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IMPLEMENTING RENEWABLE ENERGY GENERATION FOR A COLLEGE IN KENYA

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Declaration of Authenticity

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed:

Date:

Harjot Singh Ubhi

Acknowledgements

First and foremost, I thank God. It is with His grace that I have got this far, and whatever lies ahead is God's plan.

I would also like to thank Bhai Sahib Bhai (Dr) Mohinder Singh OBE KSG for their advice and guidance throughout life.

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Abstract

This report focuses on researching and implementing renewable energy generation for The Nishkam Sant Puran Singh Institute (NSPSI), a college in Kericho County, Kenya. The idea for this project came about when the author visited Kenya in 2018 and discussed the energy issues at the time with the principal and the site manager. The college experiences multiple power cuts daily while connected to the local grid and does not currently have a back up generator. As the college is in a rural setting and is part of a faith-based group, alternative renewable energy generation was seen an opportunity to stabilise the electricity supply.

The report looks at what sources of renewable energy is available in Kenya and more specifically suited to the college in a rural setting. The current sources are; geothermal power, hydropower, solar power and wind power. Due to the size of the project geothermal power and hydropower were considered as unfeasible.

The report then inspects and analyses weather data regarding the remaining sources of renewable energy, wind power and solar power. Based on the weather data it was found that solar power was the best route for the college.

Energy monitoring and targeting is also addressed, talking about the steps that should be taken to make a system or company more efficient. Energy usage needs to be calculated and then it can be determined whether or not there is wasted energy, and how it can be reduced.

An energy audit was performed, and it revealed that the college currently uses 22.6 megawatt-hours per year. It was also determined that if the college were to install air conditioning the energy usage would go up to 75 megawatt-hours a year.

It was calculated that with the use of 280 watt polycrystalline silicon solar panels, 60 panels would be required to cover the current energy usage of the college, and 108 solar panels would be required if air conditioning is installed. It was also calculated that fourteen 10.2 kilowatt-hour batteries would be required for a 60 panel setup and that 26 batteries would be required for a 108 panel setup. A consideration was also made into the use of solar panels only without the use of batteries, this yielded a cheaper cost and shorter payback period.

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1 Introduction

This report will focus on investigating the implementation of renewable energy generation for a college in Kericho County, Kenya. The name of the college is Nishkam Saint Puran Singh Institute (NSPSI) and was established in 1999 by Guru Nanak Nishkam Sewak Jatha (GNNSJ) a Sikh congregation based in Birmingham, UK. "NSPSI is a tertiary college located in the Rift Valley province in the town of Kericho. The Institute offers a range of vocational courses aimed at equipping young people with practical, realistic skills that can be deployed in local community and beyond" (NSPSI, n.d.). The college has been expanded over the years, currently covering approximately 7000 square meters of land. There are approximately 300 students that attend the college and about 20 members of staff.

Kericho is a rural county located in the west of the Kenyan Rift Valley, East Africa, 0.37 degrees south of the equator and approximately 2000 meters above sea level. Kericho is more or less on the equator so has relatively short periods of daylight compared to other parts of the world, but the days are consistent throughout the year. Kericho's high altitude means that it is relatively cooler compared to other cities and countries at the equator.

This report will be focusing on using renewable energy for electricity generation. The idea of this project came about when the author visited Kenya in 2018 and discussed the energy issues at the time with the principal and the site manager. There are other uses for renewable energy that the college could benefit from, but the college requires an uninterrupted electricity supply. The college is connected to the local grid, which is not very stable and cuts out quite often. NSPSI does not currently have access to its own backup generator for when the power cuts out, so an opportunity to introduce renewable energy generation became available.

This report will include a feasibility study to determine which source of renewable energy would be most viable and beneficial for the college. It will then focus further on the appropriate method. The main sources of energy that will be discussed are solar power, small scale hydropower, wind power, geothermal power and biomass.

With the ever-increasing requirement for energy in developing countries, renewable energy is the simplest way forward. It is easily accessible and sustainable, meaning

considerably less impact on the environment compared to other sources of energy such as coal and nuclear energy. With the college being founded by a faith based organisation, the use of renewable energy is considered a step forward in the conservation of earth.



Figure 1: Image of Nishkam Saint Puran Singh Institute (NSPSI , n.d.)

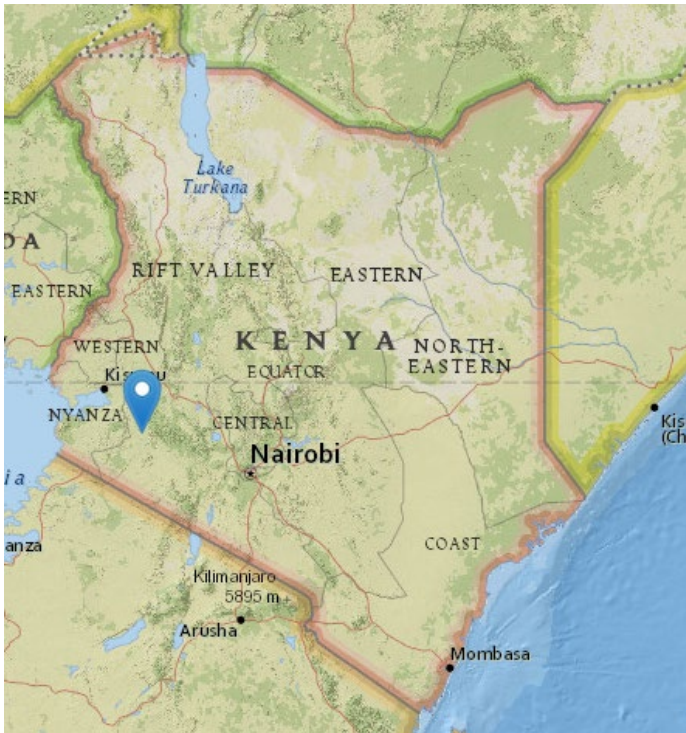


Figure 2: Map of Kenya showing the location of Kericho (National Geoprahic Mapmaker, n.d.)

