).

Table 8: Present and future power demand by households in Matsoaing

Household type	No. of HH in Matsoaing			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

3.1.2. Anchor customers

Main characteristics

The village has one health centre, two schools, one government institution, eight commercial retailers, and two crafts.

In this survey, nine anchor customers were interviewed: one school and eight commercial users,of which seven are food retail facilities (supermarkets, kiosks, sales booths) and one a B&B (Q B1). Six commercial facilities are individually owned (Q B2). All interviewed customers have one or two employees, including the school (Q B3). The earnings per month range between M250 and M30,000 (Q B5, Q B6). The school does not receive any subsidies from government.

Energy supply

Two interviewed anchor customers (school and B& B) used wood energy sources consumed over the last year, Over that period, the school used one load of wood for cooking and paid M50/load, while B&B used 3 trees for water heating obtained for free (Q C1). Two anchor customers paid for energy resources in cash last year (Q C2).

Six of the nine anchor customers used solar electricity last year. The capacity that they have at their disposal ranges from 40 to 960 W.The school has the highest capacity of 960 W, and commercial users have capacities ranging 40 to 80 W, givin anaverage capacity of 57 W for the commercial users. Solar energy is used for 7-12 hours per day; and the solar energy is in all cases used for phone charging and lighting (Q C3).

Notably, eight of the nine respondents want to have electricity in their facilities and think that it is important for companies and institutions from their branches to have electricity (Q C4, Q C5). At the same time, three users perceive electricity as expensive (Q C6).

Respondents also statethat their companies /institutions are ready to pay between M20 and M300 per month for electricity , which is a share of their monthly income of between 1% and 80% (Q C7). The preferred methodof payment for electricity is via cash (Q C8).

Most anchor customers work seven days a week, except for the school which operates for 5 days/weekand one shopwhich operates for 6 days/week (Q D1). Six commercial users operate between 7 - 12 hours per day throughout the year, and two commercial retailers work for 7 to9 hours per day over 11 months of the year, and the school operates for 10 hours over 10 months in a year (Q D2, Q D3).

The majority of individual anchor customers occupy one whole building, but B&B occupies six buildings (Q D4). Three buildings were constructed in the period of 1996-2015 .The individual building area ranges from 20 m² to 190 m² for the commercial facilities with an average of 64 m² per building, and average is 140 m² for school. One building is insulated (Q D5).

No air conditioning systems are in use by the interviewed anchor customers (Q D6). B&B has a heating system that uses wood, and operates for 7 hours every day, for 11 months (Q D7). No independent heating or cooling system are used (Q D8).

The anchor customers are willing to pay between M5 and M200 for electricity for heating/cooling. This corresponds to between 1% and 13% share of the month incomes (Q D9, Table).

Two companies use any type of light bulbs, the school uses four incandescent bulbs of 100 W, and one shop two energy saver bulbs of 100 W (Q D10). There are no light or motion sensor controls for operating the lighting in service area (Q D11-D12). Anchor customers are ready to pay for electricity for lighting between M1 and M100 (0.1% to 8% of the income per month) (Q D13, Table).

No small equipment like desktops, monitors, laptops, servers, printers, or household appliances are operated by anchor customers in Matsoaing (Q D14).

Two anchor customers in Matsoaing use cooking facilities - the school and B&B (Q D15); LPG and wood are in used as an energy source (Q D16). Willingness to pay is a minimum of M15 and a maximum of M300 per month, giving an average M93 or 0.3%-40% of their monthly income (Q D17, Table).

Four customers have refrigerating equipment at their facilities: one or two refrigerators, one or two freezers of 10-50 litres (Q D18). All anchor customers are willing to pay for electricity for refrigeration, at the rate of M50 to M180 per month (0.3% to 28% of their monthly income) (Q D20, Table).

Four anchor customers generate electricity with solar panels (Q E1), using 1 - 8 panels of 55 to 120 W capacity, and use the electricity for lighting and phone charging. The panels operate for 3 to 16 hours per day all year long (Q E2).

Two of the anchor customers use generators for heating or lighting (capacity 10 and 100 kW), fuelled by diesel 500 ppm. One of the two uses a generatorwhich runs for 5 hours per day and 30 days/month throughout the yearand the other customer uses a generator for 4 hours per day for 30 days per month and 5 months per year (Q E4).

Table 9: Ability and willingness to pay for electricity in general and for different applications of anchor customers in Matsoaing

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
Moiseloa's Shop	M750	M100	M1	M50	M50	M201	27%
Matsoaing Herd Boys School	M250	M5	M20	M100	M70	M195	78%
Numberico Riverside B&B	M7,500	M200	M100	M300	M180	M780	10%
Ntsooa's Cafe	M7,500	M50	M45	M100	M80	M275	4%
Matsoarelang General Dealers	M30,000	M20	M10	M100	M100	M230	1%
Lesole's Shop	M750	M25	M6	M15	M90	M136	18%
Koapanang Shop	M1,500	M35	M10	M100	M100	M245	16%
Tatolo's General Cafe	NA	M130	M65	M50	M50	M295	NA
Makhakhe Shop	M750	M80	M50	M20	M60	M210	28%
Total	M49,000	M645	M307	M835	M780	M2,567	-

Two anchor customers are planning to replace some units in the next five years (Q F1) by refrigerators (Q F2). They think this action will reduce their energy consumption (Q F3). Seven interviewed customers want to install new energy consuming systems or technologies. These will be sewing machine and cooking facilities by school, cash till machines, fridges, cameras, phone charging by commercial retailers (Q F4, Q F5). Seven anchor customers want to switch to electricity in the next five years, and B&B wants to renovate and advance to hotel. Some anchor customers think the replacement will increase their energy consumption, others think it will reduce it (Q F5-F8).

Six anchor customers are planning to buy solar PV, two anchor customers are planning to buy generators, and one anchor customer is planning to buy car battery in the next five years (Q F9).

Four anchor customers want to fit a ceiling in the next five years, two plan to replace windows, one wants to insulate walls and replace light bulbs with LED (Q F10).

There are no plans by some anchor customers to upgrade buildings due to high purchasing costs, high labour or installation costs; and one customer did not know about the available technologies (Q F11).

Energy demand forecast

Present power demand and supply of anchor customers in Matsoaing are summarized in Table . Presently, they have a substantial higher power demand than the group of private households. Based on the expressed willingness to pay and considering the potential ability to pay, we expect that the power demand will increase substantially once the mini-grid is available. Future power

demand of all anchor customers in the village, including non-interviewed ones, is presented in Table above.

Table 10: Future power demand of anchor customers in Matsoaing

Type	Number of institutions	Power demand, kWh/year	
		2019	2030
Health	1	14,300	28,600
School	2	1,700	11,930
Government	1	1,600	3,200
Retail	8	10,700	32,100
Craft	2	100	500
Total		**28,400**	**76,330**

Table 11: Main characteristics of anchor customers in Matsoaing

#	Name	Type	Size	Operation hours	Electrical equipment	Annual power demand	Present power supply	Willingness to pay[1], Maloti/month
1	Matsoaing Herd Boys School	**School**	1 employee; 1 building, area 140 m^2	10 h/day, 5 days/week, 10 months/year	Incandescent light bulbs, 4 units of 100 W	704 kWh	8 solar panels of 120 W, 1 generator of 10 kW	195
2	Moiseloa's Shop	**Retail**	2 employees; 1 building, area 20 m^2	7 h/day, 7 days/week, 12 months/year	1 refrigerator (10 liters), 2 freezers (20 liters)	657 kWh	1 solar panel of 40 W, 2 generators of 100 kW	201
3	Numberio Riverside B&B	**Retail**	2 employees; 6 buildings, area 190 m^2	7 h/day, 1 day/week, 11 months/year	1 refrigerator (50 liters)	390 kWh	1 solar panel of 80 W	780
4	Ntsooa's cafe	**Retail**	1 employee; 1 building, area 90 m^2	9 h/day, 6 days/week, 11 months/year	Energy saver light bulbs, 2 units of 100 W	562 kWh	1 solar panel of 55 W	275
5	Matsoarelang General Dealer	**Retail**	1 employee; 1 building, area 30 m^2	12 h/day, 7 days/week, 12 months/year	1 freezer (10 liters)	219 kWh	1 solar panel of 55 W	230
6	Lesole's Shop	**Retail**	1 employee; 1 building, area 20 m^2	12 h/day, 7 days/week, 12 months/year	2 refrigerators (20 liters)	438 kWh	None	136
7	Kopanang Shop	**Retail**	1 employee; 1 building, area 24 m^2	12 h/day, 7 days/week, 12 months/year	None	0	None	245
8	Tatolo General Cafe	**Retail**	1 employee; 1 building, area 24 m^2	8 h/day, 7 days/week, 12 months/year	1 refrigerator (10 liters, 1 freezer (10 liters)	438 kWh	1 solar panel of 55 W	295
9	Makhakhe Shop	**Retail**	1 employee; 1 building, area 110 m^2	10 h/day, 7 days/week, 12 months/year	None	0	None	210
					Total	3,408 kWh		2,567

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[1] 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 .

Table 12: Development of power demand in Matsoaing 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	3.1	0.6	0.0	3.7	24.0	4.2	0.0	28.2	100.3	17.6	0.0	117.9
Anchor customers	21.7	1.8	0.0	23.5	29.4	2.8	0.0	32.2	48.1	8.4	0.0	56.5
Total	24.8	2.4	0.0	**27.2**	53.4	7.0	0.0	**60.4**	148.3	26.0	0.0	**174.4**

3.2. Set-up for Mini-Grid

Like with most villages, the land ownership in Matsoaing is communal where the community elders and area leaders give authority for use of land for development whether domestic, business or institutional purposes. For the purpose of developing a mini-grid, the community seems receptive to allocate land for the project. The proposed site for the mini-grid's powerhouse is located ~0.8 km southeast of the village centre and is community owned. Currently no competing activity is undertaken on this site. The site is located between the Sehong-hong river and the village's centre.

We designed the mini-grid by using HOMER Pro software. For sizing 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 the present conditions, the combination of PV power plant and storage is the most optimal and least-cost. Capacity of battery storage should exceed maximum hourly output of solar panels by about 3 times, but this ratio depends to a large extent on relative costs of solar panels and battery. In this combination the unmet load accounts for about 2%, and excess electricity produced 46% which makes it possible to connect further loads.

Table 13: Elements of mini-grid setup in Matsoaing in present conditions

Element	Size	CAPEX (Maloti)	Replacement costs (Maloti)	OPEX (Maloti/year)
PV Power Plant	30.9 kW	522,210	0	6,026
Battery	88 kWh	343,200	1,372,800	11,440
System converter	8.97 kW	23,322	23,322	0
Power lines	7.08 km	148,680	0	2,974
Power meters	94 units	300,800	0	6,016
Total	-	**1,338,212**	**1,396,122**	**661,375**

Regarding the expected demand increase, it would be relevant to design a mini-grid liberally and to consider options of highly scalable systems that can be easily expandedin future. 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. However, a significant enlargement of PV and battery size leads to a more than threefold capital investment needs.

Table 14: Elements of mini-grid setup in Matsoaing in 2019

Element	Size	CAPEX (Maloti)	Replacement costs (Maloti)	OPEX (Maloti/year)
PV Power Plant	114 kW	1,926,600	0	22,230
Battery	339 kWh	1,322,100	5,288,400	44,070
System converter	39.5 kW	102,700	102,700	0
Power lines	7.15 km	150,167	0	3,003
Power meters	95 units	303,808	0	6,076
Total	**-**	**3,805,375**	**5,391,100**	**1,884,475**

Figure 10 presents the distribution of capital costs between different components of a mini-grid. It shows that power grid components (lines and meters) exceed 10% of the capital costs.
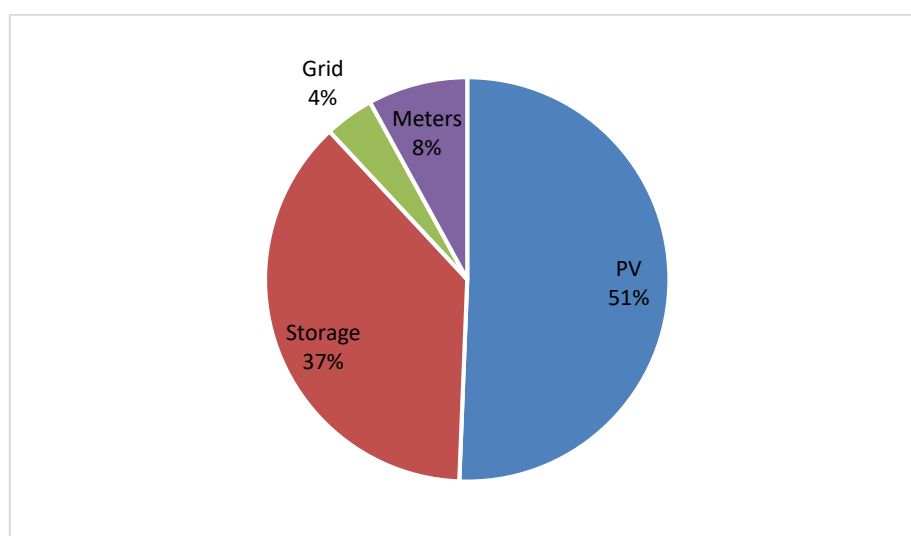

