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

Report on behalf of

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Content

1. Summary

This report provides an overview of the characteristic features and feasibility considerations of mini-grids and energy centres in selected villages in the district of Quthing. For the purpose of this study, we define mini-grids as low voltage grids with a maximum load of a few hundred kilowatts. The mini-grid is not connected to a central national grid and relies therefore on distributed power-generation placed in the grid. We regard energy centres as a service and sales point where batteries and other appliances can be charged. Additionally, other energy related services and products can be purchased enhancing the endowment with modern energy services and energy appliances. Energy demand is a critical determinant of the motivation for and sizing of renewable energy solutions in the context of rural electrification, and as such estimates have been produced in this study. Please note that the electricity demand listed for the years 2019 and 2030 considers only the electricity to be supplied by the mini-grid and energy centre respectively. It is assumed that energy centres will not supply affluent households as these households typically have already sourced an independent power supply.

Table 1: Overview selected features of energisation solutions in Quthing

Village	Tosing	Sebapala	Kubung	Qhoali
Solution	Mini-grid	Mini-grid	Energy centre	Energy centre
Number of Households	200	200	120	450
Anchor customers	One health centre, three schools, six government institutions, nine commercial retail facilities, one craft	Three schools, two government institutions, seven commercial retail facilities, one craft	One school, one government institution, three retail facilities, one mill	Three schools, one government institution, three commercial retail facilities
Present annual demand kWh	36,150	15,670	44,150	27,550
2019 annual demand kWh	110,200	82,630	3,750	13,490
2030 annual demand kWh	421,950	360,000	-	-
Size PV plant kW 2019 / 2030	129/306	95/258	5.57	17.9
Size storage kWh 2019 / 2030	395/792	300/663	17	60
Additional future power source	Hydro	Hydro	-	-
Length power lines km 2019 / 2030	4.36/4.86	7.77/8.67	-	-
Size of energy centre	-	-	Small	Large
Initial investment Maloti	4,222,142/ 14,977,886	3,648,024/ 14,171,287	760,401	2,149,833
Internal Rate of Return (with national tariff) 2019 / 2030	-16%/-12%	-15%/-13%	-	-
Required tariff 2019 / 2030 Maloti	8.71/6.95	9.42/7.47	-	-

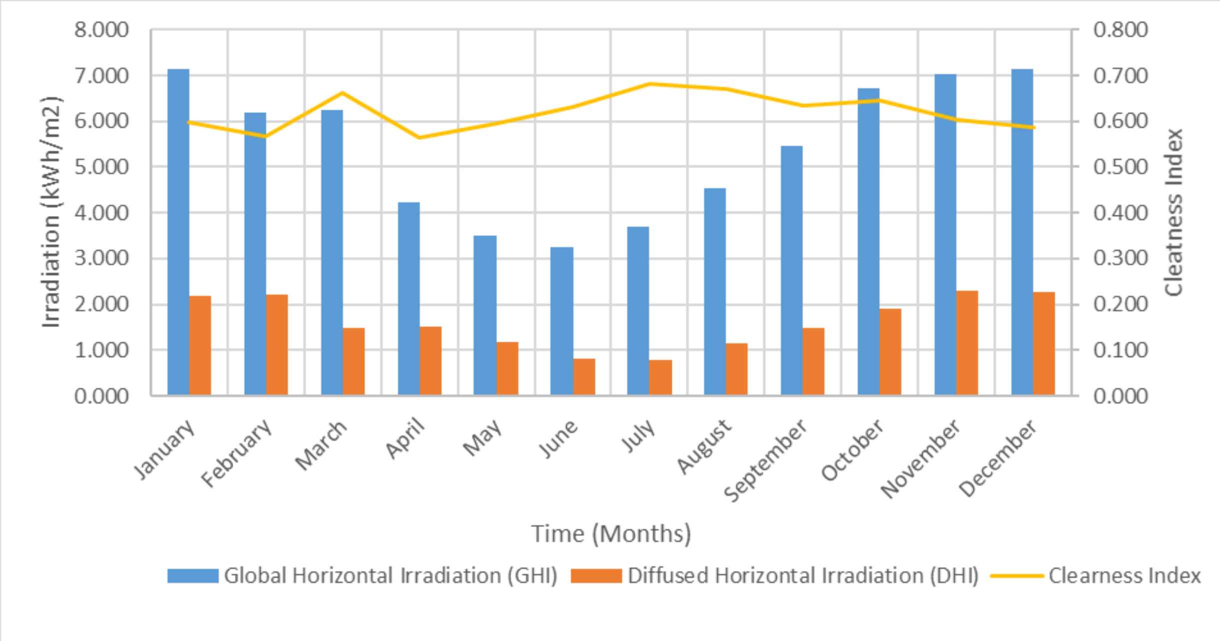
2. Quthing district

Quthing district is the most southern region in Lesotho (Figure 1), comprising an area of 2,916 km^2 and situated along the main road connecting Qacha's Nek and Mohale's Hoek town. Quthing is the 8th largest district in Lesotho, with a total population of 115,469 (accounting for 5.72% of the country's citizens) and which disaggregated by gender includes 56,866 male and 58,603 female Basotho (Census 2016 estimates). The number of households in the district is estimated at 26,345. Approximately 40% of the total households are male-headed while 60% are female-headed.

Figure 1: Location of Quthing in Lesotho

2.1 Renewable energy resource potential

The district town of Quthing is located at coordinates of latitude -30.39 (30°23'24"S), longitude +27.72 (27°43'12"E). The average (global horizontal) insolation at Quthing, as given by the NASA climatologic database, ranges from a minimum of 3.20 $kWh/m^2/day$ in June to a maximum of 6.57 $kWh/m^2/day$ in December with an annual average of 4.96 $kWh/m^2/day$ 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 highest irradiance days of the year are in the months of November-January (6.28, 6.57 and 6.49 $kWh/m^2/day$, respectively) (Figure 2, Table 2).



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

Figure 2: Monthly insolation and clearness index patterns in Quthing, Lesotho

Table 2: Average Daily global horizontal irradiation data in Quthing

Month	Clearness index	Daily GHI (kWh/m^2/day)
January	0.597	7.137
February	0.566	6.22
March	0.661	6.27
April	0.563	4.23
May	0.594	3.499
June	0.632	3.25
July	0.681	3.78
August	0.67	4.51
September	0.634	5.44
October	0.646	6.75
November	0.604	7.08
December	0.586	7.18
Average	0.6	5.4

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

Wind: The estimated average annual wind speed in Quthing using remote sensing methods is approximately 4.73 m/s, i.e. is greater than the 4 m/s threshold used by practitioners to consider the technology commercially viable. Wind resources are highly variable in the time domain, including seasonal and interannual climatic influences, and spatially whereby trees and mountains create localized shelter effects. In general site specific measurement over time is ideally used to characterize wind resource potential. Preliminary wind speed measurements conducted at Lets'eng-la-Letsie (Lesotho's only Ramsar wetland) have concluded that the site has a good wind regime.

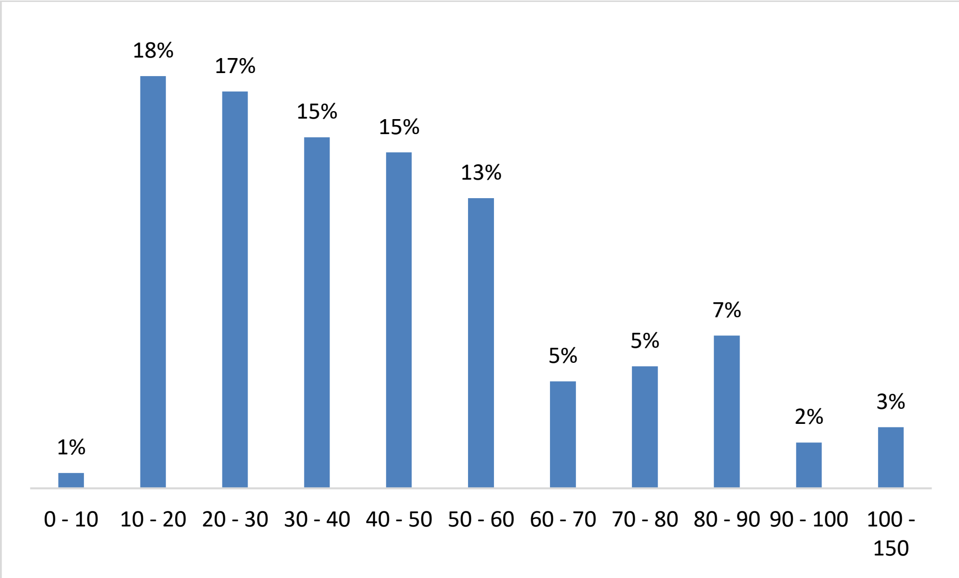
Hydro: Mini-hydropower is potentially a very promising technology in Quthing. Quthing is a home to a number of larger rivers such as Sebapala River which runs through Tosing and Sebapala, and the Quthing River, which is one of the major tributaries of the Senqu River (which also flows along the border of Quthing district). The hydropower resource is a function of streamflow volumes through river cross sections (in the case of run of river hydropower) or streamflow volumes and head potential across an elevation drop (conventional hydropower). Topographic and watershed analysis using known geotechnical characteristics and climatic (rainfall) data can be used to estimate hydro potential in river valleys in Lesotho. As with wind resources, hydropower resources are site specific and variable in the time domain, and best characterized through stream gauge measurements at sites of interest identified via watershed analysis using, e.g. geographic information system tools.

2.2 Household characteristics

Quantitative and qualitative description of households in Lesotho is tracked by the Bureau of Statistics (BOS). For the data analysis relevant to this report results of the BOS 2017 Household Study for the Quthing district were extracted, processed and consolidated to present indicators and descriptors of interest, starting with the constitution and size of average households. In the Quthing district, a typical household consists of four persons. About two thirds (60%) of households have four or more members while one third has six or more members.

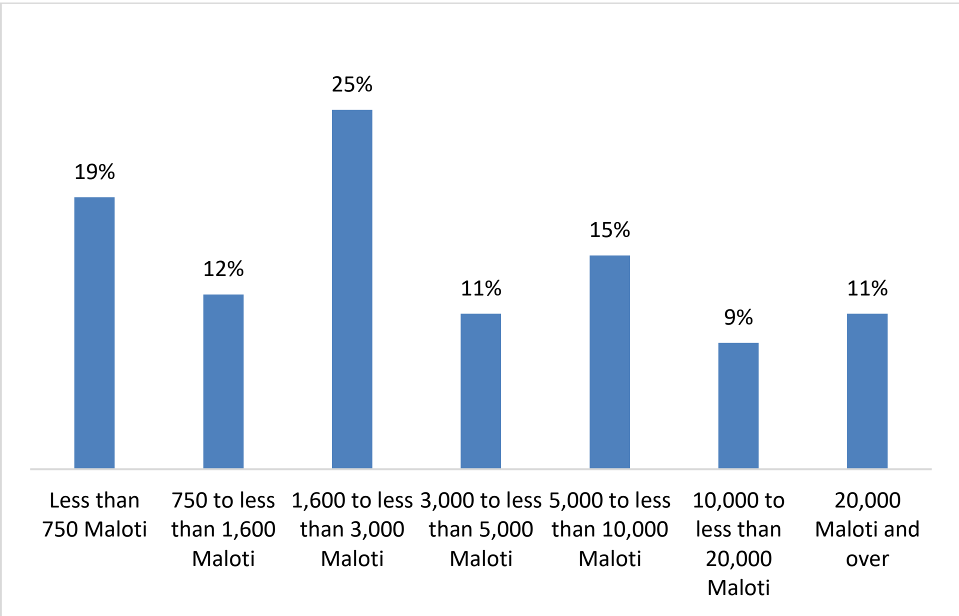
The age distribution of the residents in the households surveyed is weighted toward the younger age cohorts. Approximately 54% of residents were under 25, while 14% were between 40 to 59 years of age. Only about 10% of residents were over 60 years old. The average household size is 5.1 persons, with household size following a bell-shaped curve between a minimum of 2 persons and a maximum of 8+ persons.

The majority of Quthing inhabitants interviewed within the BOS survey (56%) have only one housing unit at their disposal, while almost one third have two units, and only about 14% have three or four units. The total housing area per household points at the existence of a broader stratum of well-off households: 35% of households feature 50 m^2 or more (Figure 3), which represents the highest share among the considered regions in Lesotho.



Source: BOS National Energy Survey 2017.

Figure 3: Distribution of household's usable area size in Quthing



Source: BOS National Energy Survey 2017.

Figure 4: Distribution of household income in Quthing

With regard to the disposable household income, 56% of households in the district earn less than M3,000 per month with almost one fifth earning less than M750. It should be acknowledged that the Quthing district is better positioned in this regard, since a relatively high share of households – 35% - earns more than M5,000 per month. However, this does not disregard the fact that some people live from direct barter and self-sustained farming. Around 36% of Quthing population receive remittances (money transfers from workers working abroad). Their value varies usually between M300 and M5,000. In general, income levels are low in rural areas, limiting the budgets available for power purchase.

In the Quthing district, Basotho households rely predominantly on three main biomass energy sources: wood and wood wastes, animal dung and straw/shrubs/grass (BOS National Energy Survey 2017). Energy consumption in summer is about 50-95% lower than in winter, indicating that heating is a significant category of energy usage. Households in Quthing invest considerable effort into acquiring wood biomass. The travelling time to reach the source of fuel wood is relatively long in the district, with half of households obliged to travel more than one hour while 37% of households travel less than an hour. In contrast to travelling time, collection time of fuel wood is relatively short amounting to below one hour for 64% of Quthing inhabitants. In view of limited household budgets and cost implications of using electrical energy for space and water heating it is surmised that present biomass collection might be not substituted even in the presence of a modern energy supply.

As in other predominantly rural districts in Lesotho, in Quthing access to electricity is limited: only 31% of households are connected to the central grid (BOS Energy Survey 2017). Another 10% of households own a solar PV system.

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%), and animal dung (17%).

Domestic space heating is another energy-intensive thermal application. In non-electrified households, wood and wood waste are the main energy source for space heating. In general, about 77% of inhabitants of Quthing use some form of energy for heating during cold months.

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. Tosing Mini-Grid

The village of Tosing was surveyed to assess its potential as a prospective mini-grid site. Tosing is situated in Quthing district, Lesotho, at geographical coordinates of latitude 30°20'29.9"S and longitude 27°55'44.3"E, which is approximately 23 km East of Quthing Town along the geodesic route at a heading of 73 degrees. Tosing is 9 km from the A4 road along the geodesic route but approximately 18km by spur road.

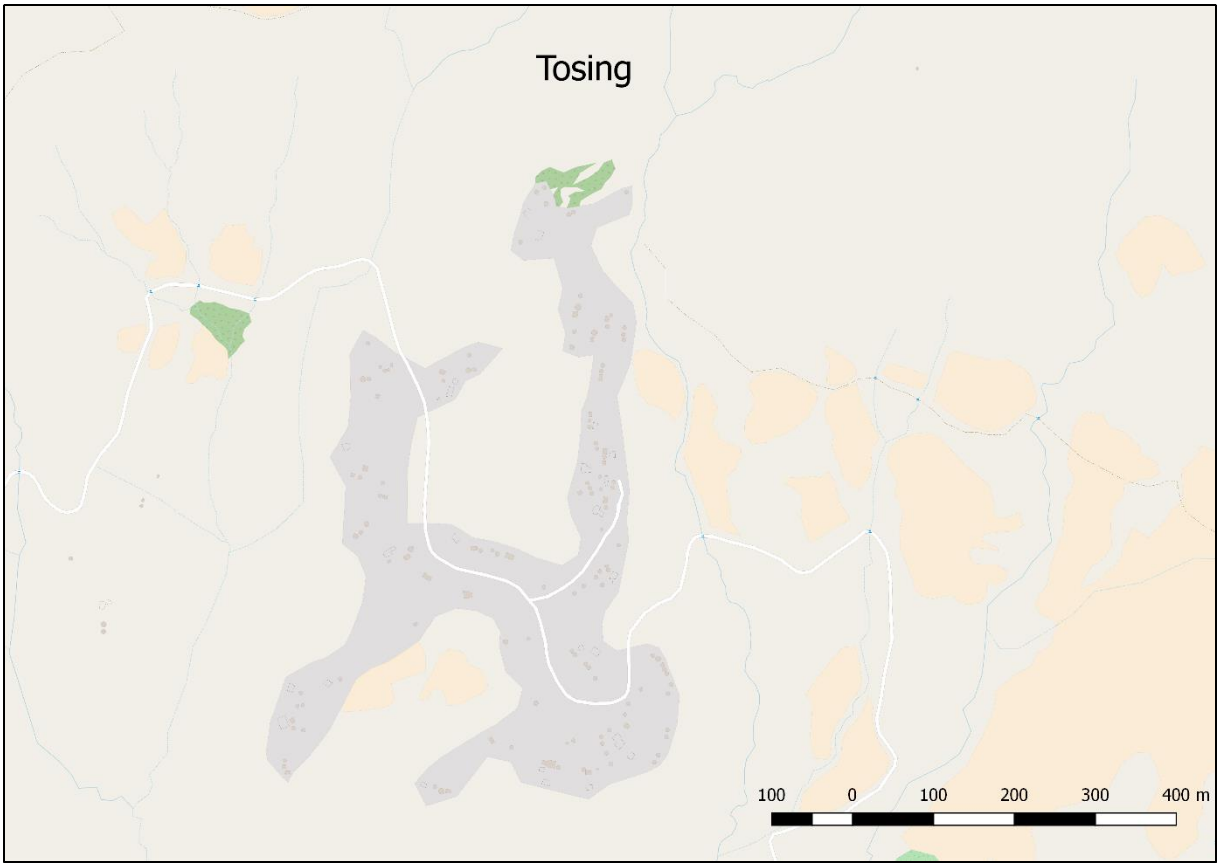


Figure 5: Map of Tosing

3.1 Customer Base

More than 200 households live in Tosing. Potential anchor loads include five medium size shops, a clinic, three primary schools, an agriculture extension office, two woolsheds, the office of the Independent Electoral Commission, a sizeable number of migrant workers, the office of the community council, the MP's residence, a guest house, the area chief's residence and office, street lighting, and a hammer mill. According to the head man of Tosing, the main income sources in order of descending importance in the village are farming, self-employment, and mines. The nearest service centre is Mt. Moorosi, at a distance of 19 km, or approximately one-hour drive under normal weather conditions.