2 Research and Literature Review

2.1 Sources of renewable energy

The potential sources of renewable energy that can be used for electricity generation in Kenya are; hydropower, solar power, wind power, geothermal power, and biomass. These are the main sources of renewable energy available in Eastern Africa.

2.1.1 Hydropower

Hydropower is one of the oldest forms of renewable energy. For electricity generation it is the converting of the kinetic energy in the water to electrical energy. Hydropower schemes can be categorized into two main categories; large scale and small scale. There are also different techniques of harnessing the water; the water can either be stored in a reservoir or used directly from a river.

The reservoir is created by building a dam to hold the water. The reason for the use of a dam to create a reservoir is because it allows for the control of flow rate through the turbines. This is more expensive to implement than the river-run-off method, due to there being more construction involved, due to the complexity of building a dam construction costs are about two-thirds of the overall cost of the hydropower project (Breeze, 2014). Different types of dams can be constructed depending on budget.

A river-run-off scheme utilises the flow rate and head height of a river to generate electricity. Even with this method there is construction involved, but not to the scale of creating a reservoir. The water will need to be syphoned off from the river, passed through the turbines and returned to the river. Some countries have legislation on how much the flow rate of a river can be affected. The main benefit of a river-run-off scheme is that because of its simplicity it is cost effective. However, flow rate of a river can fluctuate throughout the year, whereas a reservoir can be controlled.

For small scale hydropower, river-run-off schemes are a more viable option than the use of reservoirs. For cheaper applications, turbines can be placed directly into the river rather than diverting water away from the river. The disadvantage of this is that energy generation is solely reliant on the flow rate of the water and not the head height.

There is a small river nearby to the college in Kericho, the flow rate of the river is very low and slightly too far from the college for it to be a viable source. For the scale of this project hydropower is not currently a viable option.

2.1.2 Solar power

Solar power is up there with hydropower for being one of the oldest forms of energy, its energy has been harnessed for centuries for heat. The heat can be concentrated using a parabolic reflector to heat water, which then turns to steam and turns a turbine, this is known as a heat engine. More recently, the sun's energy is used to generate electricity via the use of photovoltaics. The energy within the sunlight is absorbed by a photovoltaic device and converted to electrical energy. Photovoltaic cells are most commonly made of crystalline silicon. There are two different types of crystalline silicon, monocrystalline and polycrystalline. Photovoltaic cells can also be made from gallium arsenide, amorphous silicon, cadmium telluride and copper indium gallium selenide.

The photovoltaic effect is how electricity is produced from sunlight. Photons of light transfer energy to electrons in the material, exciting them and allowing them to attain a higher energy level. When electrons are excited, they gain potential energy and become free to conduct electric current. (Boyle, 2012)

Types of solar panel

Monocrystalline silicon

Older photovoltaic cells are made from monocrystalline silicon, this is silicon with a singular crystal lattice structure, and it has very few impurities. Monocrystalline silicon cells have the highest efficiency (15-20%) at absorbing light because they are made from a high grade of silicon. However, the process of manufacturing it is time consuming which high cost, which causes the panels to be more expensive for consumers.

Polycrystalline silicon

Photovoltaic cells are now more commonly made from polycrystalline silicon. Polycrystalline silicon is just several monocrystalline layers. Polycrystalline silicon cells are easier to manufacture and also produce less waste in the manufacturing process than monocrystalline silicon cells causing them to be cheaper. A down side is that the

efficiency of the cells is slightly lower (13-17%) due to a lower grade of silicon being used. Polycrystalline cells are a compromise of cost and efficiency.

Gallium arsenide

The less common material of choice for photovoltaic cells is gallium arsenide. Gallium arsenide is similar in structure to silicon. It is very efficient as it has a high light absorption coefficient and only a thin film of the material is required. It is more time consuming to manufacture than monocrystalline silicon and has a more expensive manufacturing process. Gallium arsenide is able to operate under high temperatures which is why it is still used despite the cost.

Thin film

Thin film cells are made by placing photovoltaic substance onto a surface, typically glass. The main substances are amorphous silicon, cadmium telluride and copper indium gallium selenide. Thin film cells are currently the least efficient type of cell and also degrade a lot quicker than the other types of solar cell. However, they are easy to mass produce and are very cheap to produce.

Solar power is increasing in popularity amongst renewable energy generation, due to the fact that there are very little restrictions on where solar panels can be located, all that is required is sunlight and space for the panels, they are most commonly placed on roofs. Solar power for electricity generation for the college is ideal as there is plenty of roof space for solar panels and seemingly plenty of sunlight. (Rothman, 2018)

There are several solar power projects that are taking place in Kericho, one of which was in 2013 where the largest solar power plant in Eastern Africa (at the time) was opened with a capacity of 1 MW (Mbogo, 2013), this obviously set a precedent and smaller projects are cropping up in the area.

2.1.3 Wind power

Wind is the movement of air due to the differences in the atmospheres pressure (Breeze, 2014). Wind power is one of the most common sources of renewable energy. It consists of converting the kinetic energy in the wind into electrical energy. Wind turbines are usually built in groups called wind farms, and these can be both on shore and off shore.

Wind mills were originally built to harness the wind's horizontal kinetic energy and convert into vertical kinetic energy, e.g. grain mills and pumping water. Nowadays, wind mills are used as turbines to generate electricity. A wind turbine consists of three main parts; the tower the blades and the nacelle, where the generator and other components are located. The most common turbine design is the tri-blade horizontal-axis design. Several designs have been tried and tested, some of which are still used, but the tri-blade design is the most common because it compromises between torque generated and the rotational speed the blades can achieve. The wind hits the blades, which turns the generator. The equation for wind power is $P = \frac{1}{2} \rho A v^3 C_p$. Where P is the power output of the wind turbine in Watts (W), ρ is the density of the air (Kg/m^3), A is the area swept by the blades (m^2), v is the velocity of the wind (m/s), and C_p is the power coefficient of 0.59 based on Betz's law basically stating that a wind turbine can only capture 59% of the winds energy.

