Technical and economic feasibility assessment for a solar PV mini-grid for Matekenya village

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Abstract: Malawi is one of the sub-Saharan African countries with a low electrification rate. Its electrification rate is at 18% which is far below Africa’s average electrification rate which is 44%. One of the solutions to improve the electrification rate is to promote Mini-grid development in rural areas that are far from the national grid. This paper aims at finding out if it is technically and economically feasible to supply electricity using a solar PV Mini-grid to Matekenya village located in the Dowa district in the central region of Malawi. Data was collected using the android tool Kobo Collect and simulations were made using HOMER software and other data was analyzed using SPSS. The results without sensitivity cases showed that the Net Present cost of the system is $21,170,640. The Levelized Cost of Energy of $0.1334, the operating cost was $380,215.40 and the initial capital cost was $14,290,444.84. optimization results with sensitivity analysis showed that the NPC was $11,744,020, LCOE was 0.074, the operating cost was213036 and the initial cost was $7,890,000. Based on the Malawi feed-in tariff policy, the feed-in tariff for solar PV energy is $0.10/kWh. The results showed that it is economically feasible to supply Matekenya village with electricity using a solar PV Mini-grid. The area also showed more potential for productive use of electricity and willingness to be connected if the electricity is available.

Subjects: Power & Energy; Renewable Energy; Renewable Energy; Solar energy

Keywords: Mini-Grid; PV system; load assessment; Load profile; solar resource assessment; technical; economic feasibility

1. Introduction
Malawi is one of the countries in sub-Saharan Africa with a low electrification rate. The current electricity access rate is 18%(IEA, IRENA, UNSD, World Bank and WHO, 2020). This electricity access rate is less than that of Africa which is 44%(IEA, IRENA, UNSD, WB and WHO, 2019). This shows that Malawi’s access rate is far behind other countries within sub-Saharan Africa. Matekenya village is located in the central region of Malawi. It is in the Dowa district under the traditional authority Msakambewa. Its GPS location is Latitude –13,562,723 (13° 33'45.8028" S) and Longitude 34.04576. (34° 2’ 44.0736” E). The village is very far from the grid and it may take time for it to get access to electricity through the main electricity grid. Figure 1 and Figure 2 show some parts of Matekenya village.

The village has around 200 households, a secondary school, a primary school, a health post, and a market that has shops and some productive use of electricity. The main purpose of this paper was to find out if it was technically and economically feasible to supply Matekenya village with
electricity using a solar PV mini-grid. To achieve this objective the following specific objectives were met;

- Determining the electricity needs for Matekenya village
- Determining the available solar resource for Matekenya Village
- Determining the system size suitable for Matekenya village
- Determining if it is technically and economically viable to supply electricity using a solar PV Mini-grid to Matekenya

The site was selected based on distance from the main grid which is 10 kM based on Malawi policies and economic activities that takes place in the area. The mini-grid in this area would help...
to solve most of the problems related to lack of access to electricity. These problems include high milling costs due to use of the use of diesel maize meals. The diesel used for maize meals is sourced very far from the maize area which increases the cost of operation of the maize meals. The mini-grid can also help to improve the standard of living of people in the area by supplying them with electricity that can help in lighting homes, and entertainment, and improve the quality of service at the health center and schools. In addition to that, it can also help to improve the electricity access rate of the country. This study can serve as a pre-feasibility study of any interested stakeholder who is willing to implement the mini-grid in the area.

2. Literature review
The PV technology was started after discovering the photovoltaic effect in 1839 (Goetzberger et al., 1998; Mertens, 2014; Taguchi et al., 2019). The photovoltaic effect is a process in which PV cells convert the photon energy from the light into electricity (Simya et al., 2018; Zaidi, 2018; Zhang & Yang, 2019). The discoveries proceeded to improve and the first commercial production started in 1955 by Western Electric. The improvements made in solar PV technology include manufacturing processes, raw materials, and efficiency. Solar cells are interconnected to form solar modules and modules are interconnected to form an array. Solar panels are categorized into monocrystalline, polycrystalline, and Thin-films (Ahmad et al., 2020). Monocrystalline panels are made from multiple independent cells, each cell is made from a single wafer of silicon (Richhariya et al., 2020). They are more efficient compared to other types of solar panels (Richhariya et al., 2020). Their efficiency ranges from 15% to 24% (Ahmad et al., 2020; Tripathy et al., 2016). Polycrystalline solar panels are made from multiple solar cells, each cell is made of silicon wafers. They are more efficient than amorphous solar panels and their efficiencies range from 13% to 18% (Ahmad et al., 2020; Tripathy et al., 2016). Thin-films panels also known as amorphous panels do not contain single independent cells as in other types. They are formed by depositing silicon directly on a glass or plastic to form a panel (Tripathy et al., 2016). They have low efficiency compared to other types of panels.