Figure 10: Distribution of capital costs of a mini-grid in Matsoaing in 2019

Initially, three feasible sites were identified for the mini-grid location. The two sites marked blue on the Figure 11, were short-listed because they are also attractive according to physical criteria like direction to the sun, area size and availability of space. The optimal site, marked yellow 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. Notably, in the case of Matsoaing, the theoretically determined potential site coincides 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.
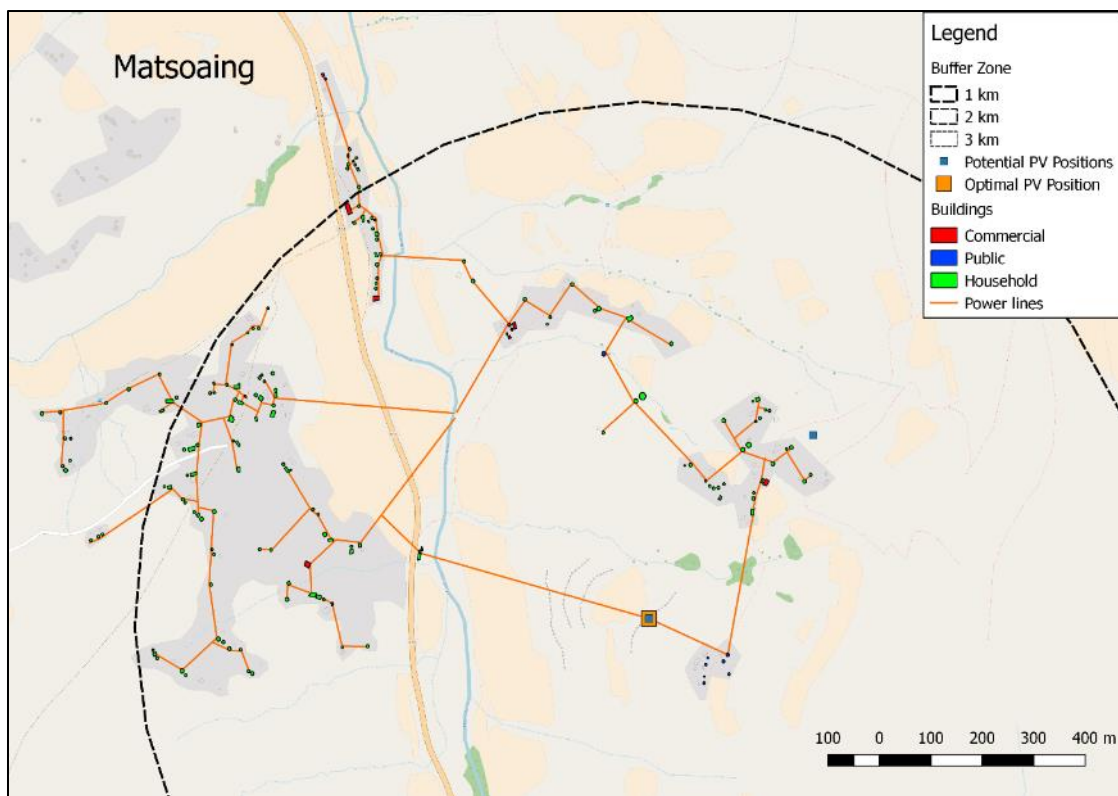
Figure 11: Map of the mini-grid set-up in Matsoaing
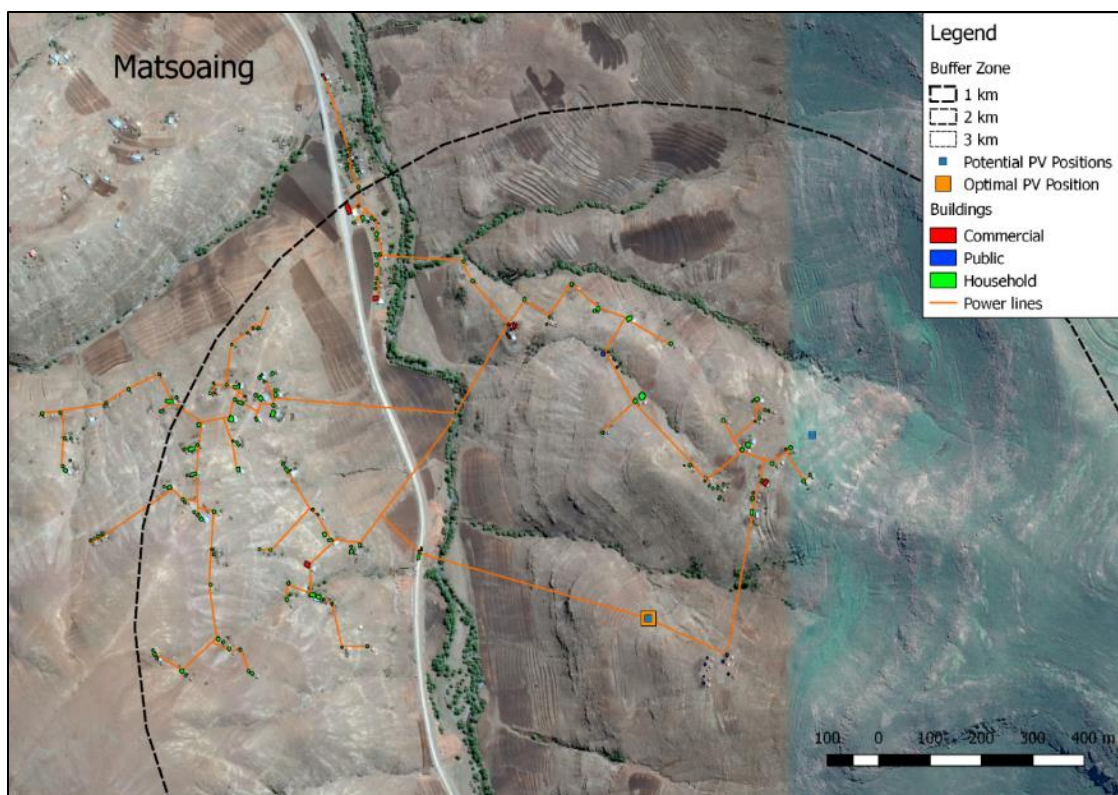
Figure 12: Satellite map of the mini-grid set-up in Matsoaing

For the long-term period (say, till 2030), additional power plant generation sites can be considered, including hydro power plants. The option with PV, storage and hydro is cited as a least-cost by

HOMER software. This indicates the need for commencement of more extensive research work to establish, among other things, river flow rates and conditions throughout the year to define hydro energy potential. Besides, in the long-term,say ten or so years from now, significant reductions in 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 15: Elements of mini-grid setup in Matsoaing in 2030

Element	Size	CAPEX (Maloti)	Replacement costs (Maloti)	OPEX (Maloti/year)
PV Power Plant	286 kW	4,833,400	0	55,770
Battery	730 kWh	2,847,000	11,388,000	94,900
Hydro Power Plant	100 kW	6,000,000	0	180,000
System converter	98.7 kW	256,620	256,620	0
Power lines	7.98 km	167,536	0	3,351
Power meters	106 units	338,949	0	6,779
Total	**-**	**14,443,505**	**11,644,620**	**8,520,000**

The expected growth of demand allows for lower generating costs in the future (Table). Moreso, we have not considered the fact that, due to technology advancements some elements to be added in the future will very likely lower specific CAPEX than it presently appears. 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. Alternatively, 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 16: Characteristics of mini-grid setup in Matsoaing in present and future

Time horizon	Unmet load, %	Excess electricity, %	LCOE, M/kWh
Present	2.10	46.3	10.364
2019	2.14	45.0	9.000
2030	2.20	71.1	7.324

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 us 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 calculations, 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, -16%.

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 M6,506,143 over 25 years, or M260,246 per year. Converted into electricity demand, the subvention need would be M2.77/kWh. Regarding allowance need in terms of customers, some M1,205 should be additionally paid per year for one customer.

The second scenario assumes a progressive increase in 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 to M20,205,986 over whole project lifetime, and M808,239 per year. Subvention need per kWh would be a little bit lower than in the first scenario (i,e M2.59/kWh). Due to significant annual increase of energy demand, allowance needs per customer would also increase to about M3,337 per customer per year.

3.4. Summary

Matsoaing is a middle-sized village with 200 households and some anchor loads. Current electricity demand is on the level of 25,000 kWh per year, of which about 66% is consumed by anchor customers, and 34% by households. This uneven distribution of shares in total energy consumption is not unique, but rather typical situation for settlements which at the moment do not have electrification. The commissioning of a mini-grid will cause this relation to change fundamentally. Residential customers will consume 70% of electricity delivered and public and commercial customers about 30%. Annual electricity demand will grow from 93,830 kWh in 2019 to approx. 381,800 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.These can be hydro power plants, and/oror wind mills. The decision would have to be made on the basis sufficient studies of the potential of various RE technologies in the region and relative costs of the technologies.

4. Tlhanyaku Mini-Grid

Tlhanyaku village (29°04'42.1"S 29°04'29.4"E) is located 38.1 km North of Mokhotlong town. The main rivers in this village are Tlhanyaku and Tsoinyane rivers and offer a good basis for mini-hydro development. The village is off the main roads.
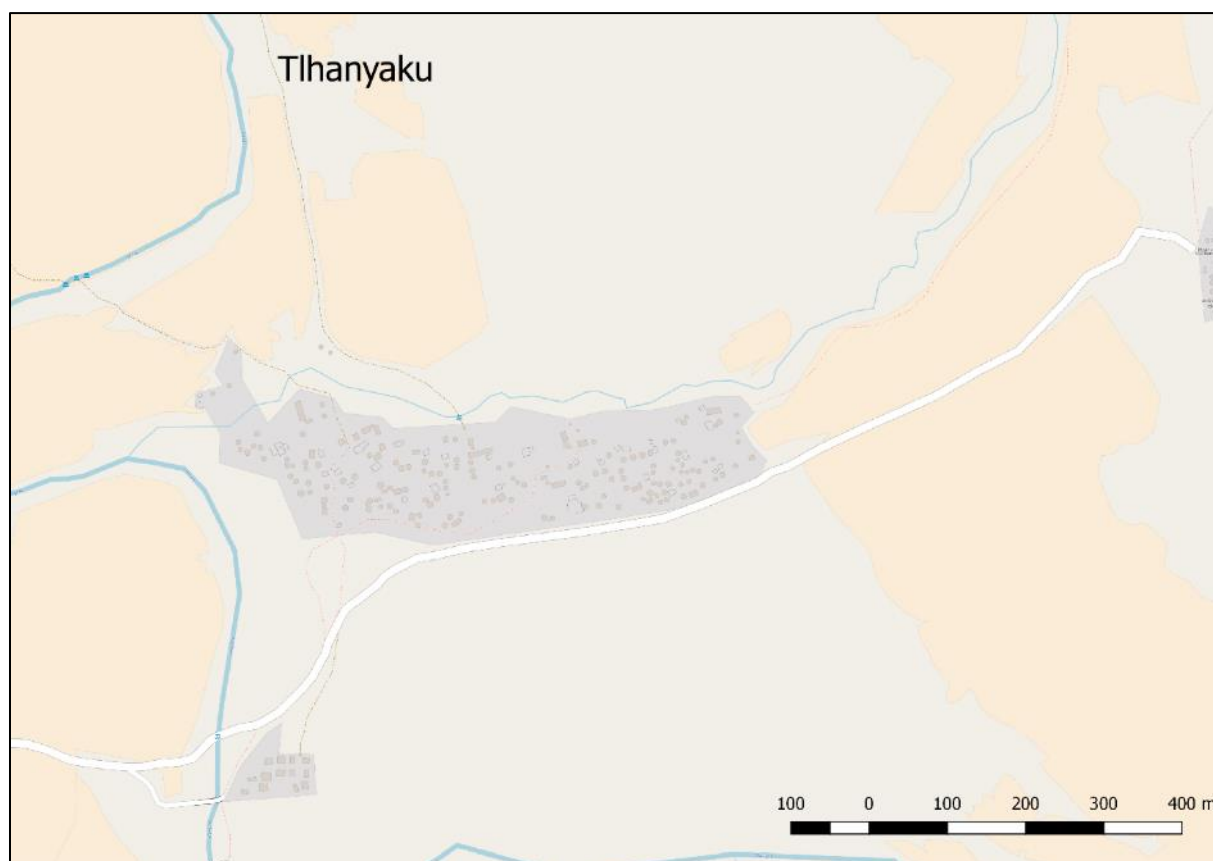
Figure 13: Map of Tlhanyaku

4.1. Customer Base

There are more than 200 households in Tlhanyaku. Potential anchor loads are a large clinic which currently runs on a 10 kVA diesel generator, hardware centre, ten medium-size shops, local chief's residence, two grain mills, woolshed and three churches. Apparently, this village has a relatively larger number of wealthy people compared to most villages in the district - as observed from modern housing structures and vehicles. Main income sources, in order of descending importance, are agriculture, medium-size retail shops, self-employment, income from clinic workers and airstrip. The major nearest service centre is Mokhotlong town which is 57 km away.