Wind power is a potential solution for the college; however, it may be difficult to implement as there is a lack of ground space. Small wind turbines could potentially be used but will most likely not generate the amount of energy required by the college.

2.1.4 Geothermal power

Geothermal power is utilizing the heat stored by the earth's body. This is made possible because the earth's crust is not uniform. Where the crust is thinner magma is able to come closer to the surface, causing an increase in temperature close to the surface. There are two natural occurrences of the heat being brought to the surface, one being geysers, where water is collected in cracks where the earth's body temperature is higher and heat transfer occurs with the water and due to an increase in pressure the water returns to the surface. The other is volcanos, where molten magma is able to flow to and above the surface.

The most common way of harnessing the heat energy from the earth's body to generate electricity, is to have underground pipes with flowing water to create a heat transfer system, which would produce steam to turn a turbine. The water can reach temperatures from about 100 degrees Celsius to about 350 degrees Celsius. (Breeze, 2014)

There are currently geothermal power stations in Kenya which make use of the Rift Valley. The closest to Kericho is Olkaria, which is a plant that extracts heat from underneath lake Naivasha. Olkaria is located about 80 miles from Kericho. The closest volcano to Kericho is north of lake Nakuru which is about 60 miles from Kericho. Both of these solutions are too far for a small-scale generation project for the college. It could potentially be viable to provide for the whole of Kericho.

The college has a strong relationship with the current governor of Kericho, Professor Chepkwony, who may wish to look into these larger scale renewable energy generation opportunities as part of his development plan for the county. As a pioneer of improving and upgrading the county and a personal advisor to the President of Kenya, he is pivotal in the mass improvements in renewable energy sources in Kenya. The author was privileged to meet with Prof Chepkwony both in Kenya in 2018 and during the Governor's visit to the UK.

2.1.5 Biomass

Biomass is the use of plant and animal derivatives as a fuel. Biomass includes wood, animal waste, some urban wastes and some agricultural wastes. The use of biomass has also been around for centuries, the early use of biomass is for heating or cooking. However, it has since been widely replaced by coal, oil and gas.

For electricity generation, biomass can be burned to provide heat for the production of steam which is used to turn a turbine. Most biomass power generation plants usually exist close to industries that can supply the fuel, e.g. the wood processing industry and the paper industry have sawdust as their waste products, which can be used as a fuel. However, as waste is seen as inefficient, industries are constantly reducing the waste that they are producing, meaning that biomass from waste is quite limited. A solution that has been proposed is the growth of plantations solely for biomass, though this is not ideal as it would be more beneficial if the land was used for food production, considering that 1 in 9 people go to bed hungry (World Food Programme, 2018).

Biomass can also be converted into gas and liquid called biogas and biofuel. These can then be burned to produce electricity in the same manner. Biogas is formed when organic material decomposes and is captured. It can occur naturally, and it can be also be produced. Biogas is a product of digesters, where bacteria digests waste and gives of

methane, this is the process of anaerobic digestion (US energy information Administration , 2018).

Some notable biofuels are ethanol and biodiesel. Ethanol is made from the fermentation of corn and sugar cane crops. Biodiesel is produced from animal fats and vegetable oils. Both ethanol and biodiesel are mainly used for vehicles.

Part of the Mau forest passes through Kericho County, this would have been an ideal source for biomass, however the forest is a national reserve. As the college is part of a faith-based organization, it wishes to minimise the impact on the environment, so deforestation is not a favourable option. However, as Kericho is one of the largest producers of tea, it may be an option to look into using the wastes of a tea plantation to produce biofuel.

2.2 Weather Data

To make a decision on which source of renewable energy source is most appropriate for the college, weather research and data collection is required for the area. The most reliable source of data was secondary data as there was not an opportunity to conduct any meaningful primary research. A year's worth of weather data is usually the minimum amount required for assessing an area, obviously the more data there is, the easier it is to predict a pattern of the weather for coming years. Although the prediction will not be 100% accurate, it will be sufficient enough to gain an understanding of the behaviour of the weather, and how much energy can be generated from the renewable sources. The caveat here is that as a result of climate change it is being observed that there are increasingly more variations in weather patterns around the world. It is important to acknowledge that there may be unpredicted changes to the weather and weather data used in this report is only a prediction based on historical data.

Due to the scale of the project, geothermal power and hydropower have been ruled out, biomass has been ruled out as there are currently insufficient viable sources of biomass in Kericho, and solar power and wind power are being investigated further.

The weather in Kenya is fairly consistent throughout the year, as Kericho is almost on the equator it has an almost constant amount of sunlight hours the whole year. The temperature in Kericho fluctuates a few degrees but can still be considered consistent compared to the rest of the world.

As seen in Figure 3, Kericho experiences approximately 12 hours of daylight consistently throughout the year, and this is again due to Kericho being very close to the equator. This is relatively short compared to what other countries further from the equator experience, but those countries will have different sunlight hours each season. For countries in the northern hemisphere e.g. U.K., daylight hours will be higher in summer months and lower in winter months.