2.1. Components of solar PV system
Solar PV systems are made up of various components. The components of a Solar PV system include solar panels, charge regulators, batteries, inverter, and protection devices. Solar is used to convert solar radiation to electricity. These are connected in parallel or series to achieve the voltage or current required by the system. Batteries are used to store energy in the system by converting the electrical energy to chemical energy and converting it back to electrical energy (Mussi et al., 2021; Wu et al., 2022). They are classified as primary batteries and secondary batteries. Primary batteries are non-rechargeable while secondary batteries are rechargeable. Types of secondary batteries include lead-acid batteries, lithium-ion batteries, nickel-cadmium batteries, nickel-metal hydride batteries, lithium-ion batteries, zinc-air batteries, and lithium polymer batteries (Price, 2018). Charge controllers are devices that are used to control overcharging and over-discharging of the batteries. They disconnect the battery from the power source when the voltage level reaches the design limit to prevent batteries from overcharging. To protect from over-discharging the charge controller disconnects the load from the battery when the voltages are below the minimum set by manufacturers. Types of charge controllers include shut type charge controllers, series charge controllers, Pulse width Modulation charge controllers (PWM), and Maximum Power Point Tracking charge controllers (MPPT; Manik et al., 2017). PWM charge controllers operate by switching transistor frequency with various modulated widths while maintaining constant voltage (Vergara et al., 2022,). MPPT charge controllers use DC-DC converters to convert voltage from the solar array to suit the battery voltage (Bhukya and Shanmugasundaram, 2021). Inverters convert direct current to alternating current. Inverters are classified based on input, output power rating, and application (Dogga & Pathak, 2019, Ketjoy et al., 2021; Parthasarathy & Vijayaraj, 2020; 2022; Vergara et al., 2021). The input-based classification includes voltage-fed inverters, current-fed inverters, and DC-link inverters. Inverter classification based on output includes pure sine wave inverters, square wave inverters, and quasi square wave inverters. Inverters classified based on output power rating include single-phase inverters and three-phase
inverters. Inverters classified based on the application include grid-tie inverters, standalone inverters, and hybrid inverters. Protection devices are used to protect against accidents associated with the system or damage to any component. These include fuses, disconnects, and circuit breakers.

2.2. Types of solar PV systems
Solar PV systems are classified as grid-tie systems, standalone systems, and hybrid systems (Aghaei et al., 2020; Baumgartner, 2017; Dufo-I., 2016; Mokhtar et al., 2021; Ortega-arriaga et al., 2021; Tan & Seng, 2011). Grid-tie systems are connected to the main grid and they do not operate when the grid goes off (Awasthi et al., 2020). Standalone systems operate without being connected to the grid (Awasthi et al., 2020). They contain batteries to serve as a backup when there is no sunshine. The hybrid system combines two or more sources to supply electricity. Examples of hybrid systems include PV/Biomass hybrid system, PV/wind hybrid system, PV/Genset hybrid system, PV/Grid, and PV/Wind/biomass hybrid system.

2.3. Mini-grid systems
These systems can be used to supply the electricity in a form of a mini-grid (Wu et al., 2021). Mini-grid is a small and isolated electricity distribution system that can be used to supply electricity to communities or institutions that are not connected to the utility grid (The Mini-Grids Partnership (MGP), 2020), (GIZ, 2016), (Magni et al., 2022), (Kumar et al., 2019), (Opjy, 2019). Minigrid can use one energy source to supply electricity or more than one source. Minigrid that use more than one source of energy to supply electricity is known as hybrid mini-grids. Examples of hybrid mini-grids are; PV/biomass mini-grids, PV/wind mini-grid, PV/Genset mini-grid, and PV/Wind/biomass (Eteiba et al., 2017; Jahangir & Cheragh, 2020; Malik et al., 2021; Samy & Barakat, 2019; Samy et al., 2020; Babatunde et al., 2022). Minigrid can also be standalone (The Mini-Grids Partnership (MGP), 2020; Wu et al., 2021), grid-tied (Samy et al., 2021), or grid connected (Pramanik et al., 2022). Mini-grids are classified as either autonomous or interconnected (IRENA, 2016). Autonomous mini-grids are independent of other grids and are subdivided into lower-tier levels and higher tier levels. The lower tier of the service grid is in Tier 3-4 and supplies power for less than 24 hours and is used to support basic loads (IRENA, 2016). Tier 5 is a higher-tier service and supplies power for 24 hours. Interconnected mini-grid are those that have the capability of connecting to neighboring grids. They are subdivided into interconnected community application which is tier 5+ and interconnected large industrial application which is tier 5++ (IRENA, 2016). The interconnected large industrial application is more reliable than the interconnected community application. Mini-grid development consists of three phases which include project development, implementation, and operation (Green Minigrid Help Desk, 2020). The first phase focuses on collecting information that will help to understand community needs and capabilities to have the right design of the mini-grid. The second involves the construction and commissioning and the third phase involves operation and maintenance.