The main business activities in the area are retail shops. There are also two grain mills in the village centre, which run on diesel. All the institutions except two, i.e., the primary school and health centre, are situated around the village nucleus/centre. There are plans to open a secondary school.

Regarding electrification status of the villages, there is currently no electrification project in Tlhanyaku. The closest electrification project is the national grid (11 kV distribution line), which is

approximately ~55 km from the village. There are at least ten Solar Home Systems (SHS) in the village for private use. These installations are in the range of 5 – 100 W and are mostly for lighting, phone charging and entertainment. The public institutions with SHS are the health facility and the primary school. The telecommunication base transceiver station in the village has a hybrid system with wind and solar PV system.

4.1.1. Households

Socio-demographic characteristics

In this survey we interviewed ten households (HH) from the village. Most households interviewed in the survey have two to 11 members, (Q B1[2]). The average number of HH members is seven persons.

Households in Tlhanyaku have between one and six housing units, the average number of housing units is 3.2 (Q C1). The most common housing types are Rontabole (12) and Polata (8). There is also one Heisi and one Apartment/town house. The housing units have between one and six rooms. The average number of rooms is 1.9. The usable area size ranges from 20 to 150 m^2 per household. The average area size which one household has at its disposal, is 90 m^2.

Five out of ten households in Tlhanyaku earn M750 per month. Incomes range between M150 and M7,500. Eight households did not receive any remittances, one household receives less than M300 while another household receives between M10,000 and M29,999. So, the average earnings consisting of incomes plus remittances are M2,758per month per HH (Q C3-C4).

Energy supply

All HH in Tlhanyaku use fuel wood which is mostly purchased. Households spend between M200 and M2,500 per year and on average M550/year on fuel wood. Two HH collect fuel wood by themselves – they do not buy. Households use between 1 bundle (3 kg) and 3 trees (3,000 kg) fuel wood per year. The average amount of fuel wood is 1,039 kg/a, which is equivalent to 5,091 kWh/a. Six households also use animal waste, which is obtained by self-production (3) and/or collection (4). Households use between 0.5 and 48 bags of animal waste per year. On average 51 kg are used, which is an equivalent of 240 kWh/a. One household use half a bundle (2.5 kg) shrubs per year (Q D1).

Seven HH point out that they have an area to collect wood, while six say that they purchase the wood (Q D2-D3). Almost all respondents from Tlhanyaku indicate that they have to travel more than two hours to the edge of a main collecting area and back (Q D4) and more than two hours to actually collect the wood (Q D5), and they collect it for 1 to 8 times per month (Q D6). In sum, it results in time spent for travelling and collecting wood per year ranging between 57 and 576 hours,

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

and on average 189 hours/HH. Assuming an hourly wage of M8 this converts into annual costs of approx. M1,514/HH.

For mostly HH only men are involved (i.e., six HH) in wood collection activities; whereas in threeHH one woman goes to collect wood, and one HH additionally engages two children (Q D7).

For purchasing biomass six HH spend between M200 and M399 per month, two HH spend between M50 and M199 and one HH does not pay (Q D9). For the fuel, they all usually pay using cash (Q D10) and they indicate cash as the preferred method of payment too (Q D11).

Again, five HH use wood, while one HH uses LPG, ans another one HH uses animal dung and straw/shrubs/grass) as main energy sources for cooking (Q F1). Paraffin, wood, LPG, and animal dung are used as alternative sources, and are listed here in descending order of number ofHH using the specific alternate source.

Table 17: Household use of energy sources for cooking in Tlhanyaku

HH No.	Use of energy sources	Annual energy consumption	Annual expenses
1	Wood, 17 kg per day	30,405 kWh/a	M3,249/a
2	Straw, 0.5 bundles per day	4,471 kWh/a	M4,380/a
3	Wood, 1 tree per month Straw, 1 bundle per day Animal dung, 1 bag per week	68,476 kWh/a	M2,400/a
4	Paraffin, 10 litres per year Wood, many pieces Animal dung, 1 bag per week	837 kWh/a	M110/a
5	LPG, 0.15 kg per day Wood, 15 kg per day	27,528 kWh/a	M19,367/a
6	Wood, 5 kg per day Animal dung, 10 pieces per day	26,098 kWh/a	M3,650/a
7	LPG, 0.16 kg per day Wood, 15 kg per day	27,575 kWh/a	M19,407/a
8	Paraffin, 0.67 litres per day Wood, 10 kg per day Animal dung 40 pieces per day	89,036 kWh/a	M14,820/a
9	Wood, 1 bundle per month	176 kWh/a	0
10	Wood, 1 tree per month Animal dung, 1 bag per 3 days LPG 0.3 kg per day	61,917 kWh/a	M5,910/a
	Average	38,722 kWh/a	M10,526/a

The HHin Tlhanyaku are prepared to pay between M5 and M500/month for electricity for cooking-on average M104/month (Q F3, Table). None of the HH has a wonder box (Q F4).

All HH in Tlhanyaku heat their houses (Q G1). For space heating, all theHH use paola, and additionally some use gas heater, coal/wood stove, paraffin heater, fireplace (Q G2) and wood (7 HH) and straw (1 HH) as main energy source (Q G3). Paraffin and animal dung are used as an alternative energy sources for space heating.

Table 18: Household use of energy sources for space and water heating in Tlhanyaku

HH #	Use of energy sources per year	Annual energy consumption	Annual expenses
1	Paraffin, 29 litres per year	300 kWh/a	M319/a
2	Wood, 20 bundles per year	294 kWh/a	-
3	-	-	-
4	Wood, 10 bundles per year Animal dung, many pieces; paraffin, 7 litres per year	300 kWh/a	M770/a
5	Wood, 4 trees per year Animal dung, 1500 pieces per year	26,650 kWh/a	M400/a
6	Coal, 100 kg per year Wood, 100 pieces per year	1,360 kWh/a	M400/a
7	Coal, 100 Kg per year Wood, 2 trees per year Animal dung, 10 bags per year	10,811 kWh/a	M800/a
8	Wood, 2 trees per year Animal dung, 500 pieces per year; paraffin, 6 litres per year	12,212 kWh/a	M466/a
	Average	12,758 kWh/a	M517/a

As for willingness to pay, HH in Tlhanyaku are ready to pay between M2 and M300/month for electricity for space heating, and on average M81/month(Q G5, Table).

The heating area of interviewed HH lies between 30 and 265 m^2, with the majority (9 HH) having between 30 and 60 m^2 and an average of 38 m^2 (Q G6).

For water heating, the majority of HH use wood and straws as main energy source. As alternative sources, paraffin and animal dung are used (Q G7).

Of the interviewed HH, six use paraffin, two use solar lantern, and two use solar home system s for lighting (Q H1). As an alternative, five households in Tlhanyaku used candles, paraffin or solar lantern. On average, the HH spend M1,339/a, so the equivalent budget would be at least available for purchasing power for lighting purposes.

Table 19: Household use of energy sources for lighting in Tlhanyaku

HH No.	Annual use of energy sources	Annual energy consumption	Annual expenses
1	Rechargeable battery lamp, one unit of 1 W Paraffin, 5 litres per month	731 kWh/a	M660/a
2	Paraffin, 12 Litres per month	1,490 kWh/a	M1,584/a
3	Solar lantern Paraffin, 15 litres per month	1,865 kWh/a	M1,980/a
4	Candle, 1 piece per week Paraffin, 5 litres per month	699 kWh/a	M920/a
5	Solar lantern Paraffin, 2 litres per month	279 kWh/a	M264/a
6	Solar lantern, 2.5 W Paraffin, 10 litres per month	1,286 kWh/a	M1,320/a
7	Candle, 1 piece per week Paraffin, 7 litres per month	947 kWh/a	M156/a
8	Candle, 5 pieces per week Paraffin, 1.5 litres per month	576 kWh/a	M1,564/a
9	Candle, 24 pieces per month Paraffin, 22 litres per month	3,164 kWh/a	M3,360/a
10	Solar home system, paraffin, 12 litres per month	2,476 kWh/a	M1,584/a
	Average	1,351 kWh/a	M1,339/a

Two of the interviewed HH in Tlhanyaku use energy saver (compact florescent) light bulbs, 2 or 4 units for 2 to 6 hours per day. OneHH uses incandescent globes, 14 units, 3 hours per day. Two HH use light bulbs of other types, 5 units each of 10 W capacity (Q H3). So, HH in this village, as in Matsoaing, are very well equipped with lighting sources, which is characteristic for the Mokhotlong district, as we can observe.

The HH are ready to pay between M10 and M100/month for electricity for lighting, and on average M40/month. Realistic values lie between 1% and 11% of the month income respectively (Q H4, Table).

Four of the interviewed HH in Tlhanyaku use electrical appliances at home (Q E1); and they all generate their own electricity using solar panels (Q E2-E3). All the four HH use electricity for lighting, three of them also use it for phone charging, and one for ironing too (Q E6). For all that, all HH want electricity in their houses (Q E7).

As for future uses of electricity, all HH without exceptions want to use it for phone charging; nine HH also want it for cooking/re-heating, TV and lighting; eight for radio; five for refrigeration and water heating; three for space heating;and one for charging other than phone. Applications such as laundry, ironing, dishwashing, sewing, air-conditioning, computer, water pumping, workshop are picked out as not relevant uses (Q E8).

Table 20: Households desired future uses of electricity in Tlhanyaku, 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
Phone charging	X	X	X	X	X	X	X	X	X	X	10
TV	X	X	X	X	X	X		X	X	X	9
Lighting	X	X	X	X		X	X	X	X	X	9
Cooking/ re-heating	X	X	X	X	X	X	X		X	X	9
Radio		X	X	X	X	X	X	X		X	8
Water heating			X		X		X	X		X	5
Refrigeration			X			X	X	X		X	5
Space heating						X		X		X	3
Charging (other than phone)	X										1
Ironing											0
Sewing											0
Dishwashing											0
Air-conditioning											0
Computer											0
Water pumping											0
Workshop											0
Laundry											0
Total	5	5	7	5	5	7	6	7	4	8	-

Interviewed HH indicate high willingness to pay for electricity, with an expressed average of M204/month. Notably, Seven HH indicate willingness to pay amounts ranging M100 to M700 per month, which represents 1-67% of their month incomely (Q E9, Table).

With regard to preferred way of paying for electricity, six respondents from Tlhanyaku prefer cash,and two prefer Mpesa (Q E10).

Table 21: Ability and willingness to pay for electricity in general and for different applications of households in Tlhanyaku

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	M763	M50 (7 %)	M20 (3 %)	M20 (3 %)	M10 (1 %)	Electric stove, television (flat screen), electrical hair clipper, phone charger,
2	M750	M20 (3 %)	-	M20 (3 %)	M10 (1 %)	Refrigerator, electrical geyser, chest/deep freezer, electric stove, electric heater, washing machine, dishwasher, tumble dryer, hoover, hair dryer, television (CRT), television (flat screen), desktop computer, laptop, air conditioner, iron, electric kettle/element, bread maker, toaster, microwave, electrical pot, electrical hair clipper, phone charger,
3	M750	M20 (3 %)	M5 (1 %)	M2 (0 %)	-	Refrigerator, electrical geyser, electric stove, electric heater, television LCD, electric kettle/element, phone charger, other
4	M7,500	M550 (7 %)	M200 (3 %)	M200 (3 %)	M50 (1 %)	Refrigerator, television (flat screen),
5	M3,500	M700 (20 %)	M500 (14 %)	M300 (9 %)	M100 (3 %)	Refrigerator, electrical geyser, electric heater, television (flat screen), electric kettle/element, microwave, phone charger,
6	M750	M200 (27 %)	M100 (13 %)	M70 (9 %)	M50 (7 %)	Refrigerator, television LDC, microwave, phone charger,
7	M7,500	M100 (1 %)	M55 (1 %)	M50 (1 %)	M50 (1 %)	Refrigerator, television (flat screen), other
8	M750	M100 (13 %)	M60 (8 %)	M70 (9 %)	M30 (4 %)	Refrigerator, electric stove, television (flat screen), toaster, microwave, electrical hair clipper,
9	M150	M100 (67 %)	M50 (33 %)	M30 (20 %)	M16 (11 %)	Refrigerator, electric stove, television (flat screen), phone charger,
10	M5,167	M200 (4 %)	M50 (1 %)	M50 (1 %)	-	Refrigerator, electrical geyser, chest/deep freezer, electric stove, electric heater, washing machine, dishwasher, tumble dryer, hoover, hair dryer, television (CRT), television (flat screen), television LCD, desktop computer, laptop, air conditioner, iron, electric kettle/element, bread maker, toaster, microwave, electrical pot, electrical hair clipper, phone charger,
	Average	M204	M104	M81	M32	

With regard to settlement plans, two HH are planning to move away from the village in the next five years for better economic conditions or health reasons (Q I1-I2).