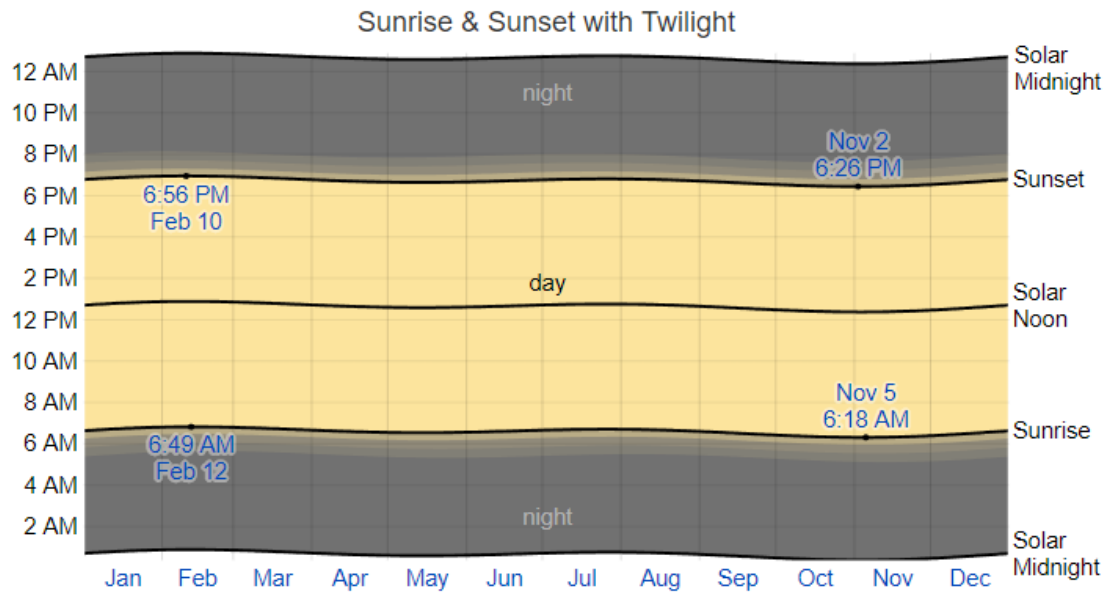


Figure 3: Average sunrise and sunset hours in Kericho (Climate-Data.org, 2018)

The average amount of sun-hours each month for a year in Kericho can be seen in Figure 4. A sun-hour is defined as an hour of sunlight that offers 1000 watts per square meter (w/m^2). It can be described as the intensity of sunlight within a specific area, it is usually achieved when the sun is at its highest point. The number of sun-hours generally increases the closer an area is to the equator, which is why the sun-hours for Kericho is considerably high, averaging up to almost 10 sun-hours a day in January. (Richardson, 2019)

From November 2017 to October 2018 Kericho experienced roughly 2500 sun-hours in total, as depicted in Figure 4. A solar panel's output is the electrical power it could produce if it received 1000 w/m^2 of solar energy, i.e. one sun-hour. Assuming a 280 watt solar panel is used, one solar panel could theoretically produce 700 kilowatt-hours in a year. (The Eco Experts, 2019)

$$280 \text{ W} \times 2500 \text{ hrs} = 700,000 \text{ Wh}$$

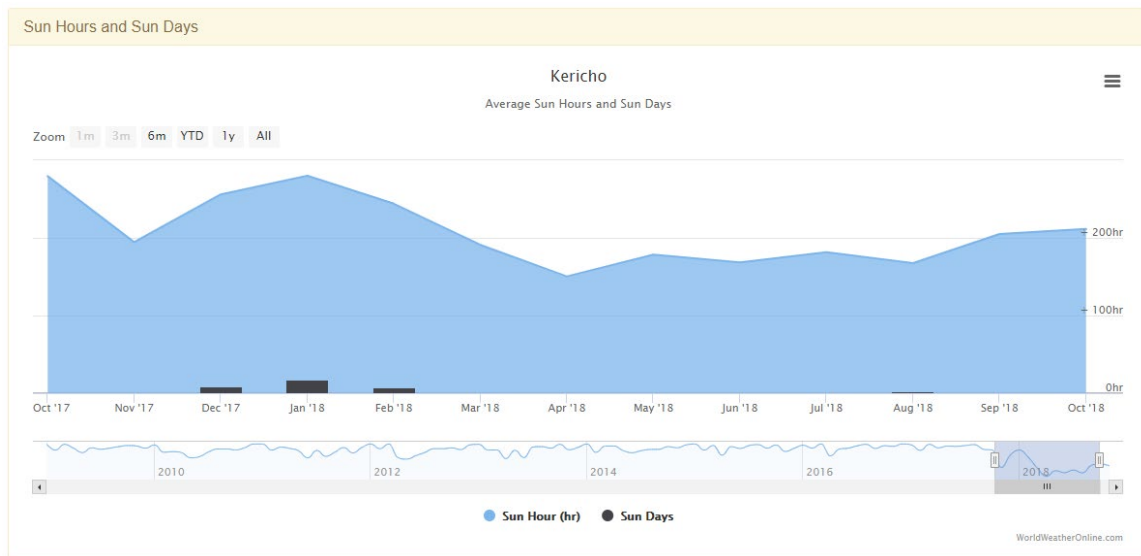


Figure 4: Average sun-hours each month in Kericho (World Weather Online, 2018)

When looking at the average maximum temperatures and average minimum temperatures for each month in Kericho, it can be seen that the highest average maximum temperature achieved is about 24 degrees Celsius and the lowest average minimum temperature is about 12 degrees Celsius (Figure 5). The maximum temperature is considerably low for a city in Africa, especially one so close to the equator, this could potentially be due to the high altitude of Kericho.

With these temperatures, the solar panels can be made from crystalline silicon rather than gallium arsenide, and they will not need to be cooled down to stop them from overheating, which is the case in some hotter countries.