2.4. Minigrids in Malawi
Mini-grids were introduced in Malawi in 2006 (GoM, 2018). Most of them were used for pilot studies and their failure has helped the country to get useful experience in terms of management and operation model (GoM, 2018). In Malawi mini-grid concept is supported by policies, strategies, and standards. Examples of policies and standards that support mini-grids include; the National energy policy 2018, Malawi Renewable Energy Strategy, Regulatory framework for mini-grids, and feed-in tariff policy. The main objective of the National Energy Policy for Malawi is to increase access to affordable, reliable, sustainable, efficient, and modern energy for people in the country (GoM, 2018). In one of the policy statements, the government shows commitment to supporting small-scale renewable energy initiatives by communities or entrepreneurs. This is done by developing appropriate regulations and reviewing feed-in tariffs to accommodate mini-grids (GoM, 2018). Malawi Renewable Energy strategy sets the target of a minimum of 50 operational Mini-grids sites by 2025 (The Government of Malawi, 2017). These mini-grids will include those for self-consumption and those selling excess power to the communities and the grid (The Government of Malawi, 2017). A regulatory framework for mini-grids was developed to provide guidelines for
mini-grid development and operation in Malawi (Malawi Energy Regulatoty Authority, 2019). It helps in the mini-grid development solicitation process and provides requirements for approval of the mini-grid project (Malawi Energy Regulatoty Authority, 2019). The feed-in tariff policy aims to facilitate resource mobilization by providing security to investments and market stability to investors in the energy sector (MERA, 2012). According to the feed-in tariff policy, solar-generated electricity supplied in bulk to the grid operator at the connection point has a fixed tariff not exceeding $0.20/kWh (MERA, 2012). These tariffs apply to the first 100 MW of power generated using solar resources and it applies for 20 years from the date of commissioning (MERA, 2012). The non-firm power fixed tariff for solar-generated electricity supplied in bulk to the grid operator is $0.10/kWh (MERA, 2012). This tariff shall apply to the first 50 MW of solar-based non-firm power plants developed in the country (MERA, 2012).

3. Methodology
The paper used both qualitative and quantitative methods. A questionnaire was used to collect data. Data collected was used to establish the load profile which was used as HOMER input on load. The details of each activity are discussed below.

3.1. Questionnaire development
An electronic questionnaire was developed using the Kobo toolbox. This tool was chosen to make sure the hat quality of data is maintained and to avoid errors that may occur during data entry from paper questionnaires to the electronic platforms for processing. Kobo toolbox also helped to take take the GPS of each respondent which helped in establishing the map of the area. The questionnaire developed had three sections the first part was for respondent identification, the second part was for the village headman and the last part was for the household.

The first part mainly was focused on respondent identification and contained identification information such as respondent serial number, name, gender, GPS coordinate, employment status, and occupation sector.

The second section was for the village headman to give information about the village and focused on the population of the area, the number of households, public institutions available in the area, and most economic activities in the area. The questions for this section were as follows; what is the population of this Matekenya village? How many public institutions do you have in Matekenya village? And what are the economic activities that most people are involved in?

The third section of the questionnaire was designed for households. This part contained three categories. These categories include questions that assess energy needs, questions that assess the ability to pay, and questions that assess willingness to pay. Questions that assess the energy needs include:

- What appliances do you have or would like to have that use or will be using electricity?
- With the follow up questions such as how long do you use or will you be using that appliance during the daytime?
- How long do you use or will you be using that appliance during nighttime?