3.1.1 Households

Sociodemographic characteristics

In the survey, ten households (HH) from the village were interviewed. A head man of Tosing indicated in the interview that the village has about 550 inhabitants living in 180 households. In the survey, the minimum number of household members was three with half of households having five or more members (Q B1[1]). One household counted 16 persons as members. The average number of household members slightly exceeds six persons.

Four households interrogated in this survey have one housing unit each, and six households have two housing units (Q C1). The number of housing units does not depend directly on the household size since it has been shown that all households with three members have two housing units at their disposal while the biggest households with 8, 10, and 16 members also have two housing units. Half of household respondents (five HH) from Tosing have *polata*[2] type of house with eight housing units having one room and the rest featuring three rooms (Q C2). The second popular house type is rontabole. Five households interviewed in Tosing have a housing unit of this type. All of these units have one room (Q C2). Four interviewed households in Tosing have between 10 and 20 m^2 of usable housing area, and there are four, five or even seven inhabitants living in these small houses (Q C2). The other six households have between 30 m^2 and 82 m^2. The mean value of usable floor area per household member in Tosing amounts to 7.75 m^2. The average area of houses owned by a single HH is 40 m^2, which is a rather low value.

Six of ten households interviewed in Tosing earn less than M300 per month, two households earn between M1,000 and M2,000 per month, one household earns between M500 and M1,000, and one household between M5,000 and M10,000 (Q C3). The majority of interviewed households in Tosing (80%) do not receive any remittances. One HH received between M300 and M500, and other between M1,000 and M2,000 last year, amounting to only M33 and M125 per month (Q C4).

No household indicated plans to move away from the village in the next five years (Q I1).

Energy supply

Eight out of ten interviewed households from Tosing use fuel wood, obtained by collection for free. Households used between 125 kg and 1,000 kg fuel wood, which is equivalent to 600-4,900 kWh in a year. It is of note that five households use fuel wood as the only biomass source, two households use only shrubs, and the remaining three households use both biomass sources. The five households that used shrubs last year consumed between 80 kg and 850 kg of shrubs (400-4,200 kWh) and obtained it at no monetary cost by collecting it with their own effort.

All interviewed households from Tosing indicated that they have access to an area for wood collection (Q D2). Nine households source the fuel wood in the communal forest, and one in a private forest (Q D3).

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

[2] *Polata* is a Sesotho rendering of ‘flat’ and typically refers to a rectangular building with three or fewer rooms and a shallow single pitched roof. The walls of concrete blocks, sandstone, rubble, burnt or mud bricks are topped by a corrugated iron roof. The flooring is earth or concrete covered by linoleum or may be covered in vinyl tiles; ceilings are either not installed or of decorated plaster board (UN-Habitat 2015).

Respondents from Tosing indicated that they have to travel between half an hour and an hour (6 HH), and four HH need to travel up to 30 minutes to the edge of a main collecting fuel wood area and back (Q D4). This demonstrates that interviewed households live relatively close to the forest. Seven households need less than half an hour to collect wood, and three HH between half an hour and an hour (Q D5). Four households need to go once or twice to collect wood per month, three households three or four times, and one household collects wood ten times in a typical month (Q D6). In summary it results in an average time spent for travelling and collecting wood per month of between 0.5 hours and two hours for seven households, and between five and six hours for two households. The maximum time spent collecting fuel is eight to ten hours per month in the most extreme case. Total travelling and collection time per year accounts for 6 to 72 hours, with an average time of 27 hours. Assuming an hourly wage of 8 Maloti this converts into annual costs of approximately 216 Maloti. Ten women, eight children and only three men from interviewed households are involved in fuel collection (Q D7).

The majority of the households (8 HH) do not have an improved fuelwood stove. One household uses a Rocket stove and one HH uses an ACE 1 Smokeless cookstove. (Q D8).

The majority of interviewed households (9 HH) do not spend money for purchasing biomass, and only one household spends less than M50 per month for purchasing biomass (Q D9) which They all usually pay for in cash for the commercial fuels (Q D10) and would prefer to continue to pay for it in cash (Q D11).

Cooking is an important end use of biomass fuels in Lesotho. Fifty percent of the interviewed households in Tosing use wood (5 HH), twenty percent use LPG (2 HH), another twenty percent use shrubs (2 HH) and only ten percent of the interviewed households use paraffin (1 HH) as their main energy source for cooking (Q F1). All households interviewed rely on a second fuel type for cooking such as paraffin (5 HH), wood (2 HH), animal dung (1 HH) and shrubs (1 HH).

Both households that use LPG consume between 0.21 and 0.3 kg per day for cooking and expended M4.7 and M6.7 per day respectively. Five households use one to two litres of paraffin per day that costs M10 to M12 per unit. One household also uses one kg of crop waste per day and the other uses 0.9 kg of animal dung per day, all collected at no monetary cost using their personal time and effort. One household additionally uses 0.87 kg of shrubs per day. Five households use wood for cooking, consuming 0.5 to 0.7 kg of it per day (Q F2).

Table 3: Household use of energy sources in Tosing

HH No.	Cooking			Space and water heating			Lighting			HH income, M/a
	Use of energy sources	Annual energy consumption, kWh/a	Annual expenses, M/a	Use of energy sources	Annual energy consumption, kWh/a	Annual expenses, M/a	Use of energy sources	Annual energy consumption, kWh/a	Annual expenses, M/a	
1	0.87 kg shrubs per day, 0.9 kg animal dung per day	3,100	0	1,896 kg animal dung per year, 928 kg shrubs	13,458	0	20 litres paraffin, 100 candles per year	222	600	1,800
2	0.7 kg shrubs per day, 1 kg crop waste per day	2,712	0	1,598 kg animal dung per year, 218 kg shrubs	8,579	0	5 litres paraffin, 120 candles per year	70	480	1,800
3	0.6 kg wood per day, 1 litre paraffin per day	4,851	4,015	1,793 kg wood per year	8,786	0	105 candles per year	16	200	1,800
4	2 litres paraffin per day, wood (not specified)	7,556	8,760	1,888 kg wood per year, 622 kg shrubs	12,299	0	24 litres paraffin, 2 candles per year	249	372	1,800
5	0.3 kg LPG per day	1,402	2,435	120 litres paraffin per year, 811 kg animal dung, 811 kg wood	9,028	1,440	12 litres paraffin per year	124	720	90,000
6	0.5 kg wood per day	894	0	1,940 kg wood per year	9,506	0	60 litres paraffin per year	621	660	1,800
7	0.21 kg LPG per day	981	1,705	20 litres paraffin, 997 kg wood per year	5,092	240	20 litres paraffin, 6 candles per year	208	241	19,500
8	1 litre paraffin per day, wood (not specified)	3,778	4,380	987 kg wood per year	4,836	0	24 litres paraffin per year	248	288	1,800
9	1 litre paraffin per day	3,778	3,650	32 litres paraffin per year, 7 kg wood	365	320	40 litres paraffin per year	414	480	9,396
10	0.66 kg wood per day, 2 litres paraffin per day	8,736	8,760	1,610 kg wood per year	7,889	0	72 litres paraffin per year	745	864	18,000
Average		**3,779**	**3,371**	**-**	**7,984**	**200**	**-**	**292**	**491**	**-**

Households in Tosing express a willingness to pay between M50 and M300 for electricity for cooking per month, although this amount does not seem feasible with monthly income between M150 and M780. High-income earners again demonstrate more reliable values between 1 and 3% of the month income (Q F3, Table 5). No household has a wonder box (insulated cooker/cooler box) (Q F4).

Space heating is a significant driver of biomass and modern fuel consumption in Lesotho (Table 7). Eight households out of ten in Tosing heat their houses (Q G1). For space heating, they use paraffin heater (3 HH), paola (3 HH), fireplace (2 HH), or open fire (2 HH) (Q G2) and wood, paraffin and shrubs as main energy source (Q G3). Two HH use animal dung, and one HH uses an ACE cookstove as an alternative energy source for space heating. Two households used 20 litres of paraffin in the last year expending between M200 and M240. Other household used 60 litres last year, spending approximately M720 (Q G4). Six households used 900-1,000 kg of collected wood for space heating. Two households used about 1,000 kg of animal dung. Two households used between 600kg and 800kg of shrubs and one household utilised about 100 kg of shrubs for space heating. When queried for willingness to pay, lower income households in Tosing respond that they would allocate between M20 and M200 for electricity for space heating per month, which at the higher end should be considered with care in terms of reliability given the constraints in monthly income of respondents. Households that are better able to afford heating express a more realistic willingness to pay of between M50 and M100, which is 1-12% of their earnings per month (Q G5, Table 5).

The buildings of interviewed households involve floor areas of between 12 and 36 m^2, with the majority of eight households heating between 10 and 20 m^2 (Q G6). The majority of households use wood (6 HH), then paraffin (2 HH) and shrubs (2 HH) as main energy source for water heating. Wood, animal dung, and shrubs are alternative sources of energy for water heating (Q G7). Eight HH used between 600 and 1,000 kg of wood last year which was collected with household labour. Three households used 98 kg, 622 kg, and 808 kg of shrubs, collected using household members time and effort (Q G8). Two households consumed 12 litres and 60 litres of paraffin respectively, per year.

Lighting is an important and high impact end use of energy resources in rural Lesotho. For lighting, the majority of the interviewed household in Tosing (7 HH) use paraffin, with the remaining thirty percent of households using candles - there are no other energy sources available for lighting. However, it is notable that households typically use a combination of the two sources of lighting. (Q H1). Households in Tosing used between 5 and 72 litres of paraffin last year and paid between M60 to M864 (One litre of paraffin costs between M10 and M12). Three households used between 100 and 120 candles, expending M200-M400 (One candle costs between M2 and M4 (Q H2)). Note that these energy consumption calculations are made on the basis of the energy content of the fuels used and 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 based service. On average, the households spent M491 per year, indicating that the equivalent budget would potentially be available for purchasing power for lighting purposes.

Interviewed households in Tosing do not currently use any light bulbs (Q H3).

Households express a willingness to pay between M20 and M200 for electricity for lighting per month. Realistic values are anticipated to be 2-6% of the month income (Q H4, Table 5). The average expressed willingness to pay exceeds declared current expenses for lighting per month by more than twofold.

All ten interviewed households in Tosing do not currently use any electrical appliances at home (Q E1) but have a desire to be supplied with electricity in their houses (Q E7). Considering plans to purchase electrical appliances in the next five years, all households without exceptions want to obtain a refrigerator and flat screen television. Next in order of priority is an electric iron, with five households desiring to acquire it. Then followed a microwave and phone charger with four votes, electric kettle and electric stove with three votes, and an electric heater with two persons interested in purchase. Washing machine, bread maker, and electrical hair clipper close the list with one vote each (Q I3).

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

With regards to mechanisms for payment, all respondents from Tosing chose Mpesa as a preferred way to pay for electricity (Q E10). In terms of willingness to pay for electricity, of the interviewed households (Q E9), five households are ready to pay M200 to M250 per month, and four declare they can pay M500, notwithstanding their disposable income. In effect, this indicates three households indicate they are willing to pay sums that exceed their income by two-three times. It is interesting to observe that households which have relatively higher incomes, i.e. starting from M1,000, indicate a more realistic willingness to pay: e.g., to pay M200 with income of M7,500 (only 2.6%) or even M200 from M1,500 (13%) (Q E9, Table 5). As with the responses to demand for heating, higher income may correspond to better knowledge of pricing and ability to estimate the cost and benefits of a given level of expenditure for energy services in a hypothetical budget for electricity-based services. This discrepancy between lower and higher income respondents is investigated further below in the context of the survey methodology.

In a first step, the survey canvassed for a general willingness to pay for power (answers in 3rd column, Table 5). In a second step queries are refined to the willingness to pay for power for specific purposes (columns 4 – 6), where notably the sum of the individual specific willingness to pay figures do not necessarily correspond to the general willingness to pay. Also, the expressed willingness to pay deviates substantially from the actual declared expenses for e.g. lighting. In summary, it seems plausible to impute some demand for power for lighting, but significant uncertainty remains especially in the implied demand for heating or cooking due to internal inconsistencies in responses and considering budget constraints, particularly among the lower income respondents. Further, it seems reasonable to impute some demand for power for additional applications like phone charging, radio, television and refrigerators, confirming what is described in the General Part. This is also reflected in the respondents' average willingness to pay for electricity of M315 monthly.

Table 5: Ability and willingness to pay for electricity in general and for different applications of households in Tosing

HH #	Earnings per month (ability to pay)	Willingness to pay for electricity (Maloti and % of earnings)				Plans to buy electric appliances
		In general	For cooking	For space heating	For lighting	
1	M150	M100 (67%)	M50 (33%)	M20 (13%)	M20 (13%)	Refrigerator, electric stove, electric heater, TV flat screen, electric kettle
2	M150	M500 (333%)	M200 (133%)	M100 (67%)	M100 (67%)	Refrigerator, TV flat screen, iron, phone charger
3	M150	M500 (333%)	M300 (200%)	M100 (67%)	M100 (67%)	Refrigerator, electric stove, TV flat screen, iron, bread maker, microwave
4	M150	M500 (333%)	M200 (133%)	M200 (133%)	M100 (67%)	Refrigerator, TV flat screen, iron, electric kettle, microwave
5	M7,500	M200 (3%)	M100 (1%)	M100 (1%)	M200 (3%)	Refrigerator, TV flat screen, hair clipper, phone charger
6	M150	M200 (133%)	M100 (67%)	M50 (33%)	M50 (33%)	Refrigerator, TV flat screen, electric kettle
7	M1,625	M250 (15%)	M50 (3%)	M100 (6%)	M100 (6%)	Refrigerator, electric heater, washing machine, TV flat screen, iron, phone charger
8	M150	M200 (133%)	M100 (67%)	M50 (33%)	M50 (33%)	Refrigerator, electric stove, TV flat screen, microwave, phone charger
9	M783	M500 (64%)	M200 (26%)	M100 (13%)	M100 (13%)	Refrigerator, TV flat screen
10	M1,500	M200 (13%)	M50 (3%)	M50 (3%)	M50 (3%)	Refrigerator, TV flat screen, iron, microwave
Average		M315	M135	M87	M87	

The appetite for electricity is widespread and not particularly anchored to a specific mode of delivery. Six households expressed an interest to acquire all proposed electrical sources (solar PV, generator running on gas, and car battery) in the next five years. However, this response should be qualified in consideration of these respondents' low monthly income (M150 in five cases, M1,625 in one case). One household with an income of M783 per month is planning to buy only a generator. Another three households (M7,500, M1,500 and M150 monthly income) are not going to buy any electrical sources in foreseeable future (Q I4).

Energy demand forecast

All households interviewed in Tosing belong to a basic type, due to absence of electricity uses, energy supply and relatively low income. For the entire village, a distribution of household types as described in the General Part is postulated and in terms of forecasting the number of households over all household types is presumed to equally increase by 1% per year. In addition, the specific demand of all household types is expected to increase once electricity is available due to the capability to utilize electrical appliances. The answers given with respect to planned purchases of appliances confirms this trend. However, experiences in other countries indicate that household demand for power remained stable even five years after power supply arrived (Blog World Bank

2017). In practice, the benefits from access to a power supply are likely to be exploited more completely by the medium income and affluent households (Table 6). From a commercial point of view, the more indigent households are less interesting, although they stand to gain the most from enhanced living conditions through electrification.

Table 6: Present and future power demand by households in Tosing

Household type	No. of HH in Tosing			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

According to the interview with the chief, the village of Tosing features a post office, a primary school, council offices, several grocery shops, a church building, water supply, taverns, and a woolshed.

In this survey ten anchor customers were interviewed: one school and nine commercial enterprises. Six of the latter are food retail facilities (supermarkets, kiosks, sales booths), two are restaurants, and one grain mill (Q B1). All of these commercial facilities are in individual ownership (Q B2). All interviewed customers are very small with one to maximum two employees. Food retail facilities all have two employees, more often permanent than temporary. Gender distribution is even, normally with one male and one female worker. One restaurant has two temporary workers, and other one permanent. In the mill one male employee contributes manual labour on a permanent basis (Q B3). One school was surveyed in Tosing (Q B1). It has seven permanent employees, five of them are females, two males (Q B3).