On plans to purchase electrical appliances in the next five years, nine HH want to obtain refrigerators; eight want TV flat-screens; seven want to obtain phone chargers, six want electric stoves, five microwaves; four want electric geysers, electric heaters, electric kettle/elements, and

electric hair clippers; three households plan to buy TV LCD, toaster; and two HH want to buy chest/deep freezer, washing machine, dishwasher, tumble dryer, hoover, TV CRT, desktop computer, laptop, air-conditioner, iron, bread maker, electric pot (Q I3). In some cases, these purchasing desires do not seem quite realistic, since two HH from the sample are planning to buy all electrical appliances from the list.

Seven HH want to buy solar PV in the next five years, six want to buy car battery, and two plan to buy generator running on gas (Q I4).

Energy demand forecast

Notably, all the HH in Tlhanyaku, who have solar panels and already using electrical appliances, belong to the affluent type, while other interviewed HH belong to either basic or medium class type, based on income levels. Considering 200 households living in the village and 1% growth rate of the HH number per year, we estimated present and future energy demand (Table 22).

Table 22: Present and future power demand by households in Tlhanyaku

Household type	No. of HH in Tlhanyaku			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

In Tlhanyaku five anchor customers were interviewed: health centre and four commercial users (three food retail facilities and one café) (Q B1). All commercial facilities are under individual ownership, and the health centre is a state institution (Q B2). The health centre has 28 employees and the individual commercial facilities have two to three workers (Q B3).

The earnings per month range from M750 to M7,500 for the commercial users (Q B5-B6).

Energy supply

Health centre consumed hard coal (4,000 kg) and wood (2,500 kg) energy sources over the last year which is equivalent to 47,050 kWh. The energy resources were used for space and water heating. At the same time, commercial users used fuel wood in the range of 25-45 kg for water and space heating as well as cooking and expended between M200-M600 per year. Café additionally used 40 kg of animal dung for water heating (Q C1).

Commercial retailers use cash to pay for energy sources (Q C2).

Four of the five interviewed customers (health centre and three food retailers) used solar electricity last year. All of them have capacities ranging 100 to 120 watts (solar panel). Solar energy was used on 50 % of days for lighting and phone charging (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 it (Q C4, Q C5). At the same time, almost all users perceive electricity as expensive (Q C6).

Respondents stated that their respective companies /institution s are ready to pay between M100 and M400 per month (on average M220/month) for electricity, whichamounts to a share of their monthly incomes of 2-4%, except in one case where it goes to 27% of the income (Q C7). Anchor customers in Tlhanyaku would prefer to pay for electricity by cash, via mobile phone or credit card (Q C8).

Most anchor customers work seven days a week (Q D1). Four commercial users operate between 9 and 10 hours per day, for 6 or seven days a week over the whole year, the health centre operates for 10 hours every day, throughout the year (Q D2, Q D3).

The individual anchor customers in Tlhanyaku have between one and 14 buildings at their disposal; with the health centre having the highest number of buildings, and commercial users having one to five buildings (Q D4). All buildings were constructed in the period of 1996-2015. The total building area ranges from 80 m² to 750 m² among commercial facilities, while the building area for the health centre is 10,000 m². Four customers heat their buildings, and two of them also cool their buildings. None of the buildings are insulated (Q D5).

No air-conditioning systems were in use by the interviewed anchor customers (Q D6). Three commercial retailers use four units or 45 kg wood for heating systems which operate four to five months a year, for between three and ten hours per day. Also LPG was used for heating by the health centre, consuming more than 100 kg over the whole year. Also paraffin was in use by three anchor customers (health centre and two retailers).Between 20 and 200+ (health centre) litres are used over two months or the whole year, for 3-10 hours per day (Q D7). No independent heating or cooling system are used (Q D8).

Anchor customers are willing to pay between M100 and M600/month for electricity for heating/cooling, or on average M340/month, which corresponds to 3-13% share of their monthly incomes (Q D9, Table).

Four companies (health centre and three commercial facilities) use any type of light bulbs. Three customers have energy savers: 40 units of 11 W (health centre), one or two units of 30 or 40 W (commercial users). Also solar lamps are used by one customer: two units of 30 W (Q D10). There are no light or motion sensor controls for operating the lighting in service area (Q D11-D12). Anchor customers are ready to pay between M40 and M200/month (i.e., 0.5% to 7% of their income per month) for electricity for lighting (Q D13, Table).

As for small equipment like desktops, monitors, laptops, servers, printers, or household appliances, the health centre is equipped with six laptops and one printer. One retailer owns a till machine (Q D14).

The only institution among anchor customers in Tlhanyaku (i.e., the health centre), has some cooking facilities (Q D15); and uses LPG as an energy source (Q D16). All respondents are ready to pay for electricity for cooking and their indicated amounts range between M10 and M60 per month, and M34/month on average (Q D17, Table).

Two anchor customers, health centre and one food retailer, have refrigerating equipment at their facilities (Q D18). They both have one refrigerator of 160 litres each (Q D19).

Anchor customers are willing to pay between M200 and M400 per month, or M290 on average (4-27% of their month income) for electricity for refrigeration (Q D20, Table).

Four anchor customers, health centre and three commercial users, generate electricity with their solar panels (Q E1).The health centre has 26 panels of 500 W capacity, and commercial users have one panel each of 100-120 W, and use electricity for lighting and phone charging. Panels operate for 3 - 12 hours per day all year long (Q E2). Three anchor customers (health centre and two commercial retailers) also use generators (capacity - 850 kW/unit) to generate electricity for heating and lighting; using diesel 50ppm and unleaded petrol fuels. The generators run for 3 - 10 hours per day for 6 - 25 days/month, and over 1 to 12 months in a year (Q E4).

Table 23: Ability and willingness to pay for electricity in general and for different applications of anchor customers in Tlhanyaku

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
Tlhanyaku Clinic	NA	M500	M100	M20	M300	M920	NA
Tlhanyaku Cafe	M750	M100	M50	M50	M200	M400	53%
Tlhanyaku Store	M7,500	M400	M40	M30	M300	M770	10%
Senqu River	M7,500	M600	M200	M10	M400	M1,210	16%
Miller	M3,500	M100	M100	M60	M250	M510	15%
Total	M19,250	M1,700	M490	M170	M1,450	M3,810	-

One anchor customer is planning to replace some units in the next five years (Q F1) with gas fridge (Q F2). All interviewed customers want to install new energy consuming systems or technologies such as: refrigerators, cash tills, lights, cameras, bar code scanners, sewing machines (Q F4-F5). They think this action will increase their energy consumption (Q F3).

Four anchor customers are planning to buy a solar PV systems, three anchor customers are planning to buy generators, and two customers plan to buy car battery in the next five years (Q F9). Two customers want to buy all of the three electrical sources.

Three interviewed anchor customers want to replace light bulbs with CFL or replace windows, two want to fit a ceiling, and one anchor customer want to insulate the walls (Q F10).

Energy demand forecast

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

Table 24: Future power demand of anchor customers in Tlhanyaku

Type	No. of institutions	Power demand, kWh/year	
		2019	2030
Health	1	5,600	11,200
School	1	500	3,500
Government	1	1,600	3,200
Retail	11	25,090	75,270
Craft	3	150	750
Total		**32,940**	**93,920**

Table 25: Main characteristics of anchor customers in Tlhanyaku

#	Name	Type	Size	Operation hours	Electrical equipment	Annual power demand	Present power supply	Willingness to pay[3], Maloti/month
1	Tlhanyaku Clinic	**Health**	28 employees; 14 buildings, area 10,000 m^2	10 h/day, 7 days/week, 12 months/year	Energy saver bulbs, 40 units of 11 W, 1 refrigerator (160 litres), 6 laptops, 1 printer	3,548 kWh	26 solar panels of 500 W; 1 generator	920
2	Tlhanyaku Cafe	**Retail**	2 employees; 3 buildings, area 80 m^2	9 h/day, 6 days/week, 12 months/year	None	0	1 generator	400
3	Tlhanyaku Store	**Retail**	3 employees; 5 buildings, area 120 m^2	10 h/day, 7 days/week, 12 months/year	Solar lamps, 2 units of 30 W	219 kWh	1 solar panel of 100 W	770
4	Senqu Store	**Retail**	2 employees; 2 buildings, area 750 m^2	10 h/day, 7 days/week, 12 months/year	Energy saver bulbs, 1 unit of 30 W, 1 refrigerator (160 litres), till machine	1,033 kWh	1 solar panel of 120 W; 1 generator of 850 kW	1,210
5	Miller	**Retail**	3 employees; 1 building, area 120 m^2	9.5 h/day, 6 days/week, 12 months/year	Energy saver bulbs, 2 units of 40 W	237 kWh	1 solar panel of 100 W	510
					Total	5,037		3,810

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[3] 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 .

Table 26: Development of power demand in Tlhanyaku 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	3.4	0.0	0.0	3.4	26.3	0.0	0.0	26.3	109.8	0.0	0.0	109.8
Anchor customers	22.6	0.0	0.0	22.6	31.5	0.0	0.0	31.5	62.0	0.0	0.0	62.0
Total	26.0	0.0	0.0	**26.0**	57.7	0.0	0.0	**57.7**	171.7	0.0	0.0	**171.7**

4.2. Set-up for Mini-Grid

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

In the case of low current demand, the solution made of solar power plant and battery storage seems to be the best. The values of unmet load and excess electricity are within the acceptable realms (about 2% and 49% respectively). Capacity of battery storage should exceed maximum hourly output of solar panels by about 3 times, but this ratio is highly dependent on relative costs of solar panels and battery. With the demand growth in the long-term perspective, till 2030, it will be necessary to consider further energy sources like hydro power plants.

**Table 27: Elements of mini-grid setup in Tlhanyaku in present conditions**

Element	Size	CAPEX (Maloti)	Replacement costs (Maloti)	OPEX (Maloti/year)
PV Power Plant	35.6 kW	601,640	0	6,942
Battery	95 kWh	370,500	1,482,000	12,350
System converter	9.08 kW	23,608	23,608	0
Power lines	3.18 km	66,759	0	1,335
Power meters	89 units	284,800	0	5,696
Total	**-**	**1,347,307**	**1,505,608**	**658,075**

Assuming the increased energy demand in 2019, the most optimal and least-cost solution still remains PV in combination with battery storage. The set-up remains rather the same, only the sizes of all elements increase substantially, leading to more than threefold higher investment need.

Table 28: Elements of mini-grid setup in Tlhanyaku in 2019

Element	Size	CAPEX (Maloti)	Replacement costs (Maloti)	OPEX (Maloti/year)
PV Power Plant	129 kW	2,180,100	0	25,155
Battery	352 kWh	1,372,800	5,491,200	45,760
System converter	38.9 kW	101,140	101,140	0
Power lines	3.21 km	67,427	0	1,349
Power meters	90 units	287,648	0	5,753
Total	**-**	**4,009,115**	**5,592,340**	**1,950,400**

Figure 14 shows the distribution of capital costs between different components of a mini-grid. It can be noticed that power grid components (lines and meters) amount to a significant share of about 10% of the capital costs.
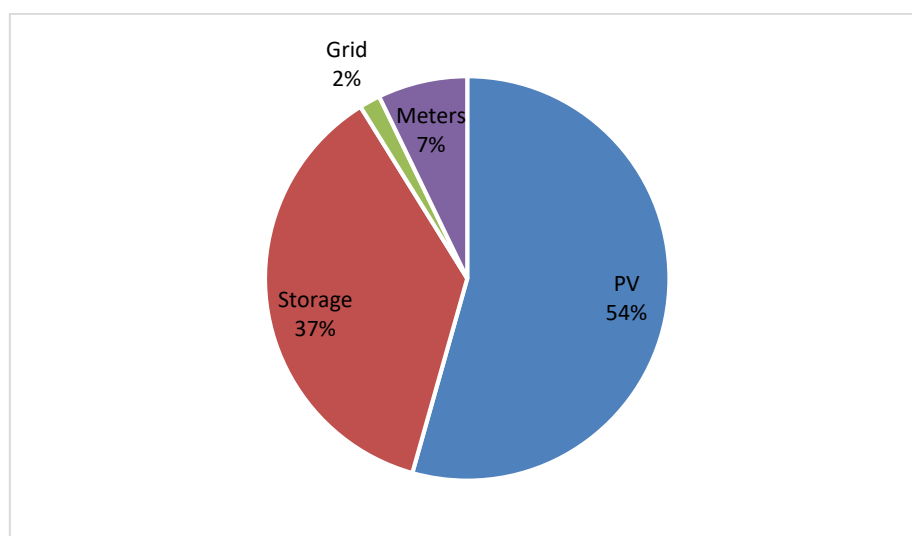