Questions that assess the ability to pay were as follows:

- What economic activities do you do to earn a living?
- How much do you spend on a monthly basis for charging your phone?
- How much do you spend on airtime in a month?

Questions that assess willingness to pay include:

- If there is a project to supply electricity to you, are you willing to be connected?
• How much are you willing to pay once you get connected?

Some questions can help to assess both ability to pay and willingness to pay these include:

• What are the current sources of energy that you are using?
• How long do you use each energy source per day for each function mentioned above?
• How much money do you spend on each type of energy mentioned?

These questions can also help to identify energy source that would compete with the mini-grid.

The data for this work was collected using Kobo collect. A total of 95 questionnaires were administered. Figure 3 shows the map of Matekenya and the positions where the questionnaires were administered. After collecting data, HOMER was used for optimization and sensitivity analysis.

3.2. Load assessment
During the survey respondents were asked some questions which aim at knowing the electrical appliances that they have and wish to have once they have the electricity in the area. This helps to establish the total demand for the area, the load profile, and the potential productive use of the area. Total demand for this area was 1751.114 kW per day, this was found by adding hourly demand for the area for 24 hours. Appendix shows a figure showing how total demand was calculated in excel. Some of the potential productive use of electricity in this area include maize mills, barber Shops, Video shows, welding, and carpentry workshop. Table 1 shows the appliances that respondents have or wish to have the power rating used for this paper and the total quantity required in the area based on the response from respondents during the survey.
The power rating of the appliances was taken using various ways such as checking the rating of the appliances that people are having or using, using the power rating of appliances that most people are using within the District, and using the average power rating from the internet for the appliances that are not found within the locality. Figure 4 shows the photo of the power rating of one of the diesel maize meals that was operating in the area.

### 3.3. Load profile

Data collected was collected and downloaded into an excel file which was used to establish the load profile. The load profile was established based on the respondent’s anticipated use of electricity and the duration that they are expecting to use their appliances. Figure 5 shows the load profile.

### 3.4. Solar resource assessment

The area under study had no nearby weather station therefore solar radiation data used was taken from NASA. According to data obtained, the average global horizontal irradiation for 22 years from July 1993 to June 2005. The Global Horizontal Irradiation for this site ranges from 4.470kWh/m²/
day to 6.540kWh/m²/day with an average of 5.22kWh/m²/day. Figure 6 shows solar GHI resources for the area under study.

### 3.5. System components

The system components for this study were the load, converter, modules, and batteries. Figure 7 shows the system configuration and its components. Further details on the system components are explained in the next sections.

### 3.6. Solar PV

The module used was Canadian solar CS6X-325P with a power rating of 325 W and an efficiency of 16.94%. The cost of panels used in these simulations was $99.4 per unit. It has a lifetime of 25 years operating temperature up to 45°C.
3.7. Storage

Standalone systems always require a battery system to store power for use at night or during the days that have no sunlight. This paper used a battery as the storage system. The battery used was a BAEPVV 12 V 210. It is a maintenance-free battery with qualities suitable for the mini-grid application. The cost per unit of the battery was $523.23. The same amount was used for battery replacement.

3.8. Converter

The inverter proposed in this system was a 100 kW inverter with 95% efficiency. The total cost for this inverter was $15,645.22. Its lifetime is 15 years.
3.9. Economic inputs
To realize the economic analysis, some economic parameters need to be entered in HOMER. These parameters include the expected inflation rate, discount rate, project lifetime, fixed capital cost, and operation and management cost. Based on the Reserve Bank of Malawi, in June, the interest rate and inflation rates were 12% and 9.1% respectively. The project lifetime used in this work was 25 years. The system fixed cost was estimated by adding the cost of the prepaid meters, distribution cost, and the cost of mounting structures. The unit cost for prepaid meters was $50 with 95 connections based on the number of respondents number and the total cost for prepaid meters was $4750. The cost of the mounting structures per kW was $75/kW and with 15,070 kW, the total cost for mounting structure rose to $1,243,500. The cost of the distribution system used was $14,980/km (The World bank group, 2017). The total distance for the mini-grid system under consideration was 2.12 km which makes the total distribution cost $317,557.6. Figure 8 shows the total distance for the distribution system. The total fixed cost used in this work was $1,280,007.6 after adding all its components. The operation cost was estimated to be $36,000 per year.