The earnings per month for most commercial enterprises range between M1,000 and M2,000. One food retail facility earns between M2,000 and M5,000, another less than M500. The food retailer with the highest income also received between M1,000 and M2,000 subsidies or money transfers last year. This translates into an average additional income of M125 per month (Q B5, Q B6). The school received subsidies at the rate of M10,000 to M50,000 in a year (Q B6). This translates into almost between M1,000 and M4,000 per month.

Most potential anchor customers work seven days a week, with the exception of the school which operates five days per week and the mill which operates for six days per week) (Q D1). All commercial respondents operate between 10 and 15 hours per day over the whole year, while the school operates for 7 hours over 10 months in a year (Q D2, Q D3).

The majority of commercial respondents occupy an entire building, two potential anchor customers use a part of the building, and the school has two buildings at its disposal (Q D4). Six buildings were constructed in the period of 1970's-1990's, five in the 2000'-2010's. The total building area ranges from 9 m^2 (mill) to 20-22 m^2 (food retail) among commercial facilities, and 50 m^2 for the school. Only the school and one food retailer heat their buildings. Half of buildings are insulated, and the remaining fifty percent of the buildings are not insulated (Q D5).

Energy supply

The Head man of Tosing indicated in the interview that the post office, the primary school, the church, as well as the water supply facilities do not use any energy sources. The grocery shop and the tavern use LPG, generator, and solar PV, and the council offices have LPG, according to the interviewees.

Table 7: Consumption of energy resources and electricity generation of selected anchor customers in Tosing

Anchor customer	Wood		Solar PV		Generator	
	Quantity, kg	End use	System size	End use	Size	End use
Boithatelo General Dealer			1,000 W	Lighting		
Katlehiso General Dealer			1,000 W	Lighting		
Leloala					3,000 W	Other uses
Khutsong General Dealer	25	Auxiliary activities				
Boithatelo Tavern			1,000 W	Lighting		
Total quantity	**25**		**3,000 W**		**3,000 W**	

Only one interviewed anchor customer (food retail) indicated the use of hard coal and biomass sources consumed over the last year: it was 25 kg wood, at the cost of M50, paid in cash and used for auxiliary activities. All other facilities stated they did not use any hard coal or biomass resources (Q C1-C2).

Five customers, among them three food retailers and one café, used solar electricity last year. All have the capacity of 1 kW (solar panel). Solar energy was used on 3-5 % of days for lighting (Q C2).

No air conditioning systems were in use by the interviewed anchor customers (Q D6). Only one customer, a food retailer, uses a heating system of wood, which operates three hours one day in a week during the winter month of June. For heating, 25 kg wood were used over the last year. No other heating systems were in use (Q D7). Neither independent heating nor cooling systems were used by any of the anchor customers (Q D8).

Potential anchor customers are willing to pay for electricity for heating/cooling between M50 and M200, what corresponds to 3-20% share of the monthly income (Q D9, Table 9).

Table 8: Electric equipment of selected anchor customers in Tosing

Anchor customer	Lighting		Refrigerating equipment	
	Type & number	Capacity (W)	Type & number	Capacity (litres)
Boithatelo General Dealer	2 LED	10		
Katlehiso General Dealer	1 LED	10	2 freezers	300
Khutsong General Dealer			1 KIC freezer	160
Sunshine Public Bar			1 freezer	320
Bafokeng Café			1 refrigerator	160
Tlhakoaneng Café			1 kilofreeze	300
Boithate Tarven			1 freezer	100

Only three companies (commercial respondents) use any type of light bulbs. Two enterprises have two LED lights, another has one LED (Q D10). There are no light or motion sensor controls for operating the lighting in service area (Q D11-D12). The potential anchor customers express that they are willing to pay between M50 and M200 (3-40% of the income per month) for electricity for lighting (Q D13, Table 9).

No small equipment like desktop computers, monitors, laptops, servers, printers, or household appliances were in operation by any of the potential anchor customers in Tosing (Q D14).

Interestingly, the only one institution with any cooking facilities among anchor customers in Tosing was a primary school (Q D15, using wood as an energy source (Q D16). Only three respondents expressed a willingness to pay for electricity for cooking: the school, a food retailer, and restaurant. Their willingness to pay is moderate: commercial customers M50 each (1% and 3% of the income), and school M100 (4% of the month income) per month (Q D17).

Six customers (all are commercial users) have refrigerating equipment at their facilities (Q D18). Among this equipment is five freezers (one of them is of a KIC type, while the capacity of the others is 320 litres), as well as two refrigerators (Q D19).

All respondents are receptive to the introduction of electricity services into their facilities and express that it is important for companies and institutions to be connected (Q C4, Q C5). At the same time, all commercial users presume electricity is expensive, with the exception of the school (possibly because it receives subsidies from the state) (Q C6).

Respondents stated that their company/institution is ready to pay for electricity between M200 and M600 per month, which as a share of their monthly income ranges from 8-80%. The commercial customer with the highest income is the most moderate with spending allocation in proportion to income, being willing to pay 8% of monthly income. The majority of other customers express a willingness to pay between 13-27% of their income; only two indicated they would spend much greater sums of 40 to 80% of the month earnings (Q C7).

The indicated preferred methods to pay for electricity were via mobile phone (six respondents), followed by cash (2 respondents), and with a credit card (one respondent) (Q C8).

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

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
Boithatelo General Dealer	M3,792	M100	M100	M50	-	M250	7%
Katlehiso General Dealer	M1,500	M100	M100	-	M100	M300	20%
Buy Pass	M250	M50	M100	-	-	M150	60%
Leloala	M1,500	M100	M200	-	-	M300	20%
Khutsong General Dealer	M1,500	M200	M200	-	M200	M600	40%
Sunshine Public Bar	M1,500	M50	M100	M50	M50	M250	17%
Thaha Primary School	M2,500	M200	M200	M100	-	M500	20%
Bafokeng Café	M1,500	M200	M100	-	M100	M400	27%
Tlhakoaneng Café	M1,500	M50	M50	-	M50	M150	10%
Boithatelo Tavern	M1,500	M100	M100	-	M100	M300	20%
Total	M17,042	M1,150	M1,250	M200	M600	M3,200	

Three of ten potential anchor customers (two food retailers, mill) are planning to get a connection to the main grid electricity supplied by LEC (Q F1-F2). They believe this action will reduce their energy consumption (Q F3). Eight interviewed customers want to install additional electrical appliances (Q F4, Q F5).

Seven anchor customers are planning to buy a generator while four respondents are planning to purchase a solar PV system and car battery in the next five years (Q F9). Two customers are interested to acquire all three electrical sources.

There are no plans to upgrade buildings due to high purchasing costs and high installation/labour costs (Q F10-F11). It could be relevant to combine suitable financing mechanisms for SME and mild lending conditions with energy access solutions to create synergy in outcomes and impacts.

Energy demand forecast

Present power demand and supply of potential anchor customers in Tosing are summarized in Table 12. Presently, they have a substantially higher power demand than the surveyed group of private households. Based on their willingness to pay and in consideration of the potential ability to pay, it can be anticipated that the power demand will increase substantially once the mini-grid is available. Estimated future power demand of all anchor customers in the village, including non-interviewed ones, is presented in the Table 10.

Table 10: Future power demand of anchor customers in Tosing

Type	Number of institutions	Power demand, kWh/year	
		2019	2030
Health	1	14,300	28,600
School	3	1,500	10,500
Government	6	9,600	19,200
Retail	9	19,300	57,900
Craft	1	50	250
Total		**44,750**	**116,450**

The power demand distributes spatially as depicted in the Table 11.

Table 11: Development of power demand in Tosing 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	3.7	0.0	0.0	3.7	27.9	0.0	0.0	27.9	116.5	0.0	0.0	116.5
Anchor customers	25.8	0.0	0.0	25.8	36.0	0.0	0.0	36.0	74.0	0.0	0.0	74.0
Total	29.4	0.0	0.0	**29.4**	63.9	0.0	0.0	**63.9**	190.5	0.0	0.0	**190.5**

Table 12: Main characteristics of anchor customers in Tosing

#	Name	Type	Size	Operation hours	Electrical equipment	Annual power demand	Present power supply	Willingness to pay, Maloti/month
1	Thaha Primary School	**School**	7 employees; 2 buildings, area 50 m^2	7 h/day, 5 days/week, 10 months/year	None	0	None	500
2	Boithatelo General Dealer	**Retail**	2 employees; 1 building, area 21 m^2	14 h/day, 7 days/week, all year round	LED, 2 units	72 kWh	Solar panels 1,000 W	250
3	Katlehiso General Dealer	**Retail**	2 employees; 1 building, area 22 m^2	13 h/day, 7 days/week, all year long	LED, 1 unit; 2 freezers	1,785 kWh	Solar panels 1,000 W	300
4	Buy Pass	**Retail**	2 employees; 1 building, area 16 m^2	13 h/day, 7 days/week, all year long	None	0	Solar panels	150
5	Khutsong General Dealer	**Retail**	1 building, area 16 m^2	10 h/day, 7 days/week, all year long	1 freezer KIC	876 kWh	None	600
6	Sunshine Public Bar	**Retail**	1 employee; 1 building, area 19 m^2	10 h/day, 7 days/week, all year long	1 freezer	3,066 kWh	None	250
7	Bafokeng Café	**Retail**	1 employee; 1 building, area 13 m^2	13 h/day, 7 days/week, all year long	1 refrigerator	876 kWh	None	400
8	Tlhakoaneng Café	**Retail**	2 employees; 1 building, area 15 m^2	13 h/day, 7 days/week, all year long	1 refrigerator	876 kWh	1 solar panel	150
9	Boithatelo Tavern	**Retail**	1 employee; 1 building, area 18 m^2	15 h/day, 7 days/week, all year long	LED, 2 units; 1 freezer	953 kWh	1 solar panel 1,000 W	300
10	Leloala	**Craft**	1 employee; 1 building, area 9 m^2	10 h/day, 6 days/week, all year long	None	0	1 generator of 3,000 W, powered by unleaded petrol	300
					Total	8,504 kWh		3,200

3.2 Set-up for Mini-Grid

A preliminary engineering design to determine the capacity of equipment and capital and operating costs can be realized using software tools to facilitate planning and financing requirements for mini-grids based on anticipated demand. In this study a mini-grid for Tosing is designed using HOMER Pro software. The consumption pattern as derived in previous sections of this report is used to predict the size of the plant generation equipment.

HOMER analysis shows that for the electricity supply under present conditions, the combination of PV power plant and battery storage is the most optimal and least-cost. The capacity of battery storage should exceed maximum hourly output of solar panels by a factor of about 3, but this ratio depends to large extent on relative costs of solar panels and battery. In this combination the unmet load accounts for about 2%, and excess electricity produced is 44% which makes it possible to meet growth in demand and connect further loads.

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

Element	Size	CAPEX (Maloti)	Replacement costs (Maloti)	OPEX (Maloti/year)
PV Power Plant	42.4 kW	716,560	0	8,268
Battery	127 kWh	495,300	1,981,200	16,510
System converter	13 kW	33,800	33,800	0
Power lines	4.32 km	90,636	0	1,813
Power meters	95 units	304,000	0	6,080
Total	-	**1,640,296**	**2,015,000**	**816,775**

Regarding present and future capacity needs, it would be prudent to design a modular mini-grid that would allow for expansion to meet the expected demand increase over time, while balancing against the trade-off of higher initial investment costs for increased PV and battery size. For expected demand increase in 2019 after commissioning of a mini-grid the most optimal configuration remains a combination of solar PV power plant and battery storage.

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

Element	Size	CAPEX (Maloti)	Replacement costs (Maloti)	OPEX (Maloti/year)
PV Power Plant	129 kW	2,180,100	0	25,155
Battery	395 kWh	1,540,500	6,162,000	51,350
System converter	39.6 kW	102,960	102,960	0
Power lines	4.36 km	91,542	0	1,831
Power meters	96 units	307,040	0	6,141
Total	-	**4,222,142**	**6,264,960**	**2,111,925**

Figure 6 presents the distribution of capital costs between different components of a mini-grid. It shows that power grid components (lines and meters) account for almost 10% of the capital costs.

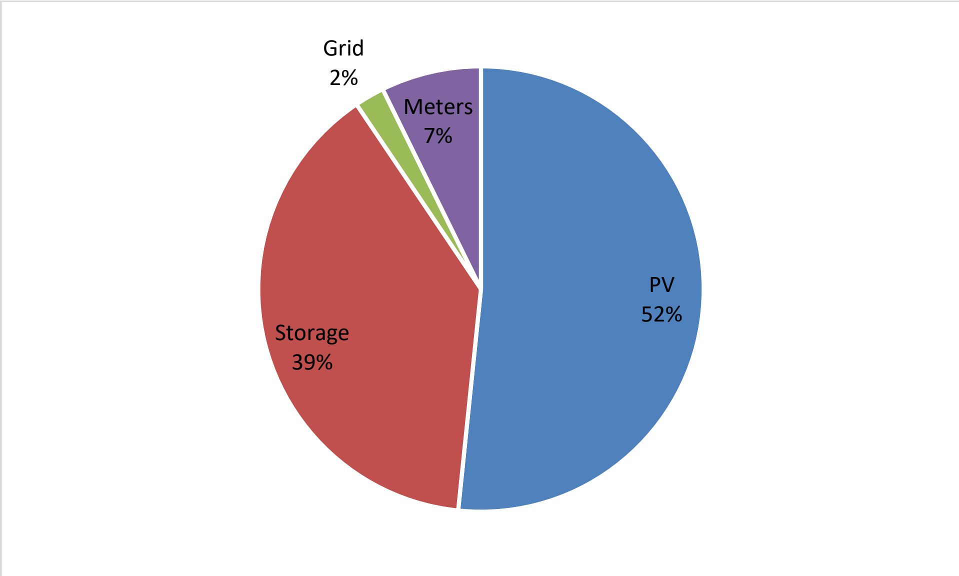

Figure 6: Distribution of capital costs of a mini-grid in Tosing in 2019

For the Mini Grid, three feasible sites were identified. Two of them, the sites marked blue on the Figure 7, were chosen according to physical criteria including orientation to the equator, area size and availability of space. The yellow marked optimal site was determined according to the calculation algorithm of the geometrical mean of all buildings within a radius of 1-3 km in the village, i.e. it is the location that minimizes the sum of distances to all existing potential residential, public and business customers. In the case of Tosing, the theoretically chosen potential site for a mini-grid coincided with the site chosen in consultation with the community during field research. This particularly suitable site is presented on the following map as two squares, blue and yellow, inscribed in each other.