Figure 14: Distribution of capital costs of a mini-grid in Tlhanyaku in 2019

For the location of the mini- grid, three feasible sites were initially identified. Two of the sites (marked blue on Figure 15), were dim as competitive according to physical criteria like direction to the sun, area size and availability of space. However, the yellow marked location turned out to be the optimal site according to the calculation algorithm of the geometrical mean of all buildings in the radius 1-3 km in the village. It is the location that has the minimum sum of distances to all existing potential residential, public and business customers. In the case of Tlhanyaku the theoretically chosen potential site for a mini-grid coincided with the site chosen as a result of field research. This most suitable site is presented on the following map (Fig. 17) as two squares, blue and yellow, inscribed in each other.
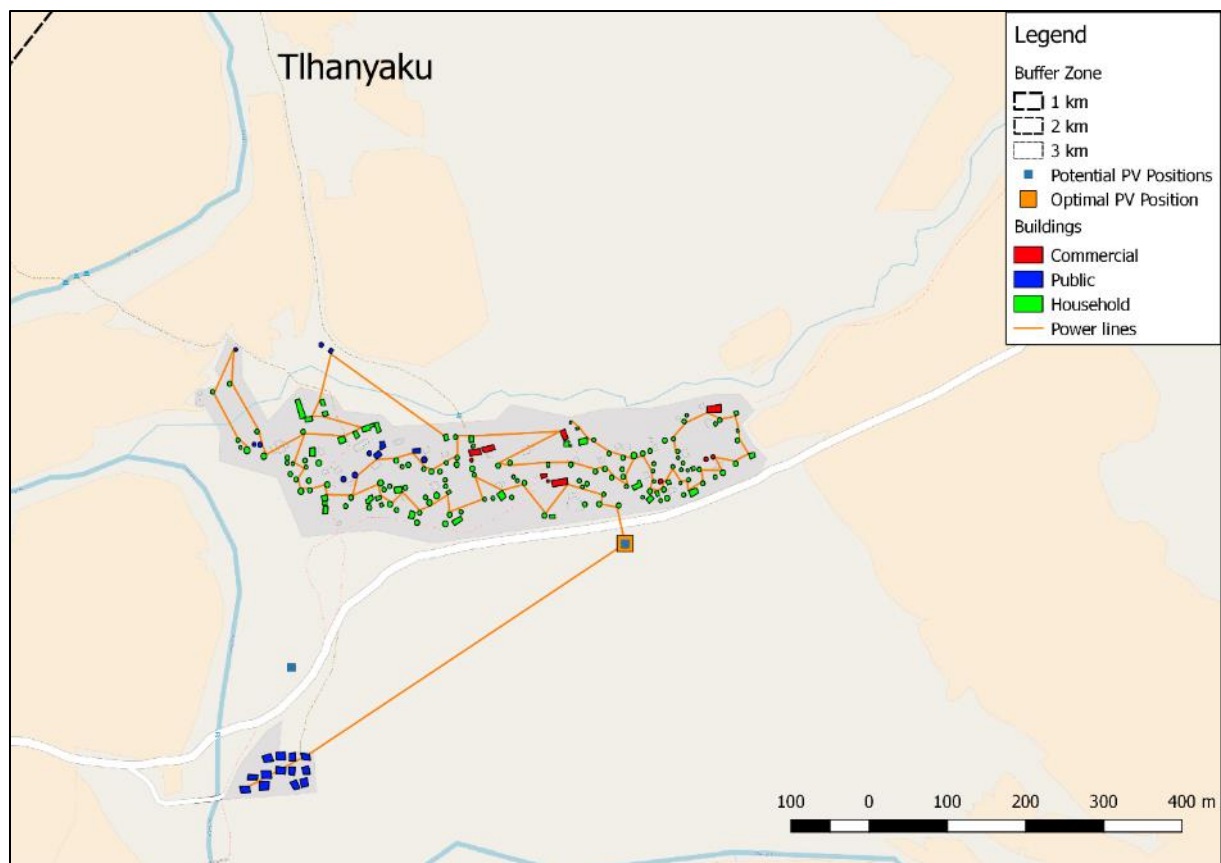
Figure 15: Map of the mini-grid set-up in Tlhanyaku
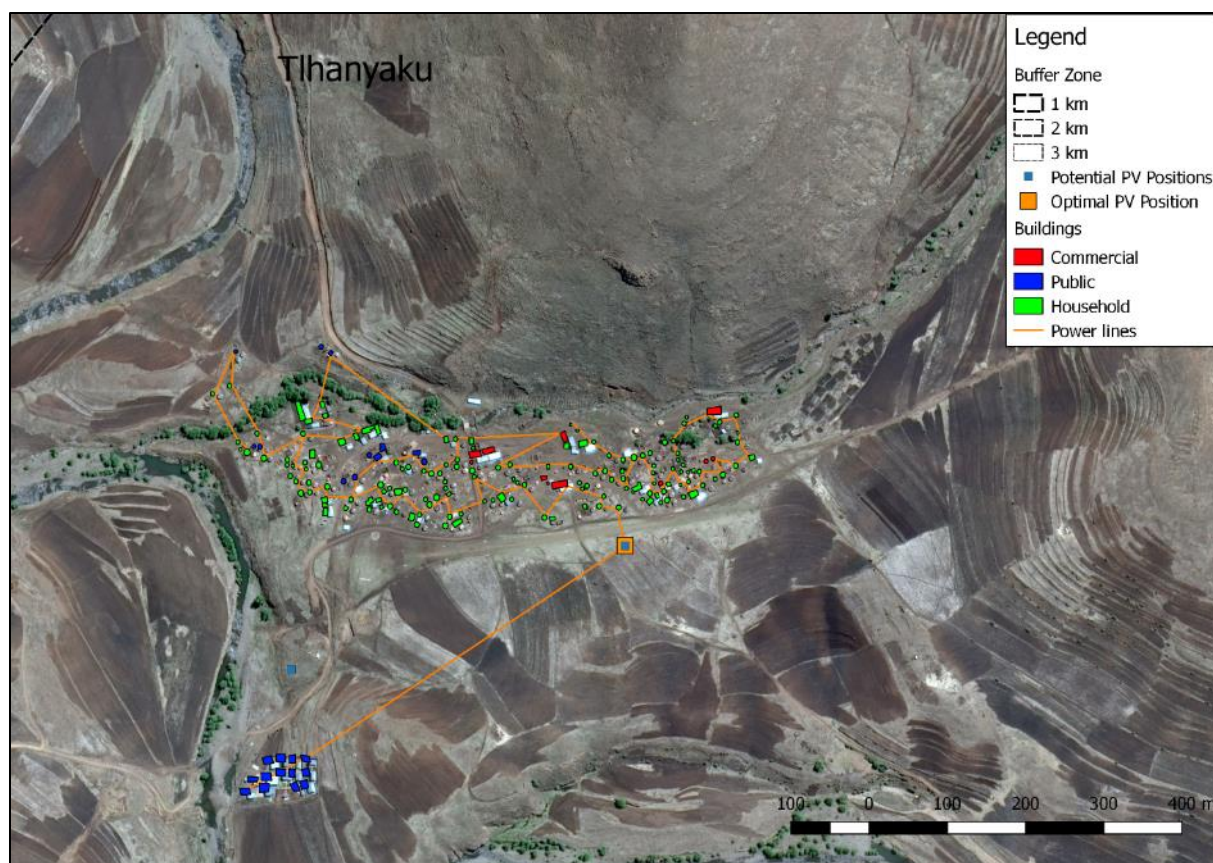
Figure 16: Satellite map of the mini-grid set-up in Tlhanyaku

Assuming power demand increase in the long-term (i.e., till 2030), the HOMER offers solution combining solar PV, storage and hydro power as an option with the lowest levelized cost of electricity (LCOE). Hence, it is recommended that extensive research to establish river flow rates and conditions throughout the year to define hydro energy potential be carried out sooner than later. Besides, in the long-term, say ten or so years from now, further reductions in solar PV and battery costs are foreseen, whereas hydropower costs would most probably remain the same given that the technology is already well-advanced, and the cost reduction potential is almost exhausted.

Table 29: Elements of mini-grid setup in Tlhanyaku in 2030

Element	Size	CAPEX (Maloti)	Replacement costs (Maloti)	OPEX (Maloti/year)
PV Power Plant	291 kW	4,917,900	0	56,745
Battery	696 kWh	2,714,400	10,857,600	90,480
Hydro Power Plant	100 kW	6,000,000	0	180,000
System converter	153 kW	397,800	397,800	0
Power lines	3.58 km	75,226	0	1,505
Power meters	100 units	320,920	0	6,418
Total	**-**	**14,426,245**	**11,255,400**	**8,378,700**

The expected growth of demand allows for lower generating costs in the future (Table). Moreso. we have not considered, the high likelihood that due to technology advancements some elements to be added in the future will have significantly lower specific CAPEX than presently. It is also

critical to note that, there is a high rate of excess power associated with a generation system which is entirely based on renewable energies. This waste of energy could be avoided in two ways. Firstly, one may 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, additional seasonal usage of the excess power can be created, e.g. refrigeration and cooling which both would perfectly match the generation patterns of solar generation.

Table 30: Characteristics of mini-grid setup in Tlhanyaku in present and future

Time horizon	Unmet load, %	Excess electricity, %	LCOE, M/kWh
Present	2.10	48.5	9.961
2019	2.10	48.2	8.985
2030	2.30	69.7	6.908

4.3. Economic Viability

We calculated the internal rate of return (IRR) with revenues on the basis of the present national electricity tariffs. This calculation allows us 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. To assess economic viability, we used two scenarios of electricity demand changes. 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, -17%. 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 M6,784,677 over 25 years, or M271,387 per year. Converted into electricity demand, the subvention need would be M2.76/kWh. Regarding allowance need in terms of customers, an amount of M1,239/year would need to be additionally paid for each customer.

The second scenario foresees the constant 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 M18,735,820 over whole project lifetime, and M749,433 per year. Subvention need per kWh would be a little bit lower than in the first scenario; at about M2.29/kWh. Due to significant annual increase of energy demand, allowance needs per customer would also increase, accounting for M3,056 per customer per year.

4.4. Summary

Tlhanyaku is a middle-sized village with a moderate number of households and some anchor loads. Current electricity demand accounts for about 27,000 kWh per year, where about 70% is consumed by anchor customers, and 30% by households. This uneven distribution of shares in total energy consumption is a rather typical situation for settlements which are not electrified at

the moment. The commissioning of a mini-grid will cause this relation to change fundamentally. Residential customers will consume about 67% of electricity delivered and public and commercial customers about 33% in 2019. Annual electricity demand will increase from 98,400 kWh in 2019 to approx. 399,400 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 thorough studies of the economic and technical potential of these RE technologies in the region and the developments in relative costs of the technologies.

5. Linakaneng Energy Centre

Linakaneng (29°29'13.0"S 28°55'49.9"E) is a village situated 42.5 km South West of Mokhotlong town and it has Linakaneng River as its main river. It has an elevation of 2,977 m and it had total population of 4,452 in 2006. It is located about 2 km to the A3 main road. The community of Linakaneng includes the villages of Boiketlo, Boinyatso, Chesalaene, Ha Matjota, Ha Moepanyane, Ha Mosollane, Ha Polaki, Ha Sekoti, Ha Soai, Khorong, Khubetsoana, Likotjaneng, Makula-Peea, Manganeng, Mankeng, Maphatsing, Meeling, Mohloaing, Mokotleng, Moreneng, Mothating, Motse-Mocha, Motsitseng, Nokeng, Rosemane, Sekokong, Tlohang and Tsatsanyane.

Figure 17: Map of Linakaneng

5.1. Customer Base

According to the chief of Linakaneng, three main income sources in the village are livestock, crops and private businesses. The administrative centre is Thaba-Tseka, which is 71 km away and can be reached in three hours of driving.

5.1.1. Households

Energy demand forecast

There are approximately 450 households who live in In Linakaneng. We calculated an energy demand forecast as described in the General report. 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 31: Present and future power demand by households in Linakaneng

Household type	No. of HH in Linakaneng	Total power demand, kWh/year	
		Present	**2019**
Basic	293	0	3,810
Medium	113	5,650	8,250
Affluent	45	13,500	0
Total	**450**	**19,150**	**12,060**

5.1.2. Anchor customers

Main characteristics

According to the interviewed chief of the village, Linakaneng village has is one health centre with health staff houses, one primary school, one church, craft shop, some grocery shops, and a barber shop. In the survey, we interviewed personnel at the health centre, a local court, two retailers and one metalworking shop (Q B1). It came out that, three commercial facilities are in individual ownership, while the health centre and court are government institutions (Q B2). The number of employees by commercial entities is 1 to 2 workers, the health centre employs 21 people, and the local court has 8 workers (Q B3).

The earnings per month among commercial users are between M750 and M3,500 (Q B5-B6).

Energy supply

Four interviewed anchor customers gave information relating to sources, amounts and costs of energy consumed over the last year. Three of them used hard coal for space and water heating, one retailer consumed 100 kg of coal at total cost of M200. Two anchor customers used some amounts of wood for space and water heating. One customer additionally used paraffin for space heating, at a total cost of M1,200 for 100 litres (Q C1).

The commercial users pay for energy sources in cash, while government pays the energy bills for state institutions (health centre and local court) (Q C2).

All interviewed anchor customers used solar electricity last year. Commercial users have capacities of 3.5, 60 or 80 W (solar panel). The solar electricity was used for lighting, phone charging (four respondents), and music (one respondent) (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 it (Q C4, Q C5). At the same time, two users (health centre and local court) suppose electricity is expensive (Q C6).

Commercial users stated that their respective companies/institutions are ready to pay between M100 and M2,000 per month for electricity, which represents a share of their monthly income of 13-57% (Q C7).

Preferred methods of paying for the electricity are via the mobile phone or cash (Q C8).