3.10. Sensitivity variables
Sensitivity analysis is used to evaluate the effects of changing a variable on a dependent variable (Ortega-arriaga et al., 2021). Using the parameters entered, HOMER formulates different cases and finds the optimal values in terms of system architecture and economics (Venkatachary et al., 2017). In this paper, 10 sensitivity parameters were considered. These parameters include the battery replacement multiplier, PV replacement multiplier, capacity shortage, PV capital cost multiplier, battery capital multiplier, nominal discount rate, scaled annual average, project lifetime, inflation rate, and system fixed cost multiplier. The values used for the capacity shortage were 0%, 10%, and 20%. The values used for batteries and PV multipliers were 0.5, 1, and 1.5. where a factor value of 0.5 means that the parameter has been reduced by half, a factor value of 1 means that there are no changes made in the parameter, and a factor value of the parameter has been increased by half. Values used for the scaled annual average used were 2424.25kWh/day, 24,022.368kWh/day, and 38,950.56 kWh/day. The values used for inflation rate and nominal discount rate range from 0% to 14% and those for the project lifetime were 15 years, 20 years,

Figure 8. Total distance measured.
25 years, and 30 years. The values for the fixed system cost were $58,482.6, $1,130,082, and $1,845,657.6. During the simulation, the parameters were divided into two groups to reduce the time needed to complete simulations. These groups were the first group and the second group. The first group consists of battery capital cost, battery replacement cost, capacity shortage, PV capital cost, PV replacement cost, and load scaled-down average. The second group consists of the expected inflation rate, project lifetime, nominal discount rate, and the system capital cost.

4. Results and discussion

4.1. Simulation results without sensitivity variable
The optimization results displayed were as follows: the system architecture PV array size, batteries, and inverter. The array size was 14,581 kW, batteries 15,472 in number, and 2912 kW inverter size. The Levelized Cost of energy was $0.133, the Net Present cost of $21,170,640, the Operating cost was $380,215.40, the initial capital cost was $14,290,444.84, and the operation and management cost of $36,000.

5. Optimization results with sensitivity variables
Optimization results that were of the first group are the ones that produced more viable results. Based on the sensitivity parameters, HOMER formulates sensitivity cases and displays the optimization results based on these cases. Table 2 shows the first 5 sensitivity cases and the top 13 optimization results. The first case is having a capacity shortage of 0%, a battery replacement cost multiplier of 0.5, a battery cost multiplier of 0.5, a PV replacement cost multiplier of 0.5, a PV cost multiplier of 0.5, and a load scaled average of 24022kWh/day. Based on the overall optimization results, the first and second optimization results are similar in all values except that the first result is Load Following (LF) and the second result is Cycle Charging (CC).

The categorized optimization results only display one result. The result displayed the system architecture of cycle charging, PV array of 14,486 kW, the number of batteries amount to 15632 and 2903 kW converters. The optimization results on the cost were a net present cost of $11,744,020, the Levelized Cost of energy of $0.074, the operating cost of $213,036, the initial capital cost of $7,890,000, and operation and management of $36,000.

5.1. Energy use and social-economic indicators of Matekenya village
This section contains the results that indicate the social-economic potential for the village, their current energy use, and their willingness to be connected and to pay. 96 questionnaires were administered. One questionnaire was for the village head and 95 questionnaires were administered per structure or household. Most structures assessed were houses which represent 54.2% of structures followed by structured being used as both houses and shops which represent 15.6%. The structures being used as shops only represented 8.3% and the remainder is shared among other types of structures. On sources of energy, the majority showed that they use solar PV lights for lighting followed by dry cells and candles. On sources of energy for cooking, the majority showed that they use wood for cooking followed by those who use charcoal and others use both. The average expenditure on the sources of energy that they were using was found to be MWK9190.19 (11.24 USD) per month. The average expenditure on airtime was found to be MWK5056 (6.18 USD) per month and the average amount they were willing to pay was 9200/ Month (11.25 USD/month) per month with a standard deviation of 12,654.333. On willingness to be connected almost all respondents were willing to be connected. Table 3 shows the results willingness to be connected.