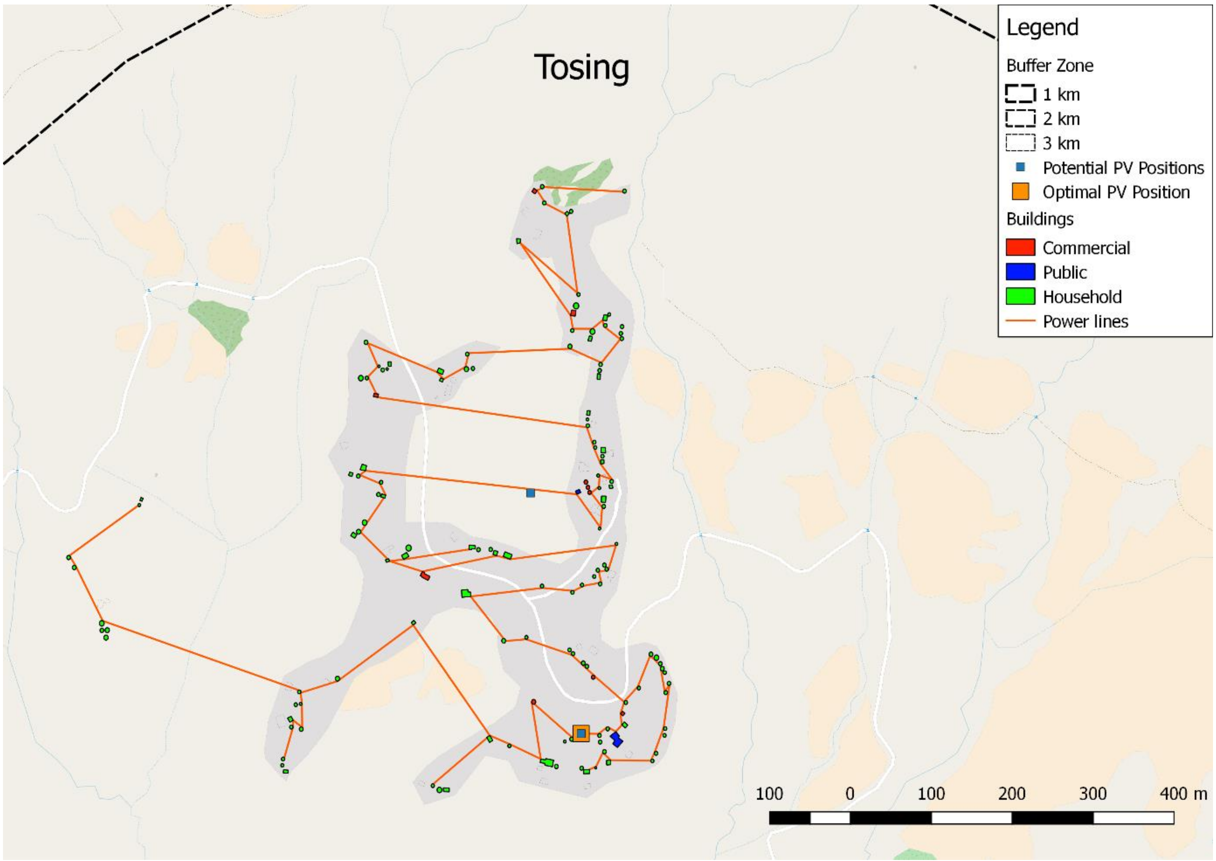

Figure 7: Map of the mini-grid set-up in Tosing

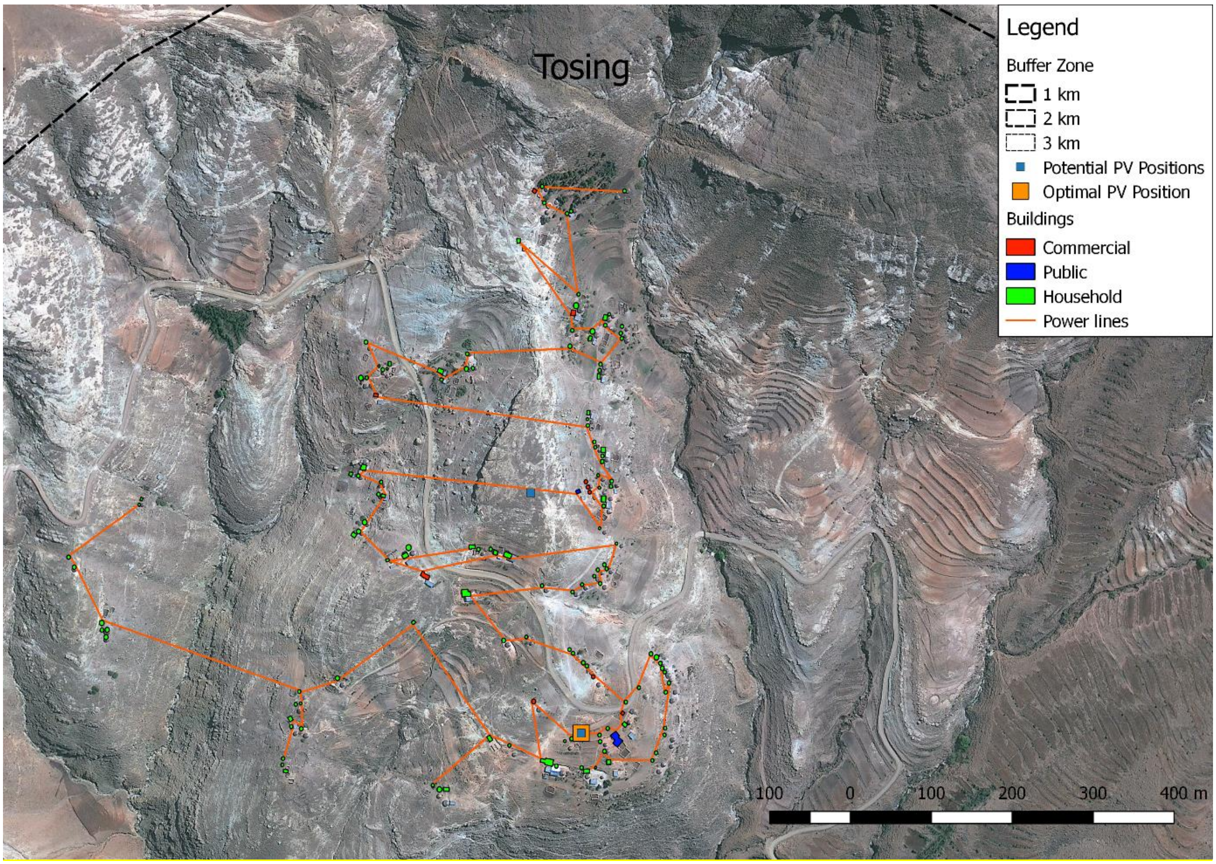

Figure 8: Satellite map of the mini-grid set-up in Tosing

During the operation period leading up to 2030, additional generation sites and equipment configurations can be considered in addition to the solar PV plant, such as e.g. mini hydro power plant. The option with PV, storage and hydro is identified as a least-cost solution by HOMER software. During operations, it is worthwhile to carry out extensive research of river flow rates and conditions throughout the year to define hydro energy potential and evaluate its suitability to meet growth in monitored demand. Costs and benefits should be considered in conjunction with the timing of capacity expansion, as market conditions are dynamic. During the operations period further reductions of PV and battery costs can be anticipated, whereas e.g. the hydropower costs would likely remain the same (as the technology is already mature and the cost reduction potential has been exploited).

Table 15: Elements of mini-grid setup in Tosing in 2030

Element	Size	CAPEX (Maloti)	Replacement costs (Maloti)	OPEX (Maloti/year)
PV Power Plant	306 kW	5,171,400	0	59,670
Battery	792 kWh	3,088,800	12,355,200	102,960
Hydro Power Plant	100 kW	6,000,000	0	180,000
System converter	105 kW	273,000	273,000	0
Power lines	4.86 km	102,131	0	2,043
Power meters	107 units	342,555	0	6,851
Total	-	**14,977,886**	**12,628,200**	**8,788,100**

The expected growth of demand will likely result in lower generating costs in the future (Table 16) although at this stage quantitative assessment of cost reduction due to technology and market maturation is not considered in this study. For the 2030 case, there is a high rate of excess power to allow for a generation entirely based on renewable energies. This oversupply of energy could be avoided in two ways: 1) allow a minor share of fossil-based generation which would run primarily during winter, when PV generation is low, leading also to lower overall generation costs, or 2) demand side management to follow seasonal availability of power e.g. additional usage of irrigation or refrigeration and cooling to match the patterns of solar generation.

Table 16: Characteristics of mini-grid setup in Tosing in present and future

Time horizon	Unmet load, %	Excess electricity, %	LCOE, M/kWh
Present	2.08	43.9	9.431
2019	2.05	43.7	8.708
2030	2.19	68.9	6.950

3.3 Economic Viability

For the assessment of economic viability of a mini-grid setup, the figure of merit selected is the internal rate of return (IRR) with revenues on the basis of the present national electricity tariffs. This calculation permits assessment of economic viability under the present framework conditions. Additionally, we calculated a uniform tariff for all customers allowing for an IRR of 8%, equivalent to levelized costs of electricity (LCOE). The difference between the LCOE tariff and the national tariff indicates the amount of public support needed to keep tariffs in the mini-grid at the level of LEC tariffs in the national grid. For the calculation, we assume two different scenarios. The first scenario assumes that the energy demand will remain stable on the level of 2019 over the entire project lifetime of 25 years. In that case, the IRR with revenues on the level of national tariffs will be negative, -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 M7,174,362 over 25 years, or M286,974 per year. Converted into electricity demand, the subvention need would be M2.60/kWh. Regarding allowance need in terms of customers, some M1,293 should be additionally paid per year per customer.

The second scenario earmarks the increase of electricity demand between 2019 and 2030 according to the load forecast and stable demand after 2030. Under these circumstances, the difference between tariff revenue and total project expenditure amounts M19,996,213 over whole project lifetime, and M799,849 per year. The subvention need per kWh would be somewhat lower than in the first scenario: M2.30/kWh. Due to significant annual increase of energy demand, allowance needs per customer would also increase, accounting for M3,223 per customer per year.

3.4 Summary

Tosing is a middle-sized village with 200 households and some anchor loads. The current electricity demand is estimated at approximately 36,150 kWh per year, where about 76% is consumed by anchor customers, and 24% by households. This uneven distribution of shares in total energy consumption is typical for settlements that lack modern energy access. The commissioning of a mini-grid and transition to electrification is anticipated significantly impact and stimulate energy demand. Residential customers are anticipated to consume almost 60% of electricity delivered and public and commercial customers about 40%. Annual electricity demand is expected to grow from 110,200 kWh in 2019 to approximately 421,950 kWh in 2030.

In order to cover this demand, initially PV power plant and battery storage solutions would be sufficient. In due course additional local energy resources such as hydro power or wind power should be evaluated for potential integration into the generation system. The decision should be made upon study of a potential of these RE technologies in the region and further estimation of the capital and levelized cost of the technologies.

4. Sebapala/Lefikeng Mini-Grid

Sebapala (30°18'22.3"S 27°52'02.5"E) is a village located about 51.4 km from Quthing town and is found next to Sebapala Spruit. It is located about 3 km from A4 main road.

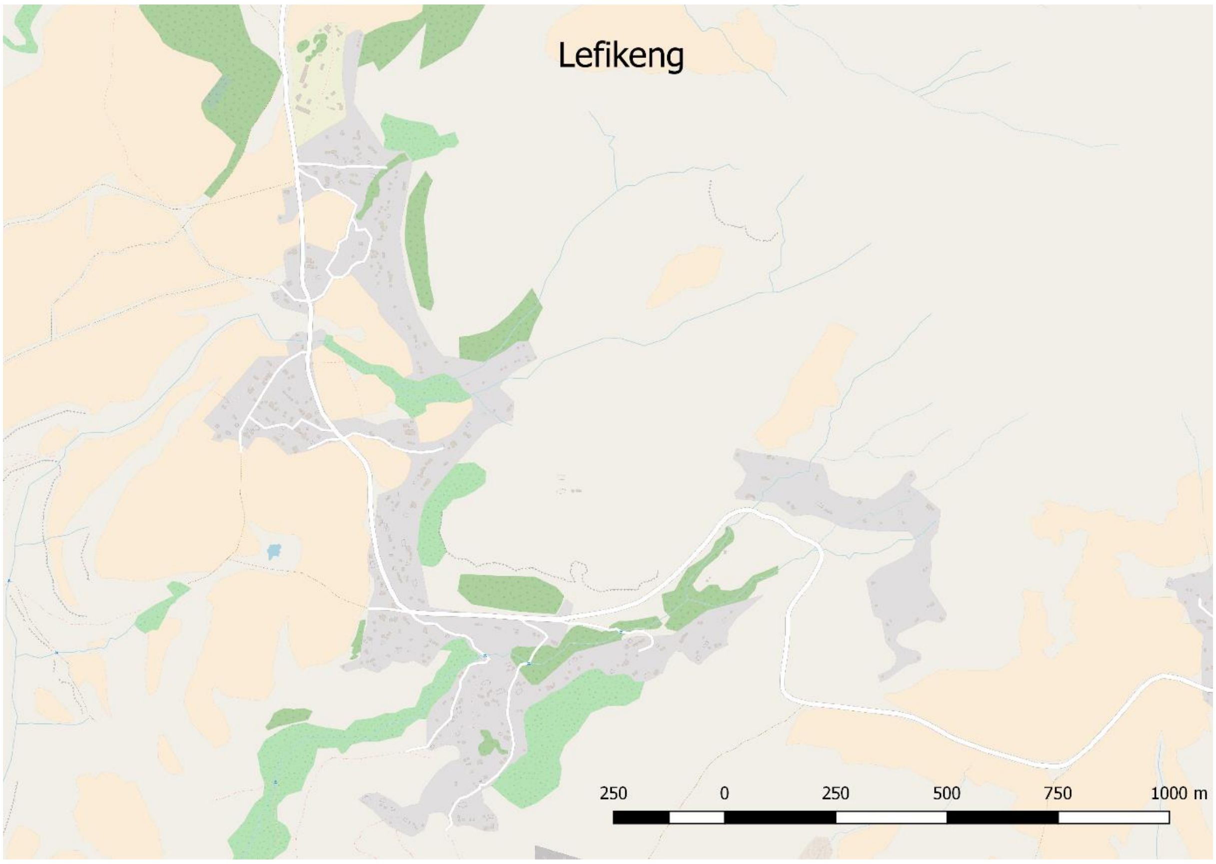

Figure 9: Map of Sebapala/Lefikeng

Figure 10: Sebapala Field Visit Pictures

4.1 Customer Base

About 200 households live in Sebapala. Potential anchor loads include six medium size shops, a church, a guest house, a secondary and two primary schools, the principal chief's residence and office, a sizable number of migrant workers, and a hammer mill. According to the head man of

Sebapala, the main sources of income of households in order of descending importance in the village are farming, self-employment, and employment in South Africa. The nearest service centre is Mt. Moorosi, which is 20 km away from Sebapala.

4.1.1 Households

Sociodemographic characteristics

In the survey ten households were interviewed. The head man indicated that there are 120 households and 350 inhabitants in the village.

Surveyed households have a minimum of two household members and a maximum of eleven members with sixty percent of the households having five or more members. The average household size is six persons (Q B1).

Nine households have one to three housing units, and one household has seven housing units. On average a household has 2.6 buildings (Q C1). Sixty percent of the household respondents from Sebapala have a rontabole type of house. The second most popular house type is polata at thirty percent ownership among respondents. The remaining household has a heisi. Most of the units have one room with the exception of two polatas. Total area ranges from 25 to 86 m^2 and the average floor area per household is 48 m^2 (Q C2).

Two of ten households interviewed in Sebapala earn less than M300 per month, one household earns between M300 and M500, and the majority of the households (4 HH) earn between M500 and M1,000 and three households earn between M1,000 and M5,000 (Q C3). The prevailing majority of interviewed households in Sebapala do not receive any remittances. Only one household received between M500 and M1,000 last year (Q C4).

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

Energy supply

All interviewed households in Sebapala used fuel wood for housing purposes. The majority (7 HH) had collected it for free. The remaining households either obtained the fuel wood by self-production or through payment in kind. They used between 640 and 997 bundles, 843 to 951 pieces, and 50 bags fuel wood, which is equivalent to between 9,400 kWh and 14,700 kWh. There were no expenses for fuel wood. Two households additionally used 182 and 970 bundles of shrubs obtained by collection using respondents' own time and effort (Q D1). All households have an area to collect fuel wood (Q D2) in either a communal or private forest (Q D3).

The majority of interviewed households (9 HH) indicated that they have to travel between half an hour and an hour to the edge of the fuel collecting area and back to collect wood. One household needs to travel up to 30 minutes to the edge of the fuel wood collecting area and back (QD4). This demonstrates that the interviewed households live relatively close to the forest. The nine households that travel between half an hour and an hour to the forest spend the same amount of time in wood collection. Maximal time spent for collection of fuel wood is between 6 and 36 hours per year. Assuming an hourly wage of M8, this converts to annual opportunity cost of approximately M178. A total of thirteen women, thirteen children and only four men from the interviewed households are involved in the fuel wood collection (Q D7).

The majority of the households (9 HH) do not have an improved fuelwood stove. Only one household uses an ACE 1 Smokeless cook stove (Q D8). Regarding expenses for biomass, eight households spend less than M50 per month, and two households between M50 and M200 (Q D9). All households pay for commercial fuels in cash and prefer to continue to do so (Q D10-D11).

Sixty percent of the interviewed households in Sebapala use wood, twenty percent use paraffin, and another twenty percent use LPG as a main source of energy for cooking. The majority of interviewed households (8 HH) rely on a second fuel type for cooking such as fuel wood (4 HH), paraffin (2 HH), LPG (2 HH) (Q F1). Quantities of used energy resources and annual expenses are shown in the Table 17.

Households in Sebapala are willing to pay between M20 and M200 for electricity for cooking per month and on average M100 (Q F3, Table 19). This number seems reasonable compared to their actual expenses for cooking fuels. No household owns a Wonder box (Q F4).

Almost all interviewed households heat their houses (Q G1). Seven households used paola, two used paraffin heater, and two used open fire (Q G2). Most households (8 HH) use wood as the main energy source for space heating while a few households use paraffin; as alternatives shrubs and animal dung are also used (Q G3). Willingness to pay for electricity for space heating ranges from M50 to M300, and is about M100 on average (Q G5, Table 19). The heating area amounts 11 to 25 m^2, with an average area of 16 m^2 (Q G6). For water heating, the prevailing energy source was wood (8 HH), and some households also use paraffin and shrubs (Q G7).

Ninety percent of households used paraffin as main energy source, and candles as an alternative source for lighting. However, it is notable that households use a combination of the two sources of lighting (Q H1). No light bulbs were utilised by any of the surveyed households (Q H3). Willingness to pay for electricity for lighting ranges from M50 to M300, with an average value of M100 (Q H4, Table 19). On average, the households spent M487/a on energy sources for lighting, so the equivalent budget would be at least available for purchasing power for lighting purposes.

All interviewed households in Sebapala do not currently use any electrical appliances at home (Q E1) but all want to have electricity in their houses (Q E7). Considering plans to purchase electrical appliances in the next five years, the most popular were a radio, television flat screen and refrigerator. Microwave, iron, electric heater, electric stove, and electric geyser are also considered to be important (Q I3).