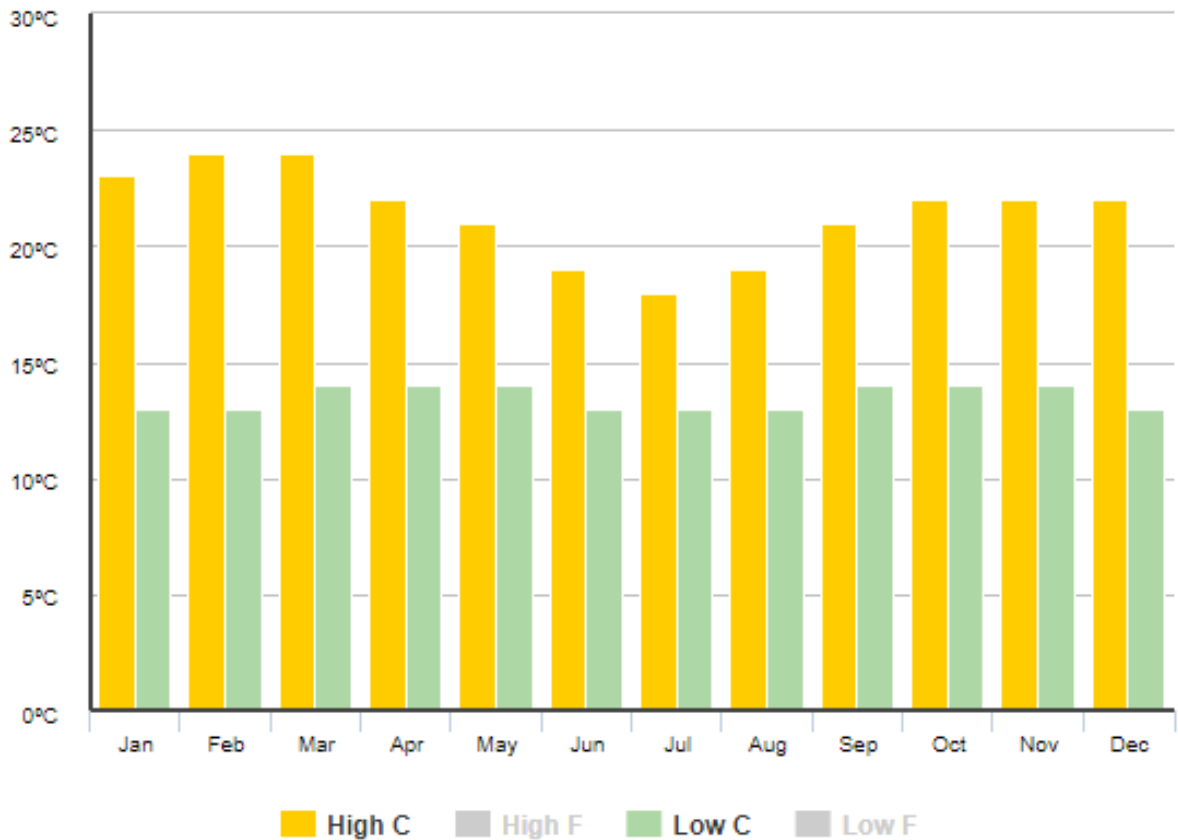


Figure 5: Average maximum and minimum temperatures each month in Kericho (Holiday-Weather.com, 2018)

The average wind speed, maximum wind speed and average wind gust for each month for a year in Kericho can be seen in Figure 6. A wind gust is “a rapid fluctuation in wind speed” (National Weather Service, n.d.). The highest maximum wind speed in a month is about 10 km/h and the maximum average wind speed is about 7 km/h. These speeds are fairly slow for large and small wind turbines. Small wind turbines having a minimum speed to start rotating at around 8 km/h and a maximum generation speed of about 30 km/h (Level, 2017). One possibility is to use even smaller wind turbines, micro turbines. Wind is also quite unpredictable compared to other renewable energy sources and also fluctuates a lot throughout the year.

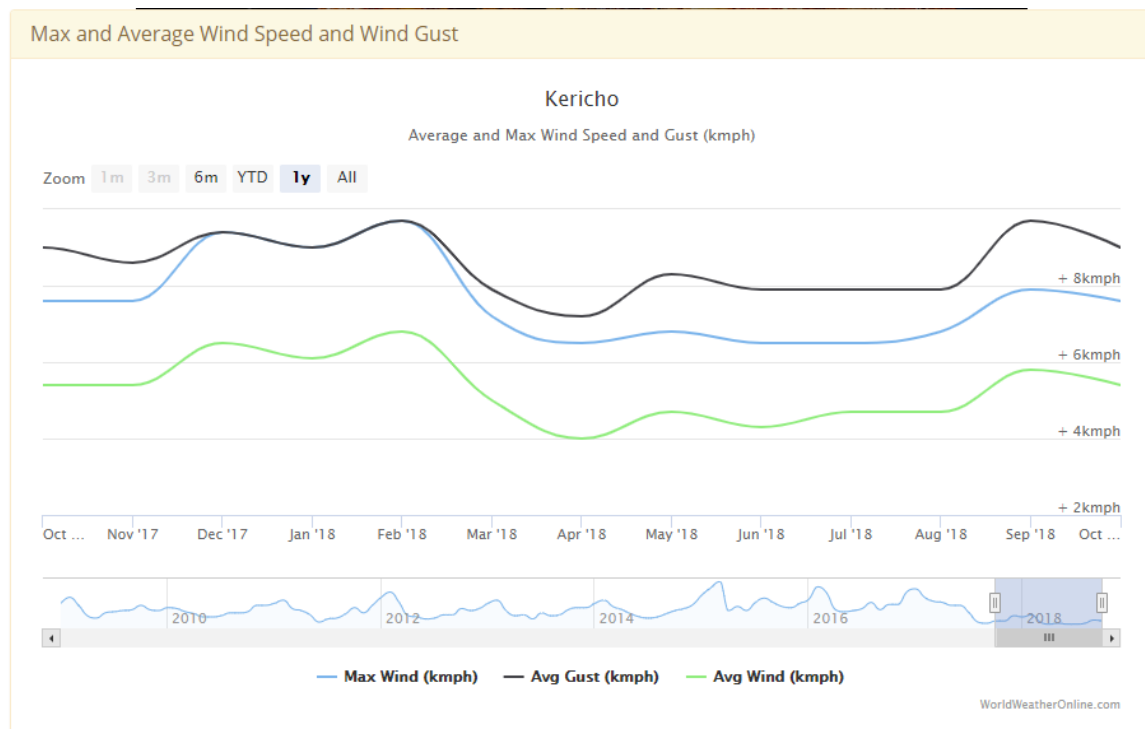


Figure 6: Average and max wind speed each month in Kericho (World Weather Online, 2018)

Looking at a map of Kenya with a contour plot of wind speed data (Figure 7), the highest wind speeds are achieved in the north of Kenya. The area where Kericho is situated has the lowest wind speeds in the country, confirming that the wind speeds achieved in Kericho are considerably low.