(1) Conclusions

This paper aimed to find out if it was technically and economically feasible to use a solar PV mini-grid to supply electricity to Matekenya village. To achieve that the electricity demand was determined using a survey. Solar resource for the area under study was taken from NASA since there
| PV Panels (CS6X-325P) (kW) | Batteries (BAE PVV210) (kW) | Converter (kW) | Dispatch | NPC ($) | LCOE ($) | Operating cost ($/yr) | Initial capital Cost($) | O&M Cost ($/yr) | Ren Frac (%) |
|--------------------------|-----------------------------|----------------|----------|---------|---------|----------------------|------------------------|-----------------|-------------|
| 14,485.76                | 15,632                      | 2903.255       | LF       | 1.17E+07| 0.074028| 213,036.6           | 7,889,017             | 36,000          | 100         |
| 14,485.76                | 15,632                      | 2903.255       | CC       | 1.17E+07| 0.074028| 213,036.6           | 7,889,017             | 36,000          | 100         |
| 14,089.91                | 15,712                      | 2953.196       | LF       | 1.17E+07| 0.074065| 215,097.5           | 7,857,225             | 36,000          | 100         |
| 14,089.91                | 15,712                      | 2953.196       | CC       | 1.17E+07| 0.074065| 215,097.5           | 7,857,225             | 36,000          | 100         |
| 14,489.08                | 15,472                      | 2951.893       | LF       | 1.18E+07| 0.074066| 215,231.6           | 7,855,275             | 36,000          | 100         |
| 14,489.08                | 15,472                      | 2951.893       | CC       | 1.18E+07| 0.074066| 215,231.6           | 7,855,275             | 36,000          | 100         |
| 14,843.06                | 15,376                      | 2938.296       | LF       | 1.18E+07| 0.074089| 213,968.9           | 7,882,165             | 36,000          | 100         |
| 14,843.06                | 15,376                      | 2938.296       | CC       | 1.18E+07| 0.074089| 213,968.9           | 7,882,165             | 36,000          | 100         |
| 14,965.82                | 15,072                      | 2973.808       | LF       | 1.18E+07| 0.074098| 217,087.1           | 7,826,961             | 36,000          | 100         |
| 14,965.82                | 15,072                      | 2973.808       | CC       | 1.18E+07| 0.074098| 217,087.1           | 7,826,961             | 36,000          | 100         |
| 14,913.42                | 15,584                      | 2903.995       | LF       | 1.18E+07| 0.074098| 210,747.8           | 7,941,975             | 36,000          | 100         |
| 14,913.42                | 15,584                      | 2903.995       | CC       | 1.18E+07| 0.074098| 210,747.8           | 7,941,975             | 36,000          | 100         |
| 15,161.93                | 14,816                      | 2993.479       | LF       | 1.18E+07| 0.074111| 219,068.5           | 7,793,056             | 36,000          | 100         |
was no nearby weather station. The sizing of the different components was determined and their cost was taken from different suppliers. The system optimization was done using HOMER and it was done with sensitivity variables and without sensitivity variables.

The preferred optimization result showed that the NPC required was $1,174,020, LCOE was $0.074, the system operating cost was $213,036, and the initial capital cost of $7,890,000. According to Malawi’s feed-in tariff policy, the feed-in tariff for solar PV energy into the main grid is $0.10/kWh and the electricity tariff for users is $0.13/kWh. From the results, it can be seen that it is technically and economically feasible to supply electricity to Matekenya using a solar PV mini-grid. In addition, the village showed that there is a high potential for productive use of electricity and a willingness to be connected.

Table 3. Results for willingness to be connected

|         | Frequency | Percent | Valid Percent | Cumulative Percent |
|---------|-----------|---------|---------------|--------------------|
| Valid   | 1         | 1.0     | 1.0           | 1.0                |
| Yes     | 95        | 99.0    | 99.0          | 100.0              |
| Total   | 96        | 100.0   |               | 100.0              |

Disclosure statement
No potential conflict of interest was reported by the author(s).

Data availability statement
Some or all data, models, or codes that support the findings of this study are available from the corresponding author upon reasonable request.

Citation information
Cite this article as: Technical and economic feasibility assessment for a solar PV mini-grid for Matekenya village, Peter Maliro, Bakary Diairra & Ravi Samikannu, Cogent Engineering (2022), 9: 2110707.

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Appendix 1. Calculation of total demand

|       | A | B   | C   | D   | E   | F   | G   | H   | I   | J   | K   | L   | M   | N   | O   | P   | Q   | R   | S   | T   | U   | V   | W   | X   | Y   | Z   | AA  | AB  | AC  | AD  |
|-------|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |

|       | A | B   | C   | D   | E   | F   | G   | H   | I   | J   | K   | L   | M   | N   | O   | P   | Q   | R   | S   | T   | U   | V   | W   | X   | Y   | Z   | AA  | AB  | AC  | AD  |
|-------|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1     |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