Table 17: Household use of energy sources in Sebapala

HH No.	Cooking			Space and water heating			Lighting			HH income, M/a
	Use of energy sources	Annual energy consumption, kWh/a	Annual expenses, M/a	Use of energy sources	Annual energy consumption, kWh/a	Annual expenses, M/a	Use of energy sources	Annual energy consumption, kWh/a	Annual expenses, M/a	
1	0.5 kg wood, 1 litre paraffin per day	4,672	4,015	136 litres paraffin per year	1,408	1,496	90 litres paraffin per year	932	990	18,000
2	0.9 kg wood per day	1,610	0	1,640 kg wood per year	8,036	0	20 litres paraffin, 5 candles per year	208	225	9,000
3	10.2 kg wood, 0.24 kg LPG per day	19,364	1,975	1,630 kg wood, 620 kg animal dung per year	10,901	0	55 litres paraffin per year, 12 candles per year	571	708	4,800
4	0.41 kg wood, 0.3 kg LPG per day	2,137	2,435	295 kg wood per year	1,446	0	48 litres paraffin, 36 candles per year	502	708	9,000
5	6.2 kg wood, 0.6 litre paraffin per day	13,355	2,044	1,794 kg wood per year, 458 kg shrubs	11,035	0	24 litres paraffin, 10 candles per year	250	314	9,000
6	0.5 kg wood, 1 litre paraffin per day	4,672	4,015	1,978 kg wood per year	9,692	0	40 litres paraffin, 20 candles per year	417	540	42,756
7	0.7 kg wood, 0.1 kg LPG per day	1,719	810	103 kg wood, 20 litres paraffin per year	712	220	20 candles per year	3	220	18,000
8	0.4 kg wood, 0.1 kg LPG per day	1,183	810	1,950 kg wood per year	9,555	0	48 litres paraffin per year	497	528	9,000
9	6.2 kg wood per day	11,089	0	1,898 kg wood, 754 kg shrubs per year	12,995	0	24 litres paraffin per year	248	264	1,800
10	0.5 kg wood, 0.5 litre paraffin per day	2,783	2,008	1,134 kg wood per year	5,557	0	12 litres paraffin, 20 candles per year	127	372	1,800
	Average	**6,258**	**1,811**	**-**	**7,134**	**172**	**-**	**376**	**487**	**-**

Table 18: Households desired future uses of electricity in Sebapala, 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
Radio	X	X	X	X	X	X	X	X	X		9
TV	X		X	X	X	X	X	X	X	X	9
Lighting	X	X	X	X		X	X		X	X	8
Phone charging	X	X	X	X		X	X		X	X	8
Water heating	X	X	X		X		X	X	X	X	8
Refrigeration	X	X	X		X	X		X	X		7
Cooking/ re-heating		X		X		X				X	4
Ironing	X	X	X						X		4
Space heating	X					X					2
Laundry					X			X			2
Charging (other than phone)	X										1
Sewing										X	1
Dishwashing											0
Air-conditioning											0
Computer											0
Water pumping											0
Workshop											0
Total	9	7	7	5	5	7	5	5	7	6	-

In terms of willingness to pay for electricity in general ranged from M100 to M600. Three households are willing to pay M200, three households willing to pay M300 and two households are willing to pay at least M500 per month thus the average willingness to pay is about M320 (Q E9, Table 19). Almost all households (9 HH) would prefer to pay for electricity with Mpesa with only one household preferring to pay cash (Q E10).

Table 19: Ability and willingness to pay for electricity in general and for different applications of households in Sebapala

HH #	Earnings per month (ability to pay)	Willingness to pay for electricity (Maloti and % of earnings)				Plans to buy electric appliances
		General	For cooking	For space heating	For lighting	
1	M1,500	M600 (40%)	M100 (7%)	M300 (20%)	M300 (20%)	Refrigerator, TV flat screen, iron
2	M750	M300 (40%)	M100 (13%)	M50 (7%)	M50 (7%)	Refrigerator, electric heater, TV flat screen
3	M400	M200 (50%)	M100 (25%)	M50 (13%)	M60 (15%)	Refrigerator, TV flat screen, iron, microwave
4	M750	M200 (27%)	M100 (13%)	M50 (7%)	M50 (7%)	Refrigerator, TV flat screen, laptop, hair clipper
5	M750	M100 (13%)	M20 (3%)	M30 (4%)	M50 (7%)	Refrigerator, TV flat screen
6	M3,563	M500 (14%)	M200 (6%)	M100 (3%)	M200 (6%)	Refrigerator, TV flat screen, iron, bread maker, toaster, hair clipper
7	M1,500	M300 (20%)	M100 (7%)	M100 (7%)	M50 (3%)	Refrigerator, electric geyser, TV flat screen, iron, bread maker, microwave
8	M750	M300 (40%)	M100 (13%)	M100 (13%)	M100 (13%)	Refrigerator, TV flat screen, electric kettle, toaster, microwave
9	M150	M200 (13%)	M50 (33%)	M50 (33%)	M50 (33%)	Refrigerator, hoover, TV flat screen, electric kettle, microwave, hair clipper
10	M150	M500 (333%)	M200 (133%)	M100 (67%)	M100 (67%)	Refrigerator, electric stove, hair dryer, TV flat screen, iron, microwave
	Average	M320	M107	M93	M101	

Three households want to acquire a solar PV set, three households plan to acquire a car battery, and two households plan to acquire a generator running on gas in the next five years (Q I4).

Energy demand forecast

All households interviewed in Sebapala belong to a basic type, given the current absence of electricity uses, supply and relatively low income. Extrapolating to the entire village, a similar distribution of household types as described in the General Part is postulated. For forecasting, it is assumed that the number of households increases equally over all household types by 1% per year. Furthermore, the specific demand of all household types is expected to increase once electricity is available due to acquired electrical appliances. The answers given on planned purchases of appliances confirms this expectation, however experiences in other countries indicate that household demand for power remained stable even five years after power supply arrived (Blog World Bank 2017). In practice, the benefits from access to a power supply are likely to be exploited more completely by the medium income and affluent households (Table 20). From a commercial point of view, the more indigent households are less interesting, although they stand to gain the most from enhanced living conditions through electrification.

Table 20: Present and future power demand by households in Sebapala

Household type	No. of HH in Sebapala			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

Sebapala village features a post office, primary schools, teacher houses, grocery shops, a church, water supply facilities, a tavern, according to the local councillor. A grocery shop and a tavern use the following types of energy sources: solar PV (grocery shop) and LPG (tavern and grocery shop).

In Sebapala eight anchor customers were interviewed: two schools and six commercial customers (three cafes, two food retail shops, and one metalworking shop) (Q B1). Schools are in state ownership; all other potential customers are private sole proprietorships (Q B2). Commercial enterprises have between one and three employees, mainly female. One school has eight employees, the other has only one (Q B3). Commercial enterprises earn between M750 and M7,500 per month, M2,125 on average, with the highest income attained by the metalworking shop; the schools have M250 or M750 at their disposal per month (Q B4-B6).

Considering operating hours, schools work 7 or 13 hours per day 5 days a week over 10 months in a year. Commercial users work (with rare exception) all days a week between 12 and 14 hours, all year round. The metalworking shop is open 9 hours per day, 6 days a week over whole year (Q D1-D3).

Regarding the number of buildings, all potential anchor customers, except one school, occupy one building while the primary school occupies four buildings (Q D4). The total area of all school buildings amounts to 109 m^2. The area of all other buildings is relatively even distributed between 11 and 18 m^2. Only the school buildings are insulated (Q D5).

Energy supply

With exception of the two schools, no interviewed potential anchor customers consumed any coal or biomass resources over the last year. The schools used wood (1,784 or 2,941 kg, equivalent to 8,742 or 14,411 kWh) for cooking, paying from M800 to M1,000 (Q C1).

Table 21: Consumption of energy resources and electricity generation of selected anchor customers in Sebapala

Anchor customer	Wood		Solar PV	
	Quantity, kg	End use	System size	End use
Lekhula's Workshop			1,000 W	Lighting
Sepabala Primary School	2,941	Cooking		
Lefikeng Pre-school	1,784	Cooking		
Tuck Shop			1,000 W	Lighting
Tuck Shop			1,000 W	Lighting
Tsoelipanang Café			5,000 W	Lighting
Total quantity	**4,725**		**8,000 W**	

Two retail shops, one café, and a metalworking shop use solar electricity with a capacity of 100 or 1,000 W, used all year long 4 hours per day for lighting (Q C2, Q E2). None of the potential anchor customers used a generator (Q E3). All respondents are receptive to the introduction of electricity services into their facilities, are concerned that it will be expensive, and express that it is important for companies and institutions to be connected (Q C4-C6). In general, prospective anchor customers express a willingness to pay between M100 to M1,200 per month for electricity, with an average value of M500 (Q C7). The preferred payment method to pay for electricity was mobile phone (4 respondents), followed by cash (3 respondents) and via credit card (1 respondent).

No interviewed anchor customer has any air-conditioning, heating or cooling system at its disposal (Q D6-D8). The willingness to pay for electricity for heating/cooling lies between M50 and M250, with an average value of M140 (Q D9).

Table 22: Electric equipment of selected anchor customers in Sebapala

Anchor customer	Lighting		Refrigerating equipment	
	Type & number	Capacity, W	Type & number	Capacity (L)l
Lekhula's Workshop	1 LED	15		
Tuck Shop	1 LED	10		
Tuck Shop	1 LED	10	1 freezer UCF 215G	60
Tsoelipanang Café	1 LED	12		

Two food retailers, one café, and a metalworking shop used LED lights, one in each case (Q D10). Other institutions did not use any lights. No customer has light or motion sensor control (Q D11-D12). The willingness to pay for electricity for lighting was a bit higher compared to other electricity uses and ranged between M100 and M500, averaging M220 (Q D13).

No interviewed organization had any small equipment in use (Q D14). The only institutions with cooking facilities are the schools, which use wood for these purposes (Q D15-D16). Only the schools and food retailers showed any willingness to pay for electricity for cooking, ranging from M100 to M200 (Q D17). One café and one food retail shop have refrigerating equipment: one freezer each (Q D18-D19). These customers are also the only respondents willing to pay for electricity for refrigeration needs (Q D20).

As for future potential, all interviewed potential anchor customers strive to have grid electricity (Q F5). One café plans to replace a lighting system (Q F2). Six customers want to acquire a generator, and one customer wants to purchase all three energy sources including solar PV system and a car battery in each case (Q F9). No upgrade of buildings is planned in the next five years (Q F10), due to high purchasing costs and high installation/labour costs (Q F11).

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

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
Lekhula's Workshop	M7,500	M100	M300	-	-	M400	5%
Sepabala Primary School	M250	M200	M300	M200	-	M700	280%
Lefikeng Pre-school	M750	M250	M250	M100	-	M600	80%
Tuck Shop	M750	M100	M100	M100	-	M300	40%
Tuck Shop	M750	M50	M100	M100	M50	M300	40%
Monyakeng Café	M750	M100	M100	-	-	M200	27%
Tsoelipanang Café	M1,500	M200	M500	-	-	M700	47%
Riverside General Café	M1,500	M100	M100	-	M100	M300	20%
Total	M13,750	M1,100	M1,750	M500	M150	M3,500	

Energy demand forecast

The present power demand and supply of potential anchor customers in Sepabala are summarized in the Table 24. The future power demand of all anchor customers in the village, including non-interviewed ones, is presented in the Table 25.

Table 24: Main characteristics of anchor customers in Sepabala

#	Name	Type	Size	Operation hours	Electrical equipment	Annual power demand	Present power supply	Willingness to pay, Maloti/month
1	Sebapala Primary School	**School**	8 employees; 4 buildings, area 96 m^2	13 h/day, 5 days/week, 10 months/year	None	0	None	700
2	Lefikeng Pre-School	**School**	1 employee; 1 building, area 18 m^2	7 h/day, 5 days/week, 10 months/year	None	0	None	600
3	Tuck Shop	**Retail**	3 employees; 1 building, area 11 m^2	12 h/day, 7 days/week, all year long	LED, 1 unit	31 kWh	Solar panels 1,000 W	300
4	Tuck Shop	**Retail**	1 employee; 1 building, area 13 m^2	12 h/day, 7 days/week, all year long	LED, 1 unit, 1 freezer	907 kWh	Solar panels 1000 W	300
5	Monyakeng Café	**Retail**	1 employee; 1 building, area 11 m^2	13 h/day, 6 days/week, all year long	None	0	None	200
6	Tsoelipanang Café	**Retail**	1 employee; 1 building, area 14 m^2	14 h/day, 7 days/week, all year long	LED, 1 unit	36 kWh	Solar panels 5000 W	700
7	Riverside General Café	**Retail**	2 employees; 1 building, area 14 m^2	13 h/day, 7 days/week, all year long	1 freezer	876 kWh	None	300
8	Lekhula's Workshop	**Craft**	1 employee; 1 building, area 15 m^2	9 h/day, 6 days/week, all year long	LED, 1 unit	20 kWh	Solar panels 1,000 W	400
					Total	1,869 kWh		3,500

Table 25: Future power demand of anchor customers in Sepabala

Type	Number of institutions	Power demand, kWh/year	
		2019	2030
School	3	1,500	10,500
Government	2	3,200	6,400
Retail	7	12,450	37,350
Craft	1	50	250
Total		**17,200**	**54,500**

The power demand distributes spatially as depicted in the Table 26.

Table 26: Development of power demand in Sebapala 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	5.5	2.4	0.0	7.9	41.9	18.2	0.0	60.0	174.8	75.9	0.0	250.7
Anchor customers	19.9	1.8	0.0	21.7	26.6	2.8	0.0	29.4	40.6	8.4	0.0	49.0
Total	25.4	4.2	0.0	**29.6**	68.4	21.0	0.0	**89.4**	215.4	84.3	0.0	**299.7**

4.2 Set-up for Mini-Grid

In this study a mini-grid for Sebapala is designed using HOMER Pro software. The consumption pattern as derived in previous sections of this report is used to predict the size of the plant generation equipment.

HOMER analysis shows that for the electricity supply under present conditions, the combination of PV power plant and battery storage is the most optimal and least-cost. The capacity of battery storage should exceed maximum hourly output of solar panels by a factor of about 3, but this ratio depends to large extent on relative costs of solar panels and battery. In this combination the unmet load accounts for about 2%, and excess electricity produced is 43% which makes it possible to meet growth in demand and connect further loads (with consideration given to evaluating alternative generation sources such as mini hydropower and wind).

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

Element	Size	CAPEX (Maloti)	Replacement costs (Maloti)	OPEX (Maloti/year)
PV Power Plant	18 kW	304,200	0	3,510
Battery	56 kWh	218,400	873,600	7,280
System converter	6.56 kW	17,056	17,056	0
Power lines	7.70 km	161,574	0	3,231
Power meters	192 units	614,400	0	12,288
Total	-	**1,315,630**	**890,656**	**657,725**

Regarding present and future capacity needs, it would be prudent to design a modular mini-grid that would allow for expansion to meet the expected demand increase over time, while balancing against the trade-off of higher initial investment costs for increased PV and battery size. For expected demand increase in 2019 after commissioning of a mini-grid the most optimal configuration remains a combination of solar PV power plant and battery storage.

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

Element	Size	CAPEX (Maloti)	Replacement costs (Maloti)	OPEX (Maloti/year)
PV Power Plant	94.9 kW	1,603,810	0	18,506
Battery	300 kWh	1,170,000	4,680,000	39,000
System converter	34.8 kW	90,480	90,480	0
Power lines	7.77 km	163,190	0	3,264
Power meters	194 units	620,544	0	12,411
Total	**-**	**3,648,024**	**4,770,480**	**1,829,500**

Figure 11 shows the distribution of capital costs between the different components of the mini-grid. It can be noticed that power grid components (lines and meters) accounts for a significant share (more than 20%) of the capital costs.

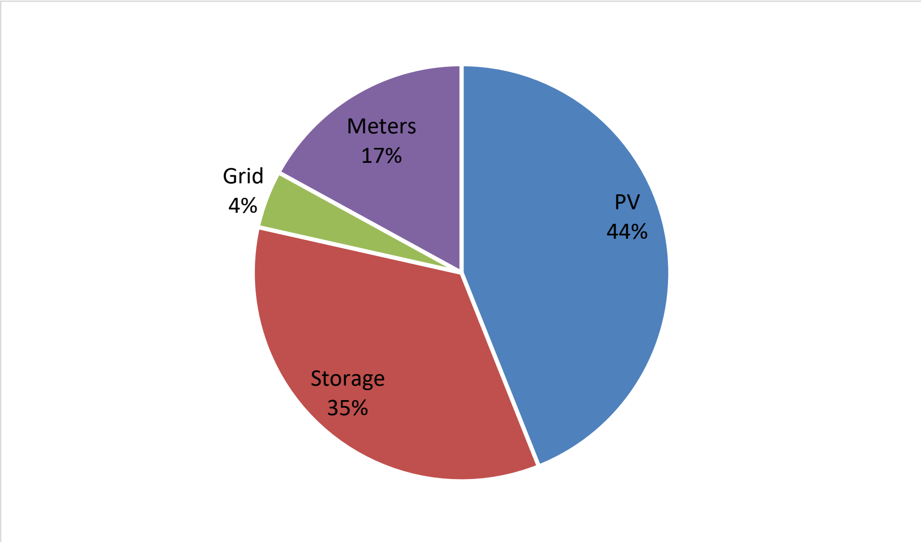

Figure 11: Distribution of capital costs of a mini-grid in Sebapala in 2019

For the Sebapala Mini Grid three feasible sites were identified. Two of them, which are marked blue on the Figure 12, were chosen according to physical criteria like orientation to the equator, area size and availability of space. The yellow marked optimal site was determined according to the calculation algorithm of the geometrical mean of all buildings within a radius of 1-3 km in the village, i.e. it is the location that minimizes the sum of distances to all existing potential residential, public and business customers. In the case of Sebapala/Lefikeng the theoretically chosen potential site for a mini-grid coincided with the site chosen in consultation with the community during field research. This particularly suitable site is presented on the following map as two squares, blue and yellow, inscribed in each other.