Most anchor customers work seven days a week, except the local court (5 days/week) and the metalworking shop (6 days/week) (Q D1). Commercial users operate between 9 - 13 hr/day over the whole year; the health centre - 8 r/ day; and the court - 8.5 hr/day (Q D2, Q D3).

The commercial customers have between one to three buildings at their disposal, while the health centre has 11 buildings, and the local court has five buildings (Q D4). The total building area ranges from 12 m² to 28 m² among commercial facilities. Local court has a total building area of 30,000 m², health centre has 1,500 m². None of the buildings are insulated (Q D5).

No air conditioning systems are in use by the interviewed anchor customers (Q D6). Two customers (health centre and local court) have a heating system running on LPG, which operate 8 – 8.5 hours per day for all days of operation of the respective institution. The court used 48 kg of LPG for heating over the last year. Besides, three coal and one paraffin heating systems were in operation throughout the year, the whole operation time of the companies using them; and 100 kg of coal and 100 litres of paraffin were used (Q D7). No independent heating or cooling systems were used last year (Q D8).

Three anchor customers (all commercial facilities) are willing to pay between M100-M200/month for electricity for heating/cooling; which corresponds to 6-13% share of their monthly incomes (Q D9, Table Table).

All interviewed companies use any type of light bulbs. The health centre uses three incandescent light bulbs of 60 W and 40 energy saver bulbs of 11 W. The local court has eight solar lamps in operation. Food retailers have three incandescent light bulbs or three LED lights of 10 W capacity. Metalworking shop uses one solar lamp of 3.5 W (Q D10). There are no light or motion sensor controls for operating the lighting in service area (Q D11-D12). Only commercial customers are ready to pay for electricity for lighting - between M100 and M200 (3-13% of their income per month) (Q D13, Table).

As for small equipment like desktops, monitors, laptops, servers, printers, or household appliances, commercial users have radios, inventors, and a drill machine which operates for the whole working day (Q D14).

Only one institution, among the anchor customers in Linakaneng, the clinic, has cooking facilities (Q D15). The clinic uses LPG as an energy source for the cooking facility (Q D16). Only three respondents (commercial users) are ready to pay for electricity for cooking. The level of willingness to pay ranges between M50 and M250 per month, translating to 7-10% of their monthly income (Q D17, Table).

Three customers (health centre and two commercial users) have refrigerating equipment at their facilities (Q D18). Health centre has two refrigerators, a food retailer and the metalworking shop have one refrigerator each (Q D19). Three anchor customers (commercial customers) are willing to pay for electricity for refrigeration, at the rate of M50-M100 per month (3-7% of their month income) (Q D20, Table).

Four anchor customers (health centre, local court, food retailer and metalworking shop) generate electricity from their individual solar panels (Q E1), with 1-4 panels of 3.5 to 120 W, and use the electricity for phone charging and lighting. The panels operate for 2-24 hours per day all year long (Q E2). The metalworking shop also uses two generators to generate electricity and/or heat (capacity 5 and 6.9 kW), fuelled by unleaded petrol. The generators are in use throughout the whole operation time of the shop and all year round (Q E4).

Table 32: Ability and willingness to pay for electricity in general and for different applications of anchor customers in Linakaneng

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
Linakaneng Clinic	N/A	N/A	N/A	N/A	N/A	N/A	-
Thaba Ntsho local court	N/A	N/A	N/A	N/A	N/A	N/A	-
Lebo's Fruit and Feg	M1,500	M200	M200	M150	M100	M650	43%
Rantekoa Cafe	M3,500	M200	M100	M250	M100	M650	19%
Spaza Shop	M750	M100	M100	M50	M50	M300	40%
Total	M5,750	M500	M400	M450	M250	M1,600	-

Two anchor customers are planning to replace some units by other units: they want to replace production unit and battery. They think it will increase their energy consumption (Q F1-F3). Four customers want to install new energy consuming systems or technologies in the next five years: health centre want to install laptops and refrigerators; local court want to install computers, electric heaters and a geyser; and commercial users plan to install refrigerators, electric heaters, or advanced technology for carpentry (Q F4-F5). Besides, four anchor customers would like to switch to electricity. Metalworking shop plans to increase a level of production (Q F6-F7).

Two anchor customers want to obtain a PV in the next five years, two want to buy generators and one wants a car battery. The local court wants to buy all these energy sources (Q F9). Some anchor customers are planning to upgrade their buildings by replacing light bulbs with CFL, installing solar water heaters, and fitting ceilings (Q F10).

Energy demand forecast

Present power demand and supply of anchor customers in Linakaneng are summarized in the Table . Future power demand of all anchor customers in the village, including non-interviewed ones, is presented in the Table 7. We derived the forecast for power demand of anchor customer on the results of the entire survey. However, only the school and crafts 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, most of the other customer types already have own generation facilities.

Table 33: Main characteristics of anchor customers in Linakaneng

#	Name	Type	Size	Operation hours	Electrical equipment	Annual power demand	Present power supply	Willingness to pay[4], Maloti/month
1	Linakaneng Clinic	**Health**	21 employees; 11 buildings, area 1,500 m^2	8 h/day, 7 days/week, 12 months/year	2 refrigerators (160 litres); 3 incandescent bulbs of 60 W, 40 energy saver of 11 W	3,562 kWh	Solar panel	NA
2	Taba ntsho local court	**Government**	8 employees; 5 buildings, area 30,000 m^2	8.5 h/day, 5 days/week, 12 months/year	8 solar lamps	442 kWh	4 solar panels of 120 W	NA
3	Lebo's fruit and Feg	**Retail**	2 employees; 2 buildings, area 24 m^2	10 h/day, 7 days/week, 12 months/year	1 refrigerator (300 litres); 3 LED lights of 10 W; radio	3,205 kWh	2 solar panels of 40 and 60 W	650
4	Spaza shop	**Retail**	1 employee; 1 building, area 28 m^2	13 h/day, 7 days/week, 12 months/year	3 incandescent bulbs, radio, inventor	892 kWh	1 solar panel of 80 W	300
5	Rantekoa café	**Craft**	2 employees; 3 buildings, area 12 m^2	9 h/day, 6 days/week, 12 months/year	1 refrigerator (160 litres); 1 solar lamp of 3.5 W; drill machine	1,601 kWh	1 solar panel of 3.5 W, 2 generators of 5 and 6.9 kW	650
					Total	9,702 kWh		1,600

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

Table 7: Present and future power demand of anchor customers in Linakaneng

| Type	Number of institutions	Power demand, kWh/year	
		Present	**2019**
Health	1	3,562	3,562
School	1	0	500
Government	1	442	442
Retail	5	9,497	9,497
Craft	2	1,601	1,701
Total		**15,100**	**15,700**

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

Table 35: Development of power demand in Linakaneng 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	2.1	0.0	0.0	2.1	2.7	0.0	0.0	2.7	67.8	0.0	0.0	67.8
Anchor customers	8.0	0.0	0.0	8.0	8.1	0.0	0.0	8.1	25.4	0.0	0.0	25.4
Total	10.1	0.0	0.0	**10.1**	10.8	0.0	0.0	**10.8**	93.2	0.0	0.0	**93.2**

5.2. Set-up for Energy Centre

For the Energy Centre two feasible sites were initially identified – one marked blue and the other marked yellow in Figure 20 - which both meet the physical criteria like direction to the sun, size of area and availability of space. The yellow marked location is the optimal site as 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 Linakaneng 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 (Fig. 20) as two squares, blue and yellow, inscribed in each other.
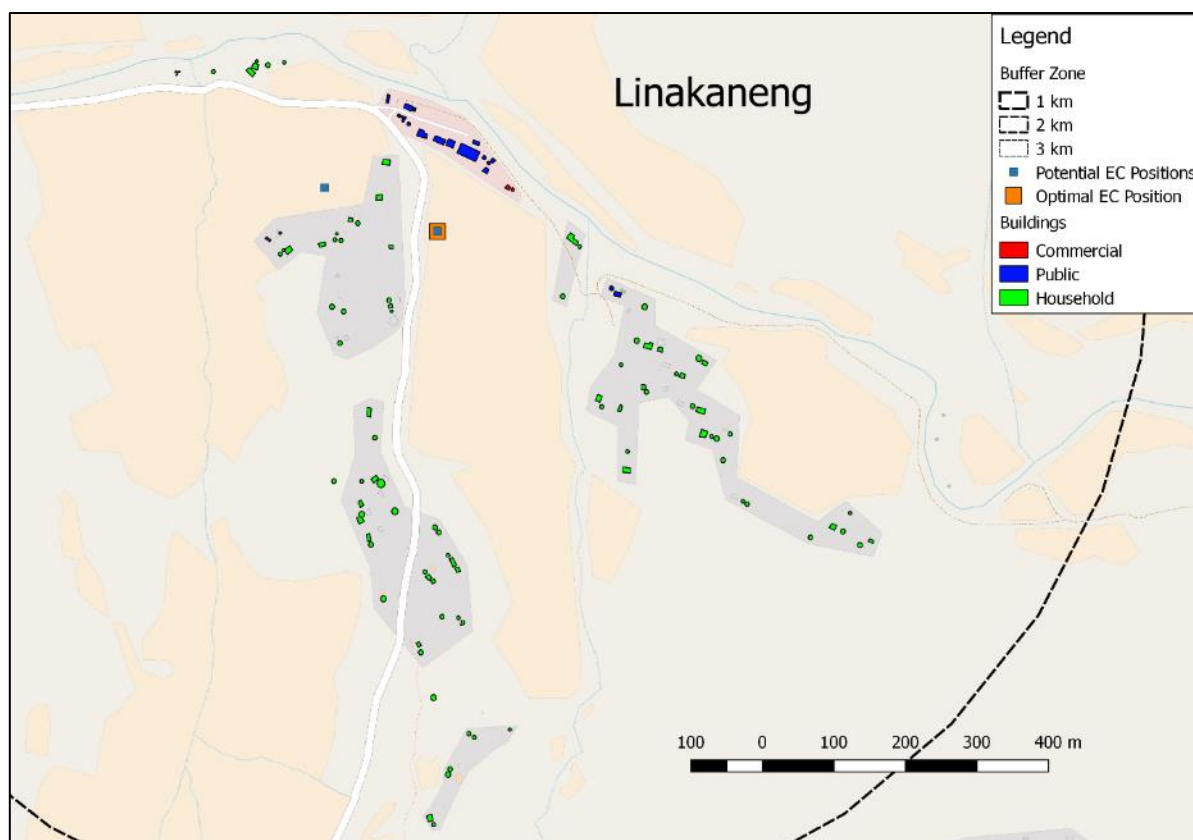
Figure 18: Spatial distribution of customers and positions of energy center in Linakaneng

5.3. Economic Viability

Linakaneng is a large village with high number of households living in there (~450 HH) and some anchor loads. Correspondingly, the village needs a large-sized energy centre. Table depicts main characteristics and financials of the proposed energy centre in Linakaneng, including initial investment, annual expenditure, replacement costs (due every five years) as well as residual value after 10 years of operation.

In order to supply energy needs of households, business and public customers in Linakaneng as well as to cover the electricity demand for the services provided through the centre, a solar power plant of 23 kW with battery storage facility of 55 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 19). Even though most of the equipment and the building will not be worn out after the 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. a year before start of operation, for purposes of calculations, and certain elements like vehicles and inverters need to be replaced after every 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 turns out to be negative, -M97,319, i.e. the energy centre is not economically feasible under these conditions. On the basis of financial indicators, the operation of an energy centre of such size in Linakaneng is not as profitable as in the other villages.
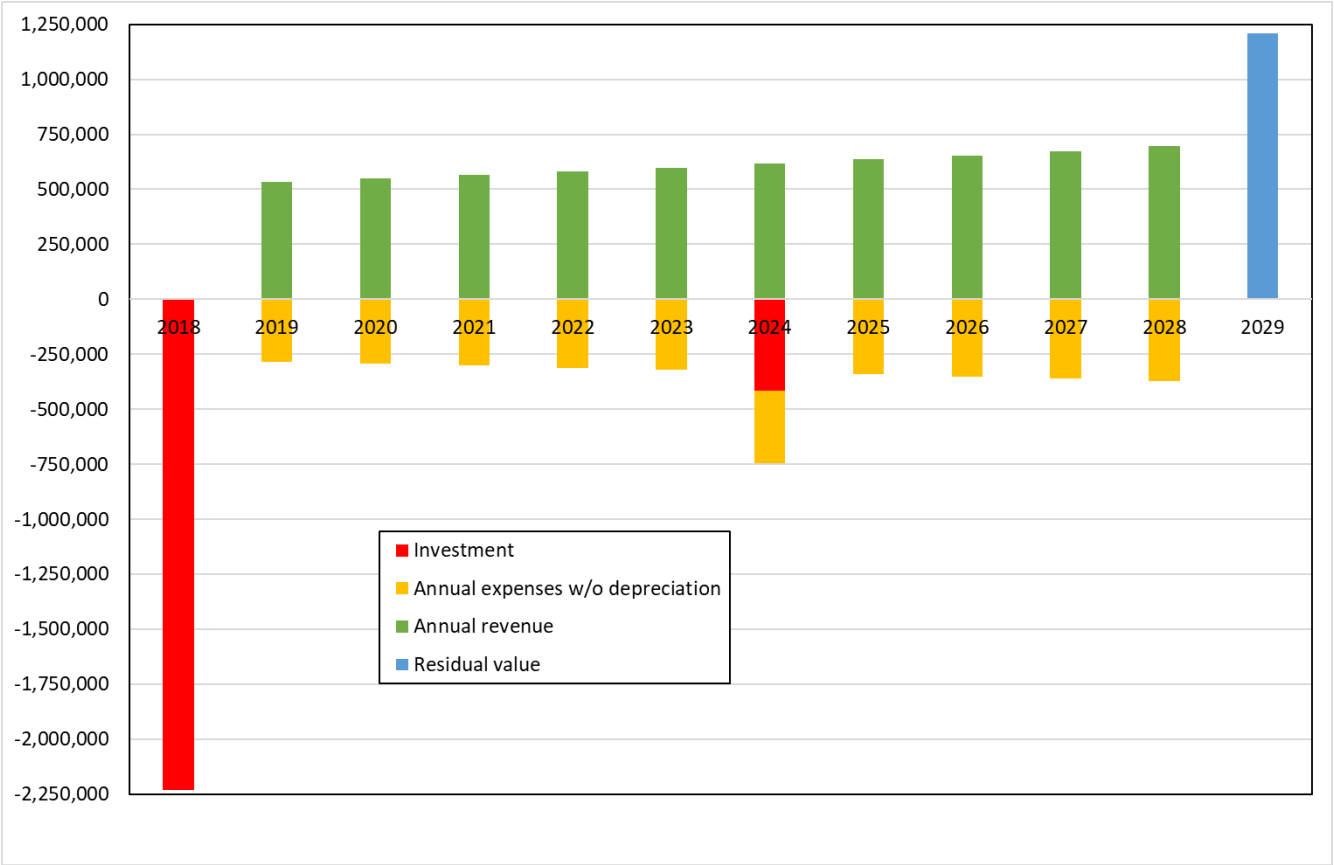