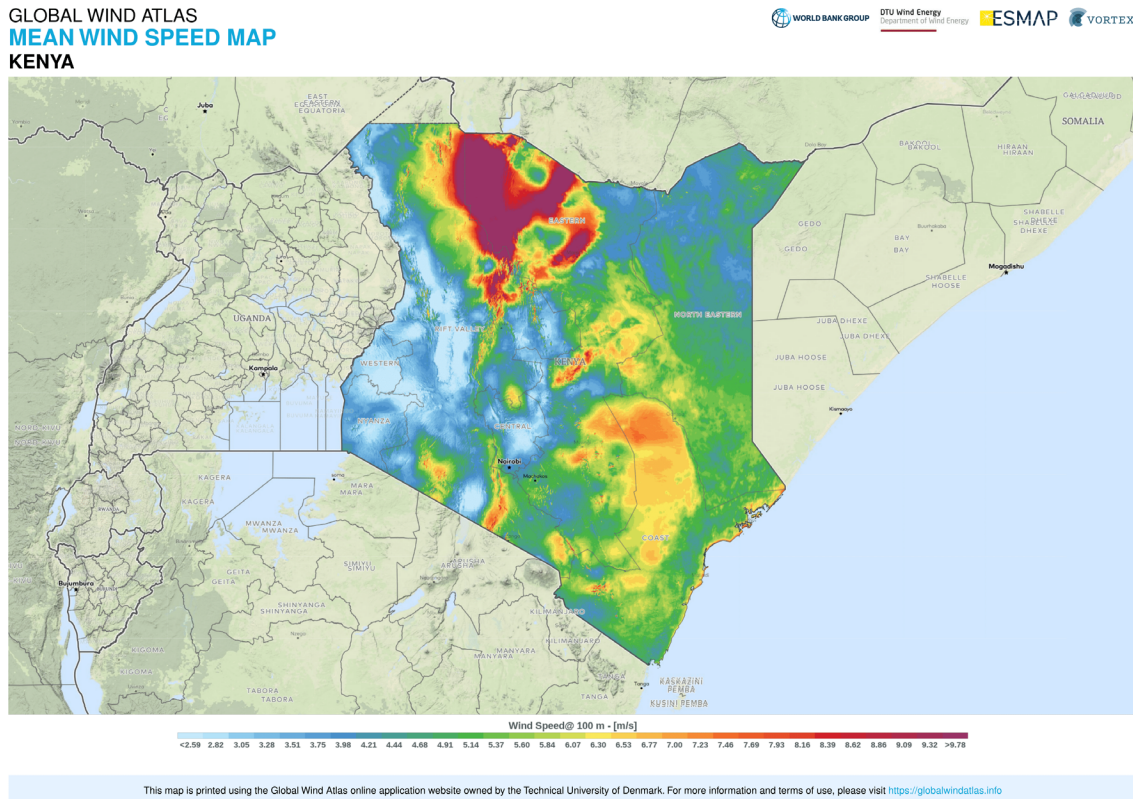


Figure 7: Wind speed contour data of Kenya (Global Wind Atlas, 2017)

According to the weather data the most viable option would be to use solar power. The wind speeds are too low to be able to generate an acceptable amount of energy required by the college. With the wind speeds achieved, micro wind turbines would have to be used and with wind being a more unpredictable source of renewable energy than other sources of energy, it would be more feasible to use solar power as it is predictable and also fairly constant.

2.3 Energy Monitoring and Targeting

Energy monitoring and targeting is a useful technique in energy management that combines energy use and statistics. It utilises energy data to identify and reduce waste, reduce current energy usage and improve the existing processes and procedures. Monitoring focuses on what the current consumption pattern is, while targeting identifies the desired level of consumption in order to conserve energy, and in turn save money.

Energy monitoring and targeting is more prominent amongst larger companies where the criteria and margins are tighter. The main industries that would use this energy management technique are; fuel, steam, refrigeration, compressed air, water and electricity. (Bureau of Energy Efficiency, n.d.)

There 5 main steps to energy management; understanding energy use; planning and organisation; implementation; verification, monitoring and reporting; company commitment. This is an ongoing cycle and an iterative process.

Ideally the college should undergo energy monitoring and targeting, before implementing renewable energy generation to ensure that the energy usage is as efficient as possible, and that no money is wasted on excess generation. It will likely be found that the most wasteful area is lighting. Lights are the most likely to be forgotten about and get left on.

The introduction of the retrofit solar panels could allow the monitoring and targeting regime to bring about a more robust and rigorous continuous improvement cycle and subsequently a greatly improved culture of working in the college.

3 Analysis

3.1 Energy Audit

An energy audit is a survey to determine how much energy is used within a building. This must be done in conjunction with deciding which forms of renewable energy are to be used to establish which would be more beneficial and efficient. As the renewable energy proposed will be used for electricity generation, the energy audit will solely be on electricity usage at the college.

The college has 32 rooms in total, these include classrooms, lecture halls, offices, washrooms and a kitchen. The majority of the rooms have florescent tube bulbs, so it is assumed that all the rooms have the same bulbs. Most of the classrooms are similar in size so again it is assumed they have the same number of bulbs, 10 bulbs per room. A total value of 295 bulbs was achieved. There is one computer room, and computers in the offices, so in total about 30 computers including monitors. Other appliances include, printers, routers, refrigerators and kettles. Most of the equipment is only in use during the school day and school term. So about 6 to 8 hours a day, 5 days a week for 40 weeks. Fridges are an exception to this as they are on for 24 hours but only ever in use about 30% of the time (Reduction Revolution, 2014). Computers are considered to be using energy only when they are in use and not in standby, due to negligible energy usage when in standby.

The college does not currently have air conditioning installed but is considering installation in the future. If air conditioning is installed, there will most likely be 1 unit per room (excluding washrooms), so about 28 units. Calculations have been based on with and without the installation of air conditioning.