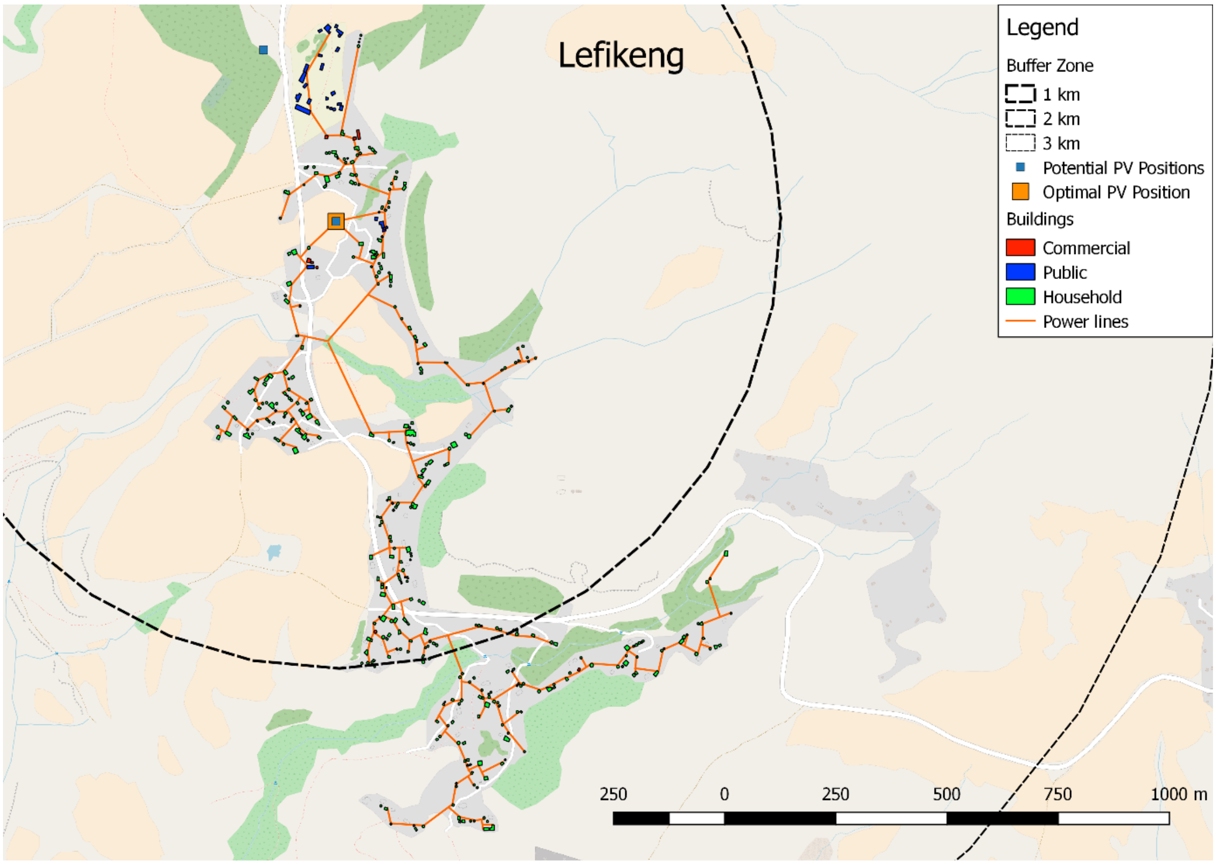

Figure 12: Map of the mini-grid set-up in Sebapala/Lefikeng

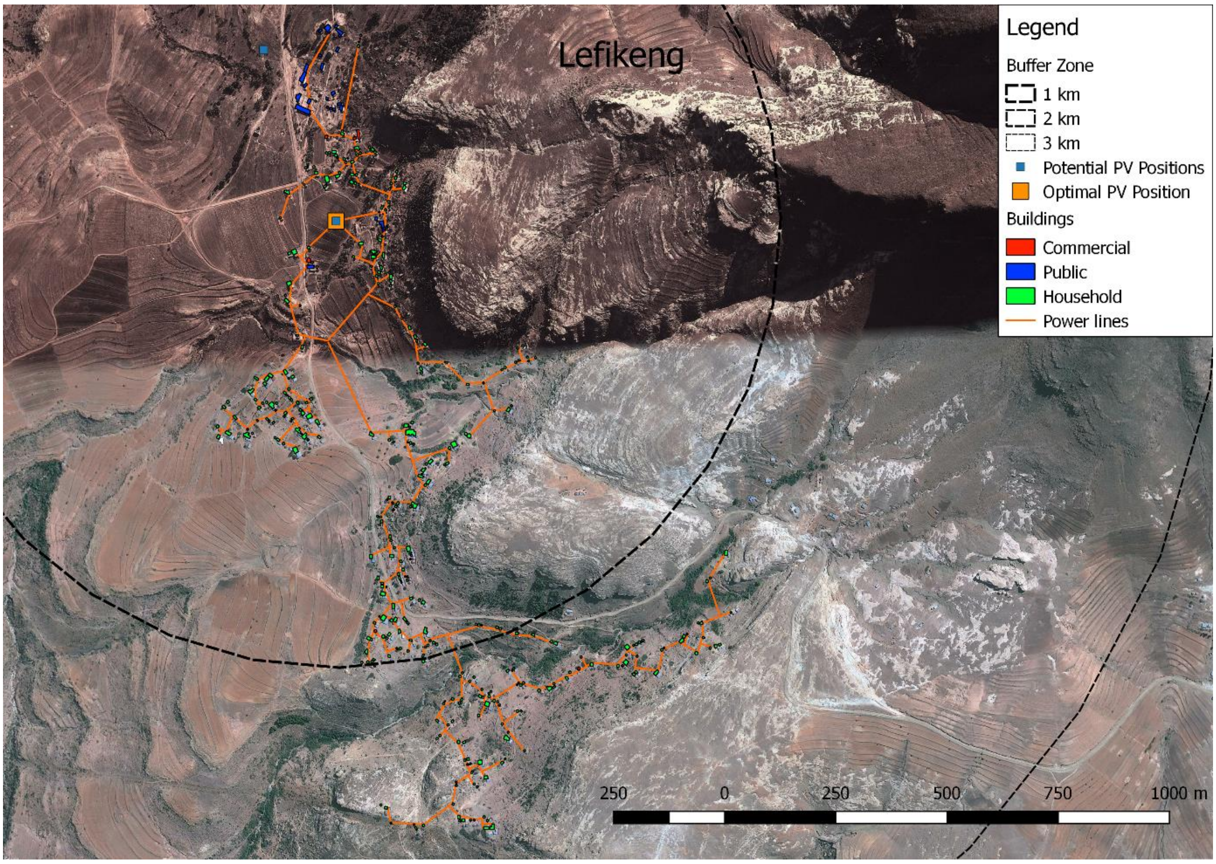

Figure 13: Satellite map of the mini-grid set-up in Sebapala/Lefikeng

During the operation period leading up to 2030, additional generation sites and equipment configurations can be considered in addition to the solar PV plant, such as e.g. mini hydro power plant. The option with PV, storage and hydro is identified as a least-cost solution by HOMER software. During operations, it is worthwhile to carry out extensive research of river flow rates and conditions throughout the year to define hydro energy potential and evaluate its suitability to meet growth in monitored demand. Costs and benefits should be considered in conjunction with the timing of capacity expansion, as market conditions are dynamic. During the operation period further reductions of PV and battery costs can be anticipated, whereas e.g. the hydropower costs would likely remain the same (as the technology is already mature and the cost reduction potential has been exploited).

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

Element	Size	CAPEX (Maloti)	Replacement costs (Maloti)	OPEX (Maloti/year)
PV Power Plant	258 kW	4,360,200	0	50,310
Battery	663 kWh	2,585,700	10,342,800	86,190
Hydro Power Plant	100 kW	6,000,000	0	180,000
System converter	135 kW	351,000	351,000	0
Power lines	8.67 km	182,066	0	3,641
Power meters	216 units	692,321	0	13,846
Total	**-**	**14,171,287**	**10,693,800**	**8,349,700**

The expected growth of demand will likely result in lower generating costs in the future (Table 16) although at this stage quantitative assessment of cost reduction due to technology and market maturation is not considered in this study. For the 2030 case, there is a high rate of excess power to allow for a generation entirely based on renewable energies. This oversupply of energy could be avoided in two ways: 1) allow a minor share of fossil-based generation which would run primarily during winter, when PV generation is low, leading also to lower overall generation costs, or 2) demand side management to follow seasonal availability of power e.g. additional usage of irrigation or refrigeration and cooling to match the patterns of solar generation.

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

Time horizon	Unmet load, %	Excess electricity, %	LCOE, M/kWh
Present	2.12	42.7	13.883
2019	2.10	42.6	9.424
2030	2.27	71.8	7.466

4.3 Economic Viability

For the assessment of economic viability of a mini-grid setup, the figure of merit selected is the internal rate of return (IRR) with revenues on the basis of the present national electricity tariffs. This calculation permits assessment of 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, -15%. Under these conditions, the project is not economiccally 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 M6,156,328 over 25 years, or M246,253 per year. Converted into electricity demand, the subvention need would be M2.98/kWh. Regarding allowance need in terms of customers, some M1,145 should be additionally paid per year per 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 M19,746,130 over whole project lifetime, and M789,845 per year. The subvention need per kWh would be a little bit lower than in the first scenario: M2.69/kWh. Due to significant annual increase of energy demand, allowance needs per customer would also increase, accounting for M3,275 per customer per year.

4.4 Summary

Sebapala is a relatively small village with a middle-size number of households and a low number of anchor loads. The absence of any health institutions (which are consumers with a high demand comparable to other public and commercial users) as well as a relatively low distribution of retail facilities is responsible for a low estimated anchor customers' demand. At present, households consume 54% of the total electricity demand in the village (about 16,000 kWh), and this proportion will shift more towards residential customers in the course of mini grid operation. For 2019, if a mini-gird will be commissioned, growth in demand up to 82,600 kWh is expected where 79% of demand will come from households, whereas 21% will be consumed by anchor customers. For 2030, the demand is forecasted to be about 360,000 kWh per year (85% households, 15% anchor customers).

As already observed in other villages in Lesotho, for the next few years the solution of PV + battery storage will be optimal for reliable and cost-effective energy supply. With the development of demand, further technologies as hydro should be considered in order to reduce unmet load and support economic sustainability.

5. Kubung Energy Centre


Figure 14: Bakoena General Café (2 sites) in Kubung

Kubung is situated 64.7 km North of Quthing town, Lesotho, its geographical coordinates are (30°05'42.6"S 28°01'04.6"E). It's about 1.07 km from the Senqu River and about 10 km from A4 main road. Three main income sources in the village of Kubung are self-employment, piece jobs[3], and formal employment. The administrative centre is Mt. Moorosi and it can be reached in six hours.

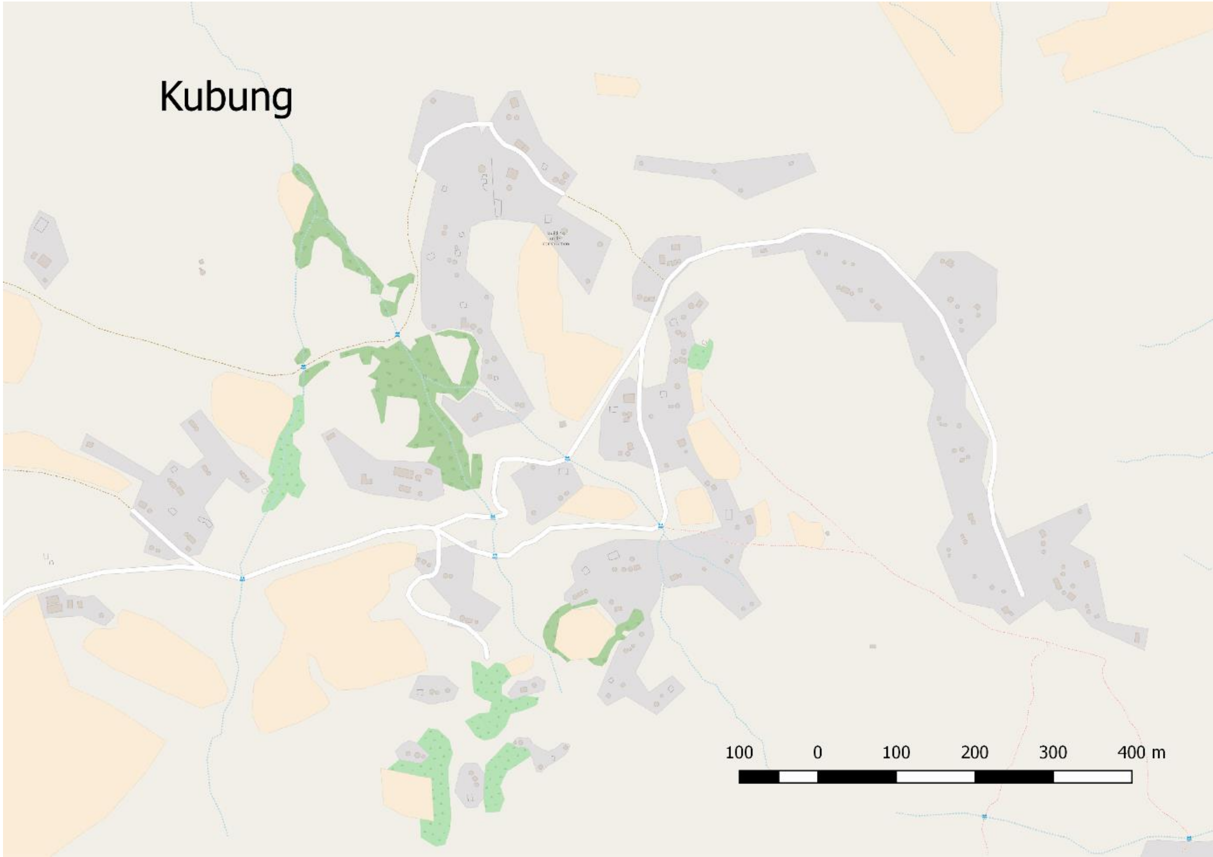

Figure 15: Map of Kubung

5.1 Customer Base

5.1.1 Households

Energy demand forecast

Kubung consists of approximately 120 households. An energy demand forecast was performed according to the assumptions described in the General Part. Power demand in 2019 reflects only the share of the total demand of households which will be covered by the Energy Centre. It is assumed that energy centres will not supply affluent households as these households typically have already sourced an independent power supply using e.g. solar home systems, solar lanterns and rechargeable batteries.

[3] Type of employment, in which worker is paid a fixed piece rate for each unit produced or action performed regardless of time spent.

Table 31: Present and future power demand by households in Kubung

Household type	No. of HH in Kubung	Total power demand, kWh/year	
		Present	2019
Basic	78	0	1,014
Medium	30	1,500	2,190
Affluent	12	3,600	0
Total	**120**	**5,100**	**3,204**

5.1.2 Anchor customers

Main characteristics

In Kubung there is one school, three retail facilities, and one grain mill. All potential anchor customers were interviewed (Q B1). The school is a state property, mill is in individual, retailers are in individual or cooperative ownership (Q B2). The school has five employees, all other enterprises one to two workers (Q B3). Earnings per month range from M250 (school and mill) to M3,500 (cafes). The school receives remittances in the range of M10,000-M50,000 over the last year (Q B4-B6).

Cafes have 7 till 11 working hours per day 6 days a week all year round, school 8 hours per day five days a week over 10 months, and the mill only one day per week for two hours (Q D1-D3). Except for the school, all potential anchor customers occupy one building; the school has four buildings at its disposal (Q D4). The total area of the school buildings amounts to 2,100 m^2, all the other potential anchor customer buildings range between 40 and 96 m^2, with an average of 72 m^2 (Q D5).

Energy supply

Table 32: Consumption of energy resources and electricity generation of selected anchor customers in Kubung

Anchor customer	Wood		LPG		Solar PV		Generator	
	Quantity, kg	End use	Quantity, kg	End use	System size	End use	Size	End use
Kubung Primary School	10,000	Cooking, heating						
Bakoena General Café					50 W (1 panel)	Phone charging		
Bakoena General Café					35 W (1 panel)	Phone charging	850 W	Other uses
Phokeng Café			19 kg	Heating	80 W (2 panels)	Phone charging		
Total quantity	**10,000**		**19 kg**		**165 W**		**850 W**	
Unit costs	M0.2/kg							
Total costs	**M2,000**							

Only the school indicated any use of coal and biomass resources over the last year: 10,000 kg wood (equivalent 49,000 kWh) for cooking, expending M2,000 (Q C1). The wood was paid for in cash (Q C2).

All three cafes used solar electricity of total capacity between 35 and 80 W for phone charging (Q C3, E1-E2). All respondents are receptive to the introduction of electricity services into their facilities, are concerned that it will be expensive, and express that it is important for companies and institutions to be connected (Q C4-C6). In general, prospective anchor customers express a willingness to pay between M200 to M500 per month for electricity, with an average value of M300 (Q C7). The preferred payment method to pay for electricity was cash (Q C8).