Figure 19: Cash flow of the energy centre in Linakaneng in 2018-2029

Table 36: Main features and financial parameters of an energy centre in Linakaneng

Features	
Number of households in the village	450
Building area, m2	100
Vehicle, #	1
Employees, #	4
Capacity PV	23
Capacity storage	55

Initial investment	
Building costs, M	200,000
Vehicle, M	200,000
PV+storage, M	622,362
Initial Stockage, M	796,510
Equipment, M	36,000
Staff Training, M	5,000
Contingencies	371,974
Total initial investment	**2,231,846**

Annual costs	
Salaries, M	100,000
Maintenance PV, M	12,447
Depreciation on hardware investment	57,200
Vehicle Maintenance and fuels	20,000
Contingencies	37,929
Total annual costs	**227,577**

Replacement costs	
Inverter+ storage	214,500
Vehicle	200,000

Annual revenue	
Charging lights, phones #/yr	36,500
Charging large batteries #/yr	7,500
Charging lights, phones, M	182,500
Charging large batteries, M	75,000
Equipment services	36,000
Profit on equipment sales	238,953
Total annual revenue	**532,453**

Residual Value	
Building costs, M	100,000
Vehicle, M	0
PV+storage, M	311,181
Initial Stockage, M	796,510
Equipment, M	0
Total residual value	**1,207,691**

5.4. Summary

Linakaneng is among the largest villages in our sample with 450 households and a a significant number of anchor loads like primary school and crafts which are potentially important customers for an energy centre. So, we assumed the construction of a large-sized energy centre in the village. An energy centre should be placed in close proximity to the households and anchor customers, so that they do not need to walk long distances to charge their batteries or mobile phones. The village offers appropriate location for it, since many potential customers are densely located around the potential site within a radius of 1 km. The centre to have a minimum size of approx. 100 m² to stock and display products and accommodate office facilities. Four workers – at least two sales assistants and two maintenance agents - will be required to provide sufficient support to customers, both in the energy centre and directly at the premises of clients, help them in the selection of goods, explain the features and advantages of energy efficient technologies, give instructions for use, undertake small repairs and deliver replacement parts. One vehicle, of a pick-up type, will be needed to deliver products and parts to the customers. Combination of PV and battery storage will be planned to cover energy needs of potential customers and own energy consumption of the centre. If a significant increase in energy demand is observed in the village, then the solar power plant can be easily extended to the appropriate dimension. Given that offered goods will be actively purchased by households and anchor customers, and services such as battery and phone charging in the centre as well as additional services like sales of cold beverages (likely to be popular among the population), the establishment of an energy centre will still be economically profitable with initial investment of M2,231,846 and will provide a rate of return of slightly more than 7% after 12 years of operation.

6. Malingoaneng Energy Centre
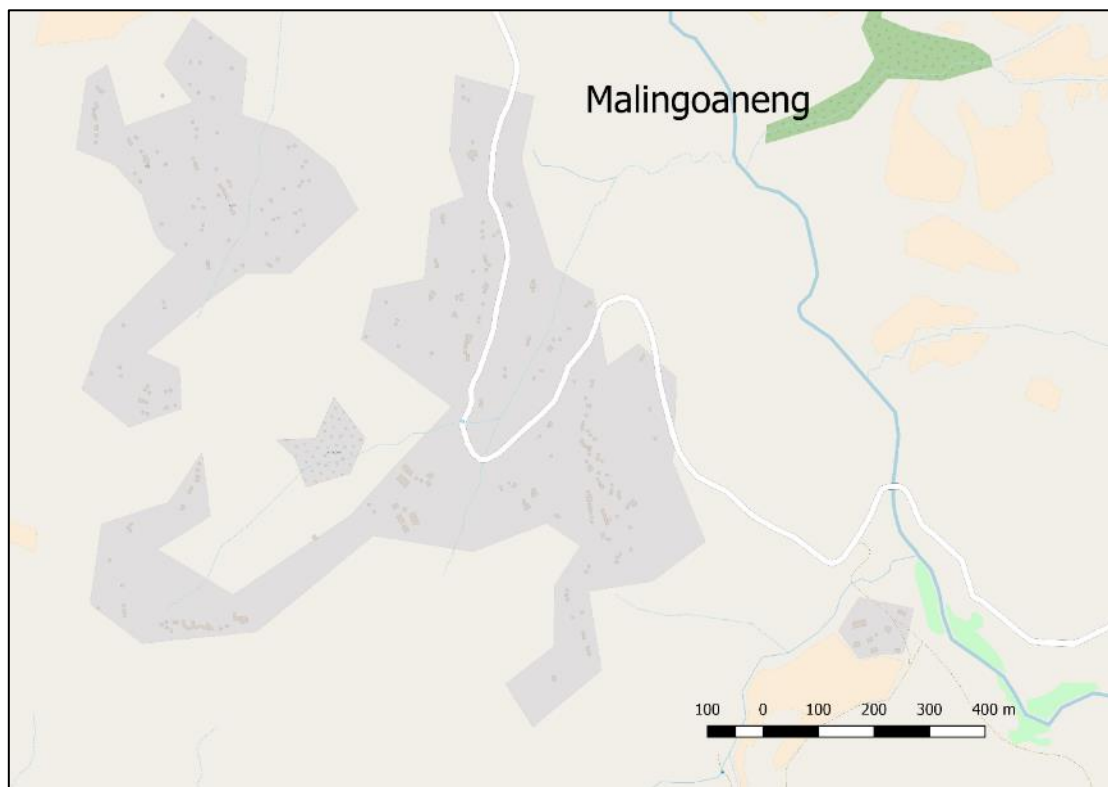
Figure 20: Map of Malingoaneng

Figure 21: Pictures from field visit in Malingoaneng

6.1. Customer Base

According to the interviewed chief of the village, the three main sources of income for the inhabitants are agriculture, self-employment and government old-age pensions. The nearest major service centre is Mapholaneng, which is located 35 km away and can be reached in 2.5 hours of driving.

6.1.1. Households

Energy demand forecast

There are approximately 250 households in Malingoaneng village. We calculated an energy demand forecast as described in the General Report. Power demand in 2019 reflects only the share of the total demand of households which will be covered by the Energy Centre. The calculations excludes the affluent households since they already cover their own energy needs using solar home systems, solar lanterns and rechargeable batteries.

Table 8: Present and future power demand by households in Malingoaneng

Household type	No. of HH in Malingoaneng	Total power demand, kWh/year	
		Present	2019
Basic	163	0	2,120
Medium	62	3,100	4,530
Affluent	25	7,500	0
Total	**250**	**10,600**	**6,650**

6.1.2. Anchor customers

Main characteristics

The Malingoaneng village chief informed the interviewers that, there is a primary school with teaching staff houses, craft shop, retail shops, a church, and a bar shop (selling alcohol) in his village.

During our survey, we interviewed five commercial facilities (food and non-food retail shops and café) (Q B1). All the commercial facilities are under individual ownership (Q B2). Anchor customers have from one to five employees (Q B3).

The earnings per month lie between M1,500 and M75,000/month, on average M19,000/month. Notably, with the exclusion of the highest income earner (of M75k /month) all other commercial users have incomes of M1.5k - 7.5k, and M5k on average (Q B5, Q B6).

Energy supply

Five interviewed anchor customers did not indicate any consumption of energy (Q C1).

Of the five customers, three used solar electricity last year. The capacity of solar panels ranges from 12 to 100 W. Solar energy was used on all days for lighting, phone charging and in one of the cases it was also used to power a till machine (Q C3).

Four respondents want to have electricity in their facilities and think that it is important for companies and institutions from their branches to have it (Q C4-C5). But, at the same time, two users perceive electricity as expensive (Q C6).

Respondents stated that their respective companies/institutions are ready to pay for electricity to the tune of between M230 and M1,000 per month, which is a share of their month income of 1-20%, and 9% on average (Q C7). The preferred methods for paying for electricity are by cash (three respondents), via mobile phone (1) and bank transfer (1) (Q C8).

All interviewed anchor customers work for 6 or 7 days per week (Q D1). Four commercial users operate between 8 and 11 hours per day over the whole year, with the exception of one customer who operates for 10 months per year (Q D2-D3).

The anchor customers in Malingoaneng have between one and five buildings at their disposal, and on average 2.2 buildings (Q D4). The total building area size ranges from 36 m^2 to 520 m^2 among commercial facilities. With the exception of the largest building of 500 m^2 the other four users have area sizes of 36 to 144 m^2, and 74 m^2 on average. No buildings are insulated (Q D5).

No air-conditioning systems are in use by the interviewed anchor customers (Q D6). A central heating system, operating on wood, is in operated by one café. It operates 8 hours per day throughout the week over five months in the year. For heating, altogether, 500 kg wood (2,450 kWh) were used over the last year. Five heating systems were in use (Q D7). No independent heating or cooling system were used (Q D8).

Anchor customers are willing to pay for electricity for heating/cooling between M100 and M600/month, and on average M236/month;which corresponds to 1-7% share of their month income (Q D9, Table 9).

One company uses any type of light bulbs: energy saver bulb of 100 W. Other uses six paraffin lamps for lighting (Q D10). There are no light or motion sensor controls for operating the lighting in service area (Q D11-D12).I terms of willingness to pay, the anchor customers are ready to pay between M50 and M200/month, on average M103/month (0-4% of their income per month) for electricity for lighting (Q D13, Table 9).

As for small equipment like desktops, monitors, laptops, servers, printers, or household appliances, only one till machine and one gas fridge are in operation by anchor customers in Malingoaneng (Q D14).

No anchor customer has any cooking facilities (Q D15). As an energy source, LPG is used for cooking (Q D16). Respondents are ready to pay between M50 and M500/ month, M190/month on average, 1-3% of their month income, towards electricity for cooking (Q D17, Table 9).

Four customers have refrigerating equipment at their facilities: one or two refrigerators of 210 or 420 litres capacity (Q D18). The same anchor customers are willing to pay for electricity for refrigeration, at the rates of M70-M200/ month, and M125/month on average (0-5% of their month income) (Q D20, Table 9).

Two anchor customers generate electricity using solar panels (Q E1), with panel capacity of 100 W, and use the electricity for lighting. The panels are operated for the whole operating time of a company all year long (Q E2). Two anchor customers also use generators for heating (capacity 50 kW and 100 kW). The generators are fuelled by diesel 500ppm, the generators are in use for 4 - 5 hours per day all over the year (Q E4).

As for future plans, four customers want to replace some units (gas fridges in two cases, globes for light) by others in the next five years (Q F1-F2). Four users also want to install new energy consuming systems: (electric) fridges, cash till machines, cameras, bar code scanner, due box (Q F4-F5). Four interviewed anchor customers would like to switch to electricity. Majority supposes these activities will reduce their energy consumption (Q F8).

Four anchor customers are planning to buy solar PV in the next five years, three want to obtain generators, and one wants a car battery (Q F9). One anchor customer plans to replace light bulbs with CFL and replace windows too (Q F10).