To obtain a value for energy usage; output of the appliance and the usage time need to be known. Multiplying the output, in watts, by usage time, in hours, gives a value for energy usage in watt-hours.

Appliance	Qty	Capacity /W	Duration in use (per day) /hrs	Energy Consumption per day /kWh	Notes
Lights	295	32	8	75.52	30 rooms + 2 lecture halls
Computers	30	170	6	30.6	
Router	5	10	24	1.2	
Fridge	2	150	7.2	2.16	On 24 hrs but fridges only run 30% of the time
Kettle	2	3000	0.5	3	
Printer	5	800	0.16	0.64	On 24 hrs but on standby, in use 10 mins
				Total kWh per day	113.12
				MWh per year	22.624
					5 day a week, 40 weeks a year

Appliance	Qty	Capacity /W	Duration in use (per year) /hrs	Energy Consumption per year /MWh	Notes
Air con	28	3500	540	52.92	3 hours a day for 6 months
				Total Energy usage per year including Air con.	75.544

Table 1: Table showing a breakdown of the energy audit

The current electricity usage was calculated to be 113 kilowatt-hours per day. With a 5-day week and a 40-week year, the kilowatt-hour per year value was calculated to be 22,600, which can be simplified to 22.6 megawatt-hours. Assuming that one air conditioning unit will be installed in each room (excluding washrooms), there will be about 28 units. It is also assumed that the units will be used for about 3 hours a day for half of the year. With these assumptions in mind, it was calculated that the installation of air conditioning would increase energy usage by about 52 megawatt-hours per year. Giving a total of 75 megawatt-hours per year, which is over three times the usage than without air conditioning. (see Table 1)

For the remaining 12 weeks of the year, let it be assumed that about 30 bulbs are turned on for 20 mins a day during security checks, and that the fridge is left on for the whole period. The bulbs will use 0.3 kilowatt-hours a day and the fridges will use 2.1 kilowatt-hours a day.

$$30 \times 32 \text{ W} \times 0.33 \text{ hrs} = 316 \text{ Wh}$$

$$3 \times 150 \text{ W} \times 7.2 \text{ hrs} = 2,160 \text{ Wh}$$

$$2.4 \text{ kWh} \times (12 \times 7) = 201.6 \text{ kWh}$$

So, for the 12 weeks of the year when college is unoccupied, a total of 201 kilowatt-hours is used.

3.2 Implementation

Based on the review of the sources of renewable energy, weather data and the energy audit, it would appear that the most viable source of renewable energy appropriate for NSPSI, is a solar power option. With the use of the energy audit together with the weather data, an estimate can be made on the sizing of the project, i.e. what solar panels to use and how many to use. The most appropriate location for the solar panels is on the roofs of the college. There are a few factors to consider while installing solar panels, such as things like the pitch of the roof, required tilt of the panel, and weight of the panel. Any structures that are likely to cause shade will reduce the efficiency of the system.

3.2.1 Solar panels

The solar panel that has been used for calculations is a 280 watt polycrystalline silicon solar panel. There are a few reasons why a polycrystalline silicon panel has been recommended, one being it is cheaper than both monocrystalline silicon panels and gallium arsenide panels. Gallium arsenide panels are not required in Kericho as the temperature stays relatively cool throughout the year and they are mainly required in countries where the temperature is too hot for crystalline silicon panels. Polycrystalline silicon is chosen over monocrystalline silicon because, again, it is cheaper and does not sacrifice much with regards to efficiency. A panel of 280 watts was recommended as a benchmark because it was the median standard and efficiency when comparing panels for power output and price.

As mentioned earlier, there were roughly 2,500 sun-hours in total for a year in Kericho, which averages to 6.8 sun-hours a day.

$$2,500 \div 365 = 6.84$$

Assuming a 280 watt solar panel is used, one solar panel produces 1.9 kilowatt-hours in a day.

$$280 \text{ W} \times 6.84 \text{ hrs} = 1.915 \text{ kWh}$$

Again, calculations are made with and without the installation of air conditioning. Without air conditioning, the college uses 113 kilowatt-hours a day. Dividing 113 kilowatt-hours by 1.9 kilowatt-hours gives the quantity of 280 watt solar panels required as 60.

$$113 \text{ kWh} \div 1.9 \text{ kWh} = 59.4 \text{ (60 panels)}$$

With air conditioning the college uses about 205 kilowatt-hours a day. Dividing 205 kilowatt-hours by 1.9 kilowatt-hours gives a requirement of 108 solar panels.

$$205 \text{ kWh} \div 1.9 \text{ kWh} = 107.8 \text{ (108 panels)}$$

These quotes for the number of solar panels are calculated so that the college is run solely on solar energy. Becoming self-sufficient is ideal for the college as the grid connection is very unstable and can cut out almost once a day for a few hours. An easy option would be to use a generator to mitigate the down time, however the college is looking for an environmentally sustainable solution. It may be an option to remain connected to the grid in the off chance that the energy usage does exceed energy generation. The college is also looking to expand in the future, so provisions need to be made to allow for easy installation of more panels as and when required.

Most of the buildings that make up the college campus are of a similar size, the campus is made up of six buildings surrounding a glass atrium, three of the buildings are about 30 m by 10 m and the other three buildings are about 20 m by 10 m, roughly depicted in Figure 8. The college has approximately 1500 m² of roof space.

$$3(30\text{m} \times 10\text{m}) + 3(20\text{m} \times 10\text{m}) = 1500\text{m}^2$$

The size of a 280 watt roof panel is about 1.6 m by 1 m, so an area of about 1.6 m². So NSPSI college can fit roughly around 930 panels on the roofs.

$$1,500 \div 1.6 = 937.5$$

Meaning that the quotes of 60 panels and 108 panels are achievable.