One café has a heating system running on LPG with capacity of 19 kg, operating around the clock in the winter. The school heats their facilities with wood. No other air-conditioning or heating/cooling systems are in operation (Q D6-D8). The willingness to pay for electricity for heating/cooling ranges between M200 and M500, averaging M270 (Q D9, Table 34). For lighting, only candles were used (Q D10). School and cafes are willing to pay M100 monthly for electricity for lighting; the mill is not willing to pay for it (Q D13, Table 34).

Table 33: Electric equipment of selected anchor customers in Kubung

Anchor customer	Small equipment	Refrigerating equipment	
	Type & number	Type & number	Capacity, l
Bakoena General Café	1 HH appliance	1 freezer	60
Bakoena General Café	1 HH appliance	1 freezer	300
Phokeng Café	2 HH appliances	1 freezer	100

All three cafes have one or two household appliances, which are used around the clock (Q D14). The school and one café have cooking facilities, running on wood and paraffin respectively (Q D15-D16). The school and cafes are willing to pay from M200 to M700 per month (average M320) for electricity for cooking (Q D17, Table 34). All cafes have refrigerating equipment, one freezer each (Q D18-D19). Correspondingly, they are the only companies that are ready to pay for electricity for these purposes (M150-M200, Q D20, Table 34).

As mentioned, all cafes use solar electricity generated by their own solar panels generating electricity over 7-8 hours per day all year long. Additionally, one café uses a generator of 850 W fuelled by unleaded petrol, used for a short time of the year (only one month) (Q E3-E4).

Regarding future plans, potential anchor customers from Kubung are quite active. They want to replace a fridge (one café), a generator (another café), a fan belt, and a sieve (mill). The mill plans to install solar PV, and the cafes also solar PV and light bulbs (Q F1-F4). Two cafes want to switch to LPG, and the school to biogas (Q F4-F6). The school plans to buy a generator in the next five years. The school and two cafes plan to install CFL and LED light bulbs, a solar water heater, insulate the walls, fit a ceiling, and replace windows (Q F10). The stated explanation for the obstacles to realizing these measures is the high capital cost, high installation / labour costs, the lack of devices on the local market, and unawareness of the best choice (Q F11).

Table 34: Ability and willingness to pay for electricity in general and for different applications of anchor customers in Kubung

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
Kubung Primary School	M2,750	M500	M100	M700	-	M1,300	47%
Khamali Milling Company	M250	-	-	-	-	-	-
Bakoena General Café	M3,500	M350	M100	M400	M150	M1,000	29%
Bakoena General Café	M750	M300	M100	M300	M200	M900	120%
Phokeng Café	M3,500	M200	M100	M200	M200	M700	20%
Total	M10,750	M1,350	M400	M1,600	M550	M3,900	

Energy demand forecast

The present power demand and supply of anchor customers in Kubung is summarized in Table 35. The future power demand of all anchor customers in the village, including non-interviewed ones, is presented in the Table 36.

The forecast for power demand of potential anchor customers is derived from the results of the entire survey. However, only the school and the craft workshop 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 and are expected to utilize their own generation facilities.

Table 35: Main characteristics of anchor customers in Kubung

#	Name	Type	Size	Operation hours	Electrical equipment	Annual power demand	Present power supply	Budget, Maloti/month
1	Kubung Primary School	**School**	5 employees; 4 buildings, area 2,100 m^2	8 h/day, 5 days/week, 10 months/year	None	0	None	1,300
2	Bakoena General Café	**Retail**	1 employee; 1 building, area 72 m^2	7 h/day, 6 days/week, all year long	1 HH appliance, 1 freezer	9,734 kWh	Solar panel 50 W	1,000
3	Bakoena General Café	**Retail**	2 employees; 1 building, area 96 m^2	11 h/day, 6 days/week, all year long	1 HH appliance, 1 freezer	9,734 kWh	Solar panel 35 W, generator 850 W	900
4	Phokeng Café	**Retail**	2 employees; 1 building, area 78 m^2	7 h/day, 6 days/week, all year long	2 HH appliances, 1 freezer	18,720 kWh	Solar panels 80 W	700
5	Khamali Milling Company	**Craft**	1 employee; 1 building, area 40 m^2	2 h/day, 1 day/week, all year long	None	0	None	0
					Total	38,188 kWh		3,900

Table 36: Present and future power demand of anchor customers in Kubung

Type	**Number of institutions**	**Power demand, kWh/year**	
		Present	**2019**
Health	0	-	-
School	1	0	500
Government	1	850	850
Retail	3	38,200	38,200
Craft	1	0	50
Total		**39,050**	**39,600**

The power demand distributes spatially as depicted in the Table 37. Here, also anchor customers and affluent households are included even though they are not expected to be supplied by the energy centre.

Table 37: Development of power demand in Kubung by distance from energy centre

Customer	Annual Power Demand MWh											
	Present				2019				2030			
	1km	2km	3km	total	1km	2km	3km	total	1km	2km	3km	total
Households	4.3	0.0	0.0	4.3	5.5	0.0	0.0	5.5	135.5	0.0	0.0	135.5
Anchor customers	39.0	0.0	0.0	39.0	39.5	0.0	0.0	39.5	119.8	0.0	0.0	119.8
Total	43.3	0.0	0.0	**43.3**	45.0	0.0	0.0	**45.0**	255.3	0.0	0.0	**255.3**

5.2 Set-up for Energy Center

For the Energy Centre two feasible sites were identified. One site is marked blue on the Figure 16 and was chosen according to physical criteria like orientation to the equator, area size and availability of space. The yellow marked optimal site was determined according to the calculation algorithm of the geometrical mean of all buildings in the radius 1-3 km in the village i.e. it is the location that minimizes the sum of distances to all existing potential residential, public and business customers. In the case of Kubung the theoretically chosen potential site for EC coincided with the site chosen in consultation with the community during field research. This particularly suitable site is presented on the following map as two squares, blue and yellow, inscribed in each other.

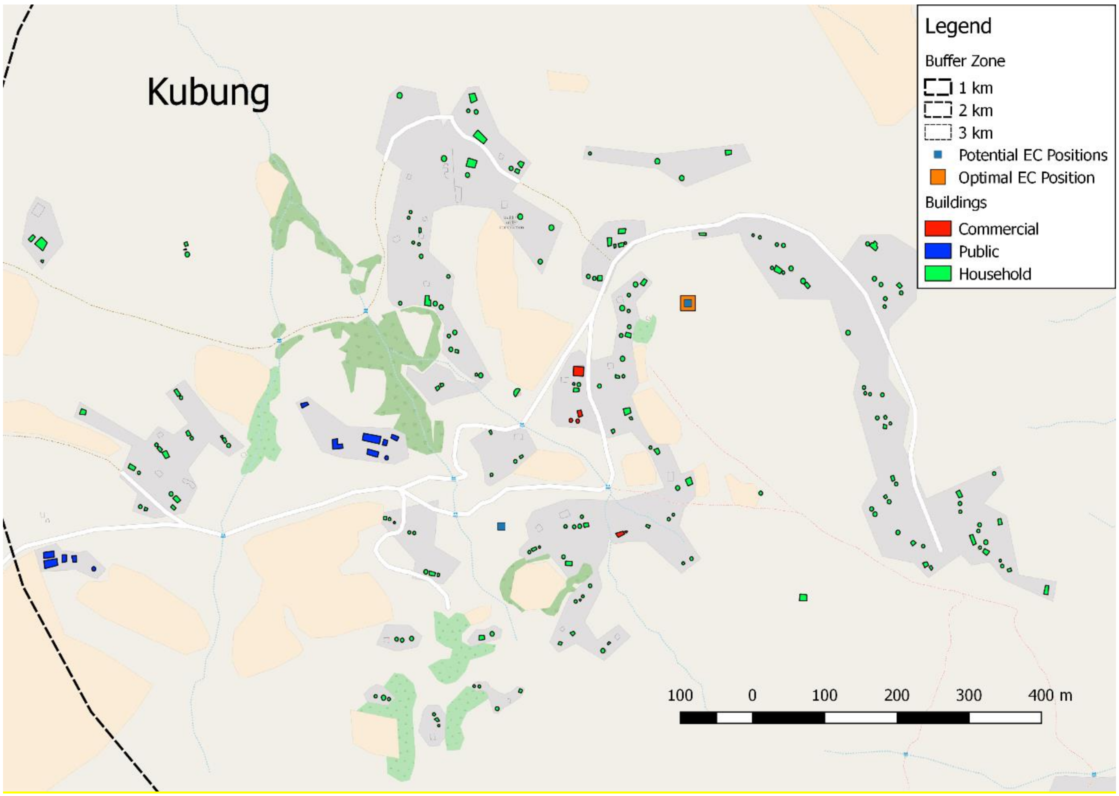

Figure 16: Spatial distribution of customers and positions of energy center in Kubung

5.3 Economic Viability

Kubung is classified within the group of small villages in the sample set of this study, with 120 households and very few anchor customers. Correspondingly, the planned energy centre should be designed in consideration of the relatively small extent of demand. Table 38 illustrates the main characteristics and financials of the energy centre in Kubung, including initial investment, annual expenditure, replacement costs due every five years as well as residual value after 10 years of operation.

To supply an energy demand of potential customers for battery and phone charging, as well as cover electricity demand for the services provided through the energy centre, a combination of a solar PV and battery storage is optimal. A small power plant with capacity of 5.57 kW and battery with nominal capacity of 17 kWh is selected for this case. This plant could be scaled along the expected increase in power demand and power related services.

A cash flow is generated over a period of ten years after establishing the energy centre (Figure 17). While most of the equipment as well as the building will be fully depreciated after ten years it is expected that batteries will be replaced either by a mini-grid or a connection to the central grid after 2029. Aside from the initial investment (2018 is chosen as a start year for convenience) certain elements such as vehicles or inverters need 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 M67,686, i.e. the energy centre is economically feasible.

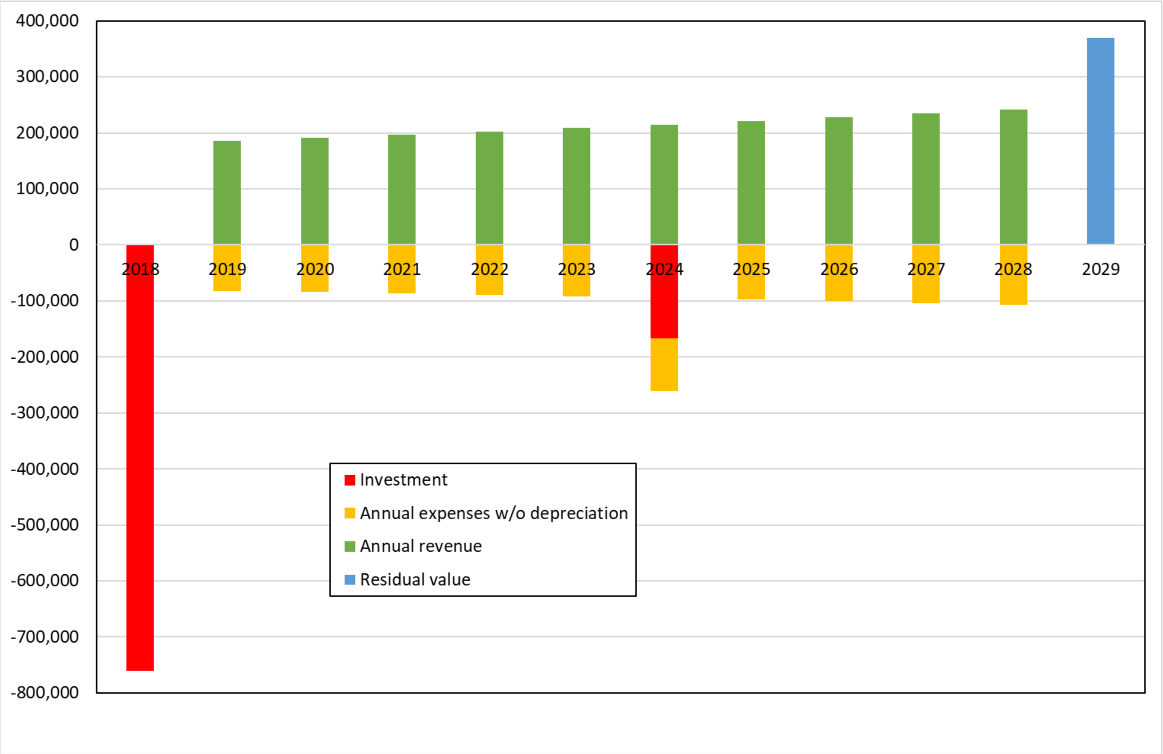

Figure 17: Cash flow of the energy centre in Kubung in 2018-2029

Table 38: Main features and financial parameters of an energy centre in Kubung

Features	
Number of households in the village	120
Building area, m2	50
Vehicle, #	0.5
Employees, #	2
Capacity PV	5.57
Capacity storage	17
Initial investment	
Building costs, M	100,000
Vehicle, M	100,000
PV+storage, M	166,318
Initial Stockage, M	236,550
Equipment, M	25,800
Staff Training, M	5,000
Contingencies	126,734
Total initial investment	**760,401**
Annual costs	
Salaries, M	50,000
Maintenance PV, M	3,326
Depreciation on hardware investment	30,160
Vehicle Maintenance and fuels	10,000
Contingencies	18,697
Total annual costs	**112,184**
Replacement costs	
Inverter+ storage	66,300
Vehicle	100,000
Annual revenue	
Charging lights, phones #/yr	12,167
Charging large batteries #/yr	2,850
Charging lights, phones, M	60,833
Charging large batteries, M	28,500
Equipment services	25,000
Profit on equipment sales	70,965
Total annual revenue	**185,298**
Residual value	
Building costs, M	50,000
Vehicle, M	0
PV+storage, M	83,159
Initial Stockage, M	236,550
Equipment, M	0
Total residual value	**369,709**

5.4 Summary

Kubung is a small village with a limited number of households and anchor loads and this study recommends that a small-sized energy centre represents an optimal solution to bring energy services closer to the potential customers. Loads are located in close proximity within a radius of 1 km, so the ideal site for energy centre would be in the centre with shortest distances to the customers. The building size would be in the range of 50 m^2 to accommodate stocked goods, display facilities and office rooms. The centre would hire two employees, one sales assistant and one maintenance agent. The agent will deliver products and spare parts directly to the customers, and one vehicle (single cab pick-up van) could be shared with another energy centre or business or public facility located in the locality. A combination of solar PV and battery storage will cover energy needs of potential customers and internal energy consumption of the centre. If a significant increase of energy demand is observed in the village, the solar power plant can be readily extended. Given that offered goods will find demand by households and anchor customers, the village population can subscribe to battery and phone charging service, the establishment of an energy centre is expected to be economically profitable with initial investment of M760,401 and provides a rate of return of almost 10% in the period up until 2029 (after ten years of operation).

6. Qhoali Energy Centre

Qhoali (30°09'19.9"S 28°06'56.4"E) is a village located 43.5 km North East of Quthing town. The main river flowing nearby is Qhoaling/Qwadi River. It is about 4.35 km from A4 main road. According to the acting chief, the main income sources in Qhoali are migrant labour, livestock and crops. The service centre is Mphaki, which is 13 km away from Qhoali and can be reached in 4.5 hours.

Figure 18: Anchor customers in Qhoali (clockwise: Letele RC Primary School, Marabeng Store, Qhoali Primary School, Makhetheng Store)

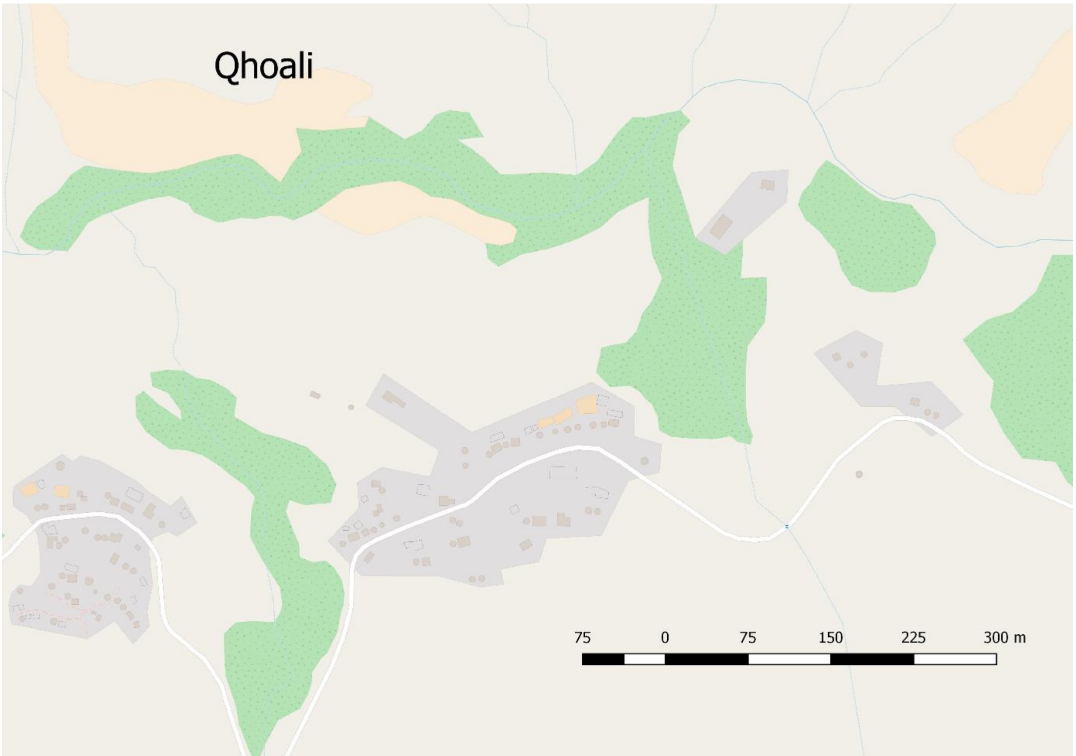

Figure 19: Map of Qhoali

6.1 Customer Base

6.1.1 Households

Energy demand forecast

Qhoali consists of approximately 450 households. An energy demand forecast was performed according to the assumptions on current and future demand described in the General Part. Power demand in 2019 reflects only the share of the total demand of households which will be covered by the Energy Centre. It is assumed that energy centres will not supply affluent households as these households typically have already sourced an independent power supply using e.g. solar home systems, solar lanterns and rechargeable batteries.