Table 9: Ability and willingness to pay for electricity in general and for different applications of anchor customers in Malingoaneng

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
Nycon Foan	M75,000	M600	M200	M500	M200	M1,500	2%
Leeto Café	M7,500	M130	M55	M200	-	M385	5%
Tlou General Dealer	M7,500	M200	M150	M100	M150	M600	8%
Smakaleng Café	M1,500	M100	M60	M50	M70	M280	19%
Tlokoeng Offsales	M3,500	M150	M50	M100	M80	M380	11%
Total	M95,000	M1,180	M515	M950	M500	M3,145	-

Energy demand forecast

Present power demand and supply of anchor customers in Malingoaneng are summarized in the Table 11. Future power demand of all anchor customers in the village, including non-interviewed ones, is presented in the Table 10.

We derived the forecast for power demand of anchor customer on the results of the entire survey. However, only school and crafts will be supplied with energy by the energy centre whereas for the other type specific individual demand is too high to be covered by the energy centre. Moreover, most of the other customer types already have own generation facilities.

Table 10: Present and future power demand of anchor customers in Malingoaneng

Type	Number of institutions	Power demand, kWh/year	
		Present	**2019**
School	1	0	500
Government	1	850	850
Retail	5	18,960	18,960
Craft	1	0	50
Total		**19,810**	**20,360**

Table 11: Main characteristics of anchor customers in Malingoaneng

#	Name	Type	Size	Operation hours	Electrical equipment	Annual power demand	Present power supply	Willingness to pay[5], Maloti/month
1	Nyeng Foan	**Retail**	5 employees; 5 buildings, area 500 m^2	8 h/day, 6 days/week, 12 months/year	Till machine, 2 refrigerators (210 and 420 litres)	5,274 kWh	Solar panel of 12 W, 2 generators of 100 kW	1,500
2	Leeto Cafe	**Retail**	1 employee; 1 building, area 36 m^2	9 h/day, 6 days/week, 10 months/year	Energy saver bulb of 100 W	238 kWh	Solar panel of 100 W	385
3	Tlou General Dealer	**Retail**	2 employees; 1 building, area 120 m^2	11 h/day, 7 days/week, 12 months/year	Gas fridge, 1 refrigerator (210 litres)	2,672 kWh	Solar panel of 50 W, 1 generator of 50 kW	600
4	Semakaleng Cafe	**Retail**	1 employee; 2 building, area 66 m^2	9 h/day, 7 days/week, 12 months/year	1 refrigerator (210 litres)	2,015 kWh	None/NA	280
5	Tlokoeng offsales	**Retail**	3 employees; 2 buildings, area 50 m^2	11 h/day, 7 days/week, 12 months/year	2 refrigerators (420 litres each)	8,760 kWh	None/NA	380
					Total	18,958 kWh		3,145

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[5] 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 12. Here, also anchor customers and affluent households are included even though we do not expect them to be supplied by the energy centre.

Table 12: Development of power demand in Malingoaneng 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	5.4	0.1	0.0	5.5	7.0	0.1	0.0	7.1	173.4	2.7	0.0	176.2
Anchor customers	13.5	0.0	0.0	13.5	14.8	0.0	0.0	14.8	47.1	0.0	0.0	47.1
Total	18.9	0.1	0.0	**19.0**	21.8	0.1	0.0	**21.9**	220.6	2.7	0.0	**223.3**

6.2. Set-up for Energy Centre

For the location of the Energy Centre, two feasible sites were initially identified – one marked blue and the other marked yellow (Figure 22). Both sites are attractive according to physical criteria like direction to the sun, area size and availability of space. The yellow marked location is identified as the optimal site as determined according to the calculation algorithm of the geometrical mean of all buildings within a radius of 1-3 km in the village. Effectively, it is the location that has the minimum sum of distances to all existing potential residential, public and business customers. In the case of Malingoaneng the theoretically identified potential site for the energy centre coincides with the site chosen as a result of field research. This particularly suitable site is presented on the map (Fig.24) as two squares, blue and yellow, inscribed in each other.
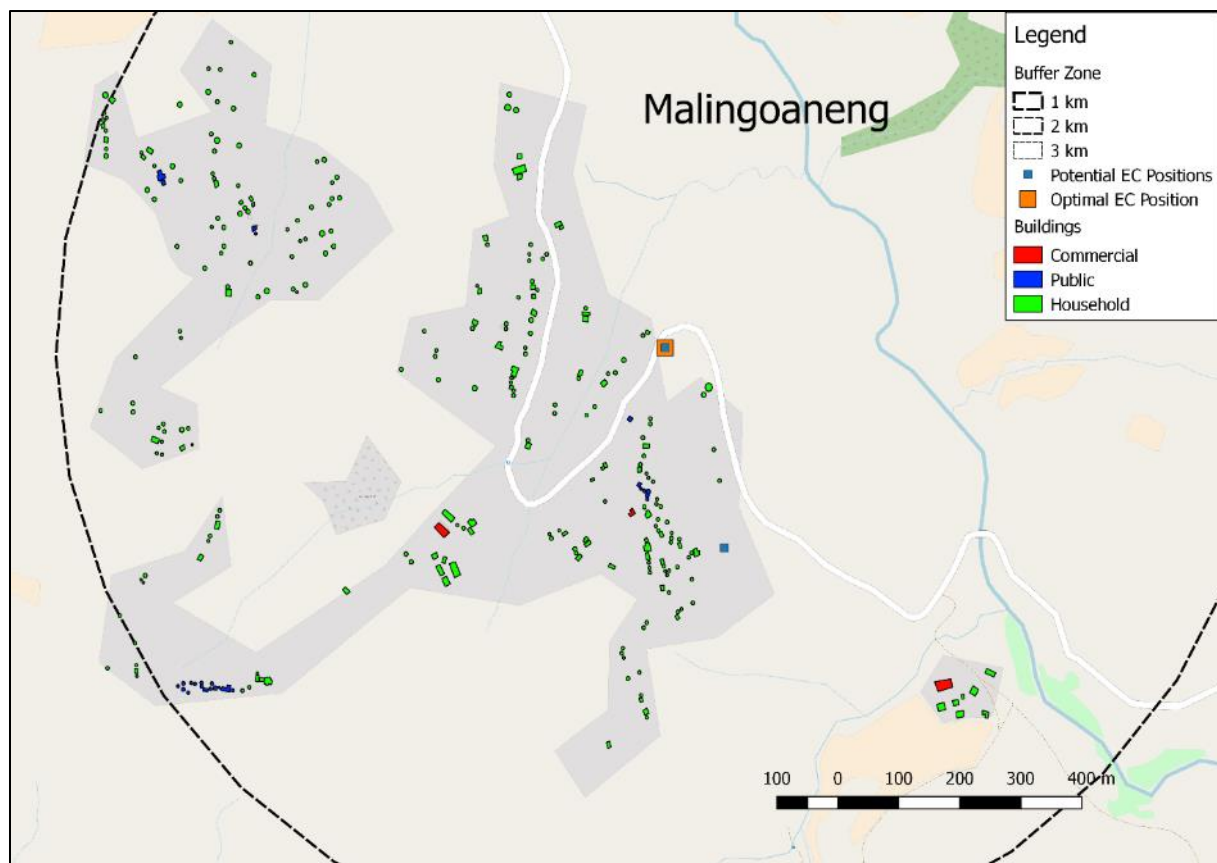
Figure 22: Spatial distribution of customers and positions of energy centre in Malingoaneng

6.3. Economic Viability

Malingoaneng is a medium-sized village with mediocre number of households living in there and rather few anchor loads. The village apparently needs a medium-sized energy centre. Table 13 details the main characteristics and financials of the proposed energy centre in Malingoaneng - these include 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 Malingoaneng as well as to cover the electricity demand for the services provided through the centre, a solar power plant of 11.8 kW with battery storage facility of 33 kWh is needed. It might be prudent to consider constructing the plant in a stepwise mode along the expected increase in power demand and power-related services.

We calculated the cash-flows over a period of ten years after commissioning the energy centre (Figure 23). Even though most of the equipment as well as the buildings will not be 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 M431,423, that makes this energy centre setup economically feasible and very profitable compared to other setups (small and large).
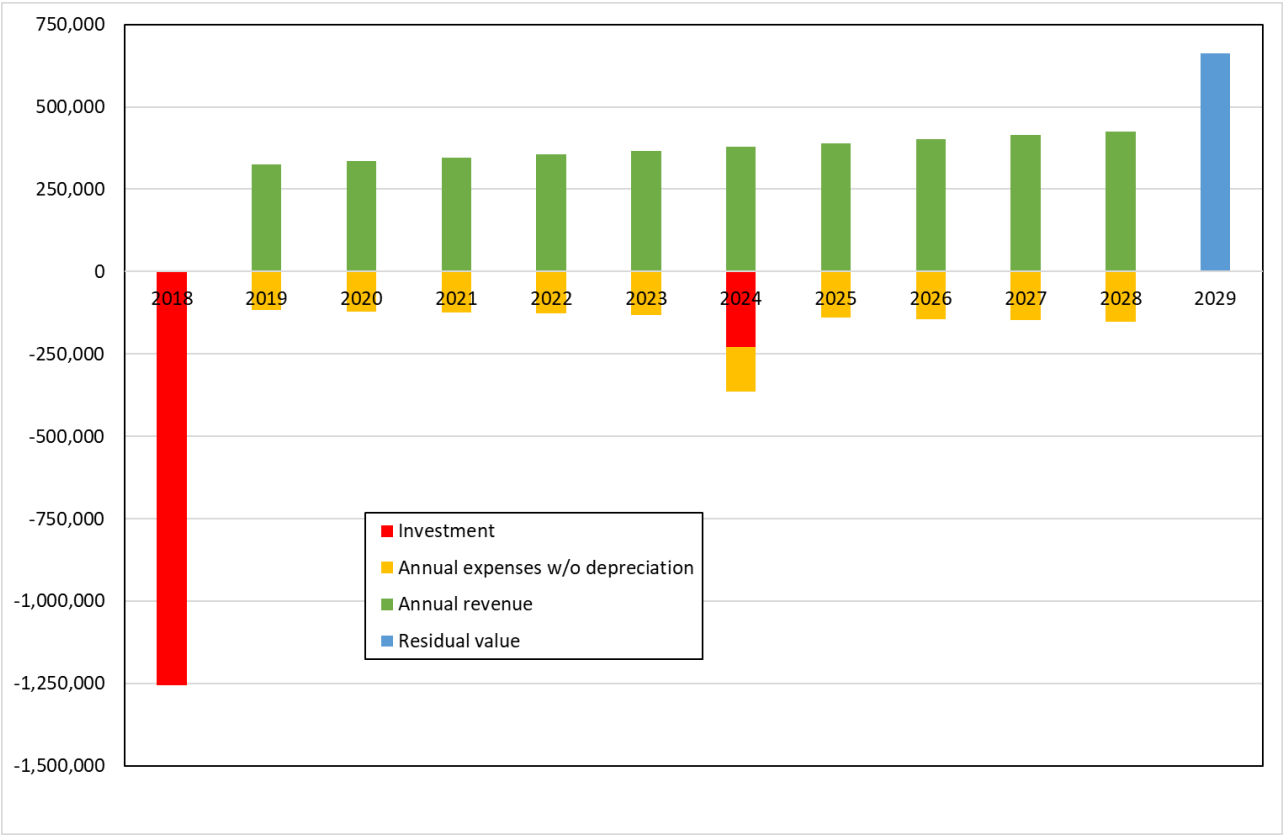

Figure 23: Cash flow of the energy centre in Malingoaneng in 2018-2029

Table 13: Main features and financial parameters of an energy centre in Malingoaneng

Features	
Number of households in the village	250
Building area, m2	80
Vehicle, #	0.5
Employees, #	3
Capacity PV, kW	11.8
Capacity storage, kWh	33
Initial investment	
Building costs, M	160,000
Vehicle, M	100,000
PV+storage, M	337,874
Initial Stockage, M	412,545
Equipment, M	30,700
Staff Training, M	5,000
Contingencies	209,224
Total initial investment	**1,255,343**
Annual costs	
Salaries, M	75,000
Maintenance PV, M	6,757
Depreciation on hardware investment	34,140
Vehicle Maintenance and fuels	10,000
Contingencies	25,179
Total annual costs	**151,077**
Replacement costs	
Inverter+ storage	128,700
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	168,937
Initial Stockage, M	412,545
Equipment, M	0
Total residual value	**661,482**

6.4. Summary

Malingoaneng village, with 250 households living in the village, is on the upper limit of the interval of middle-sized villages, so the energy centre needs to be medium-sized. The settlement is relative densely populated within a small radius, which makes it an attractive location for an energy centre - providing easy access on foot by all potential customers. Such a medium-size energy centre should ideally have a minimum building area of about 80 m^2 to accommodate stock, display and office. Three employees - two sales assistants and one maintenance agent - may be able to sufficiently support customers in terms of choosing the right energy products, explaining advantages and profits of using energy efficient products and technologies, as well as handling small repairs and deliver y of products and spare parts. A vehicle will be needed for trips around the village and neighbourhoods, which for cost-saving purposes can be shared with another energy centre or some business located in its 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 is observed, then the 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 M1,255,343 and provides a rate of return of more than 14% over a period of ten years of operation.

7. References

Bureau of Statistics Lesotho, National Energy Survey 2017

HOMER Pro Software Tool

Photovoltaic Geographical Information System (PVGIS), European Commission