Table 39: Present and future power demand by households in Qhoali

Household type	No. of HH in Qhoali	Total power demand, kWh/year	
		Present	**2019**
Basic	293	0	3,810
Medium	112	5,600	8,180
Affluent	45	13,500	0
Total	**450**	**19,100**	**11,990**

6.1.2 Anchor customers

Main characteristics

In Qhoali there are three schools, several grocery shops, water supply, church, and a grain mill. Three schools and two food retail shops were interviewed in the survey (Q B1). Schools are state owned, while retailers are privately owned (Q B2). All potential anchor customers are very small: the schools have two employees each, and they are temporary; the food retailers have three (Q B3). With respect to earnings, food retailers receive M30,000, or M7,500 on average per month, schools pay their bills with remittances of M3,500 per year, or less than M300 per month (Q B4-B6).

Schools work over 10 months in a year, for 6 or 8 hours a day, 5 days a week. Retailers work 8 or 9 hours a day, 6 or 7 days a week, all year round (Q D1-D3).

The surveyed anchor customers have relatively many buildings at their disposal: schools occupy between 2 and 6, and the retailers 3 or 4. The total area is ample: schools have between 105 and 260 m^2, retailers 74 or 112 m^2. Some fraction of the school buildings are insulated (Q D4-D5).

Energy supply

Table 40: Consumption of energy resources of selected anchor customers in Qhoali

Anchor customer	Wood		Diesel	
	Quantity, kg	End use	Quantity, l	End use
Marabeng General Dealer			1,440	Production process
Makhetheng Store			360	Production process
Qhoali LEC Primary School	1,932	Cooking		
Latele RC Primary School	2,000	Cooking		
Total quantity	**3,932**		**1,800**	
Unit costs	M3/kg		M12/l	
Total costs	**M11,800**		**M21,600**	

Two schools use wood for cooking, 1,932 or 2,000 kg last year, paying M4,800 and M7,000 (9,500-9,800 kWh). Two retailers used diesel for production processes, consuming 360 and 1,440 liters last year, expending M4,200 and M16,800 (4,550 and 18,000 kWh). All respondents pay for energy sources in cash (Q C2).

No anchor customer consumes solar electricity (Q C2) from solar panels or uses a generator (Q E1-E4). All respondents are receptive to the introduction of electricity services into their facilities, are concerned that it will be expensive, and express that it is important for companies and institutions to be connected (Q C4-C6). Willingness to pay for electricity remained undisclosed (Q C7). The preferred payment method to pay for electricity was cash with one respondent preferring mobile phone (Q C8).

No anchor customer has any air-conditioning, heating or heating/cooling systems at their facilities (Q D6-D8). Willingness to pay for electricity for heating/cooling ranges from M300 to M5,000 (Q D9, Table 42). Since schools indicated willingness to pay that exceeded their current monthly income, it remains unclear if their remittances would and could be correspondingly increased by the arrival of electricity services.

Table 41: Electric equipment of selected anchor customers in Qhoali

Anchor customer	Lighting		Refrigerating equipment	
	Type & number	Capacity, W	Type & number	Capacity (L) l
Marabeng General Dealer	2 incandescent	60	1 refrigerator	300
Makhetheng Store	2 incandescent	60	1 refrigerator	254

The retailers both use incandescent light bulbs, and one also uses a cell phone as a flashlight (Q D10). The willingness to pay for electricity for lighting ranges between M50 and M500, with an average value of M200 (Q D13, Table 42).

No small equipment was in use over last year (Q D14). Schools have cooking facilities powered by wood (Q D15-D16). They also show a very high willingness to pay for electricity for cooking, up to M9,700 per month (Q D17, Table 42). It remains for the state or district council to decide whether sufficient budgets will be allocated for this purpose. Retailers have refrigerators, one unit each, capacity of 300 and 254 liters (Q D18-D19). Only one retailer expressed willingness to pay something for electricity for refrigeration (Q D20, Table 42).

All interviewed organizations are planning to install new energy consuming systems. In four cases out of five the preference was for a computer or computer systems (three schools + one retailer), and in one case an electric mill is mentioned (another retailer). All respondents would like to switch to electricity (Q F1-F8). Two retailers and one school would buy a generator in the next five years, and two schools a solar PV system (Q F9). Additionally, some plan to fit a ceiling, replace windows or insulate walls (Q F10).

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

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
Marabeng General Dealer	M7,500	M1,200	M500	-	M300	M2,000	27%
Makhetheng Store	M30,000	-	-	-	-	-	-
Qhoali LEC Primary School	M292	M300	M50	M400	-	M750	257%
Lesholu ACL Primary School	M292	M5,000	M400	M9,700	-	M15,100	5,171%
Latele RC Primary School	M292	M300	M50	M500	-	M850	291%
Total	M38,376	M6,800	M1,000	M10,600	M300	M18,700	

Energy demand forecast

The present power demand and supply of anchor customers in Qhoali is summarized in Table 43. The future power demand of all anchor customers in the village, including non-interviewed ones, is presented in the Table 44. The forecast for power demand of potential anchor customers is derived from the entire survey. However, only schools 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 and they are expected to utilize their own generation facilities.

Table 43: Main characteristics of anchor customers in Qhoali

#	Name	Type	Size	Operation hours	Electrical equipment	Annual power demand	Present power supply	Willingness to pay, Maloti/month
1	Qhoali LEC Primary School	**School**	2 employees; 6 buildings, area 260 m^2	8 h/day, 5 days/week, 10 months/year	None	0	None	750
2	Lesholu ACL Primary School	**School**	2 employees; 5 building, area 216 m^2	6 h/day, 5 days/week, 10 months/year	None	0	None	15,100
3	Latele RC Primary School	**School**	2 employees; 2 buildings, area 105 m^2	8 h/day, 5 days/week, 10 months/year	None	0	None	850
4	Marabeng General Dealer	**Retail**	3 employees; 3 buildings, area 74 m^2	8 h/day, 6 days/week, all year long	Incandescent lights, 2 units; 1 refrigerator	2,920 kWh	None	2,000
5	Makhetheng Store	**Retail**	1 employee; 4 buildings, area 122 m^2	9 h/day, 7 days/week, all year long	Incandescent lights, 2 units; cell phone torch; 1 refrigerator	2,891 kWh	None	0
					Total	5,811 kWh		18,700

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

Type	Number of institutions	Power demand, kWh/year	
		Present	2019
School	3	0	1,500
Government	1	850	850
Retail	3	7,600	7,600
Total		**8,450**	**9,950**

The power demand distributes spatially as depicted in the Table 45. Here, potential anchor customers and affluent households are included even though it is not expected that they will be supplied by the energy centre.

Table 45: Development of power demand in Qhoali 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	2.0	0.0	0.0	2.0	2.5	0.0	0.0	2.5	62.3	0.0	0.0	62.3
Anchor customers	6.7	0.0	0.0	6.7	7.2	0.0	0.0	7.2	22.6	0.0	0.0	22.6
Total	8.6	0.0	0.0	**8.6**	9.7	0.0	0.0	**9.7**	85.0	0.0	0.0	**85.0**

6.2 Set-up for Energy Center

For the Energy Centre two feasible sites were identified. One site is marked blue on the Figure 20, and was chosen according to physical criteria like orientation to the equator, area size and availability of space. The yellow marked optimal site was determined according to the calculation algorithm of the geometrical mean of all buildings in the radius 1-3 km in the village i.e. it is the location that minimizes the sum of distances to all existing potential residential, public and business customers. In the case of Qhoali the theoretically chosen potential site for the energy centre coincided with the site chosen in consultation with the community during field research. This particularly suitable site is presented on the following map as two squares, blue and yellow, inscribed in each other.

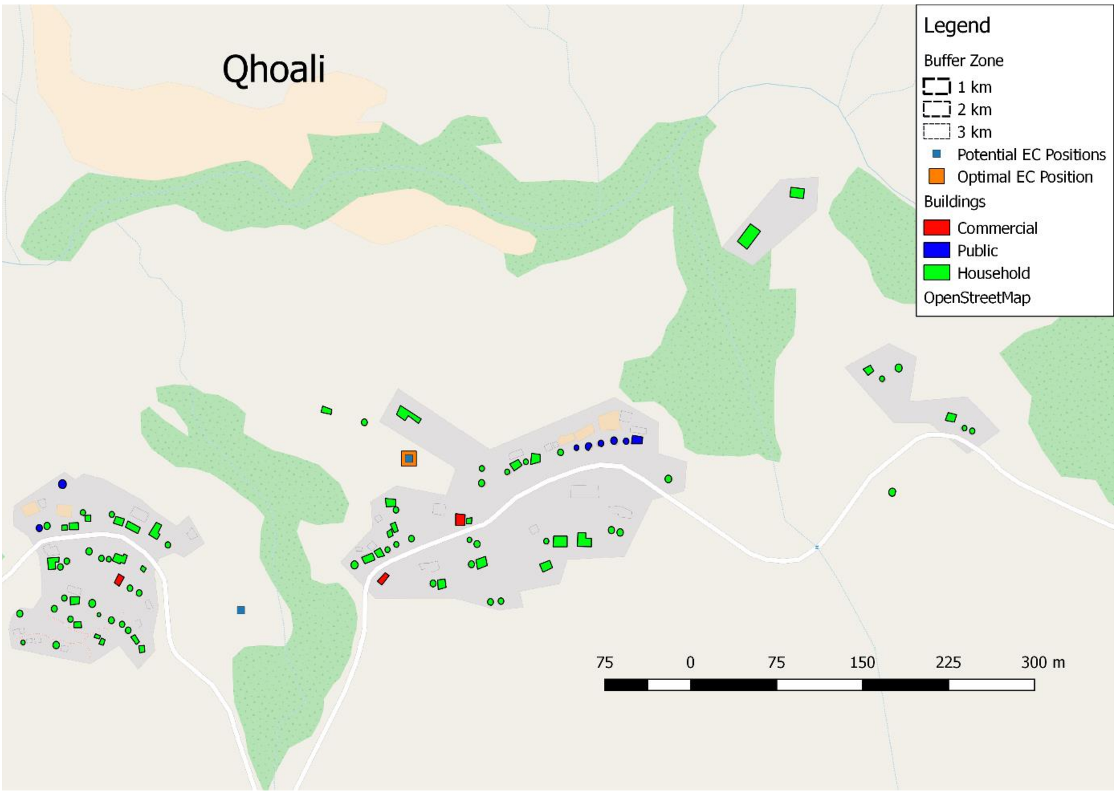

Figure 20: Spatial distribution of customers and positions of energy center in Qhoali

6.3 Economic Viability

Qhoali is a large village with 450 households and some potential anchor customers, therefore the energy centre should be developed to be suitably large. The main features, initial investment, annual expenditure, replacement costs due every five years as well as residual value after 10 years of operation are presented in the Table 46 below.

A relatively capacious solar power plant of 17.9 kW combined with battery storage of 60 kWh nominal capacity will supply energy needs of basic and medium household types in Qhoali as well as the demand of schools, and electricity to support the services provided through the energy centre. This plant could be scaled along the expected increase in power demand and power related services.

A cash flow is generated over a period of ten years after establishing the energy centre (Figure 17). While most of the equipment as well as the building will be fully depreciated after ten years it is expected that batteries will be replaced either by a mini-grid or a connection to the central grid after 2029. Aside from the initial investment (2018 is chosen as a start year for convenience) certain elements such as vehicles or inverters need 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 turns out to be negative, -M34,862, 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 Qhoali is not as profitable as in the other villages.

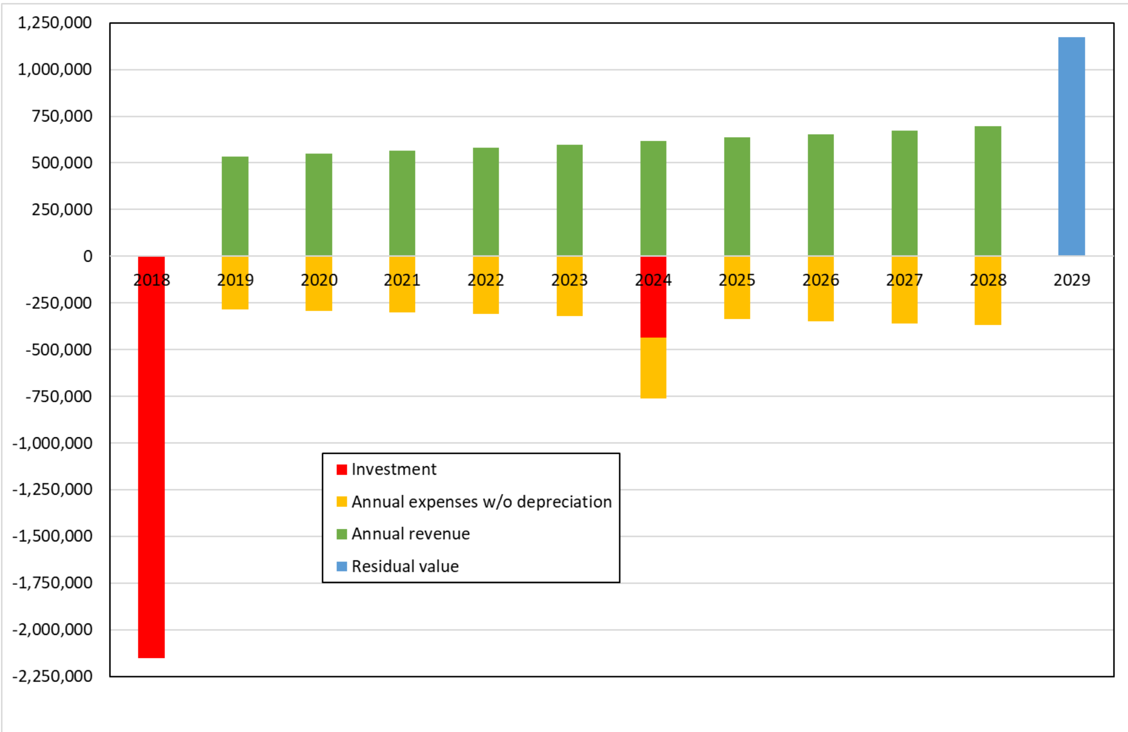

Figure 21: Cash flow of the energy centre in Qhoali in 2018-2029

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

Features	
Number of households in the village	450
Building area, m2	100
Vehicle, #	1
Employees, #	4
Capacity PV	17.9
Capacity storage	60

Initial investment	
Building costs, M	200,000
Vehicle, M	200,000
PV+storage, M	554,017
Initial Stockage, M	796,510
Equipment, M	36,000
Staff Training, M	5,000
Contingencies	358,305
Total initial investment	**2,149,833**

Annual costs	
Salaries, M	100,000
Maintenance PV, M	11,080
Depreciation on hardware investment	57,200
Vehicle Maintenance and fuels	20,000
Contingencies	37,656
Total annual costs	**225,936**

Replacement costs	
Inverter+ storage	234,000
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	277,009
Initial Stockage, M	796,510
Equipment, M	0
Total residual value	**1,173,519**

6.4 Summary

Qhoali belongs to the largest villages in our sample with 450 households and some significant potential anchor loads such as schools which can become important customers. This study recommends the construction of a large-sized energy centre in the village. The energy centre should be placed in the close proximity to the households and anchor customers, so that they will not need to walk long distances on foot to charge their battery or mobile phone. The centre should have a size of approximately 100 m^2 to stock and display products and accommodate office facilities. Four workers – two sales assistants and two maintenance agents – should support customers in the 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, take over small repairs and deliver replacement parts. One vehicle of a pick-up type will be needed to deliver products and parts to the customers. A combination of PV and battery storage can be developed to cover energy needs of potential customers and internal energy consumption of the centre. If a significant increase of energy demand will be observed in the village, the solar power plant can be readily extended to the necessary capacity. Given that offered goods will be actively purchased by households and anchor customers and the village population can subscribe to battery and phone charging service, the establishment of an energy centre can be economically profitable with initial investment of M2,149,833 at an internal rate of return of almost 8% after 12 years of operation.

7. References

Bureau of Statistics Lesotho, National Energy Survey 2017

HOMER Pro Software Tool

Photovoltaic Geographical Information System (PVGIS), European Commission