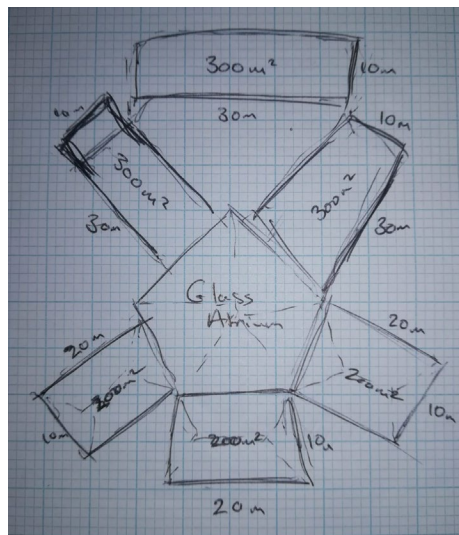


Figure 8: Rough sketch of an aerial view of the college with approximate dimensions

The weight of a 280 watt panel is approximately 18 kg (CCL Components, n.d.), so 60 solar panels would weigh a total of 1,080 kg and the weight of 108 solar panels would be a total of 1,944 kg.

$$60 \times 18 \text{ kg} = 1,080 \text{ kg}$$

$$108 \times 18 \text{ kg} = 1,944 \text{ kg}$$

The campus is made up of 6 similar sized buildings, so for 60 solar panels each roof would have to bear approximately 180 kg and for 108 solar panels each roof would have to bear 324 kg.

$$1080 \text{ kg} \div 6 = 180 \text{ kg}$$

$$1944 \div 6 = 324 \text{ kg}$$

The building was built with future-proofing in mind and to standards similar to the UK, due to the parent organisation of the college being based in the UK. Discussion with the site manager confirmed that this weight loading would be easily accommodated but further investigation needs to be done to validate this.

Different materials can support different loads, concrete is one of the strongest as it can support heavy loads and is the most durable material that roofs can be made from. The college roof has clay tile, supported by a timber structure. If manufactured correctly a clay tile is very strong yet light in weight. This would allow the roof to take more weight from solar panels than if the tiles were made from concrete. A concrete tile weighs twice the amount of a clay tile, yet a clay tile is just as strong (occasionally stronger) (T&S Roofing Systems, n.d.).

The pitch on most of the college's roofs are quite shallow, with the exception of a couple. The ideal pitch of a roof would be 45 degrees as the load of the solar panels would be the most evenly distributed on a roof with this angle. On the contrary, the flatter the surface is, the easier the installation of the solar panels will be. The solar panels will still need to be installed with a tilt for optimum generation. As Kericho is located 0.37 degree south of the equator, the optimal angle of tilt is almost horizontal and should be facing due north, i.e. towards the path of the sun. The angle of tilt for solar panels in Kericho is calculated as the latitude multiplied by 0.87.

$$0.37 \times 0.87 = 0.32$$

So, the angle of tilt required is 0.32 degrees (Landau, 2017).

As the solar panels are going to be retrofitted onto an older roof, the ideal situation is that the remaining roof life is longer than the life of the solar panels, if not then the roof could potentially fail under the load of the solar panels, causing damage to both the roof and solar panels. An assessment on the condition of the roof must be done prior to installation. Another precaution that should be made is that the installer should take extra care when installing the solar panels, as not to cause unnecessary damage to the roof.

As well as the constant sunshine, Kericho, notoriously, experiences a lot of rainfall throughout the year. Unfortunately, the roofs were not designed with the plan to install solar panels, so drainage of rainwater will most likely be interrupted by the installation. If not addressed then leaks can occur and cause damage to the roof, and with solar panels installed it would be a lot harder to repair (Pacific West Roofing, n.d.). A benefit of the rainfall, however, would be that the solar panels will not require much hands-on cleaning, as the rain will keep them from dusting over.

3.2.2 Storage

Storage is one of the most important things to consider when implementing any renewable energy generation techniques. The main reason is to allow for use of energy outside the hours of generation, in the case of solar energy, after sunset. Because the energy being stored is electricity, the storage device being used will be a battery, or multiple batteries. There are three types of battery that are typically used; flooded lead acid, sealed lead acid and lithium.

Flooded lead acid battery

The flooded lead acid battery is the cheapest of the three, its life span is about 5 to 7 years. When using lead acid batteries, it is recommended that they are only discharged up to about 40%, any more than this and the life time of the battery is reduced considerably. The flooded lead acid battery requires a lot of maintenance, it needs to have distilled water added and the charge to be equalised on a monthly basis. It also needs to be situated in a well-ventilated area due to the build-up of hydrogen gas. High concentrations of hydrogen can cause an oxygen-deficient environment. Breathing in hydrogen gas can cause symptoms such as; headaches, ringing in ears, dizziness, unconsciousness, and more (Lenntech, n.d.).

Sealed lead acid battery

The more expensive option is the sealed lead acid battery where no maintenance is required, but its life span is the shortest of the three with an estimated 3 to 5 years. When using lead acid batteries, it is recommended that they are only discharged up to about 40%, any more than this and the life time of the battery is reduced considerably. The sealed lead acid battery does not require any maintenance and is not expected to emit hydrogen gas, but it should still be situated in a well-ventilated area, as it is still a possibility.

Lithium battery

The most expensive battery is the lithium battery because it has a lifespan of more than 10 years. The lithium battery does not require any maintenance. It is the most efficient of the three types of battery with a faster charging rate, a (typically) greater capacity and a greater discharge depth (about 15-20%). (Wholesale Solar, n.d.)

When sizing the battery bank there are a few things that need to be considered; energy consumption, days of autonomy and system voltage. These will influence how many batteries are required, based on the capacity requirement. Another factor that will influence choice of battery is the cost. Configuration of the batteries should also be considered, when in series the voltage increases and when in parallel the amp-hours increase.

Days of autonomy is the number of days that the system can provide energy without having to recharge the batteries. This is considered in order to account for bad weather and hence no solar power generation. Three days is commonly quoted for days of autonomy, but as Kericho has fairly consistent weather, and the college will remain connected to the grid this should not be an issue.

The battery that would be considered most appropriate for this application is a lithium battery pack, made up of eight 1.28 kilowatt-hour batteries, with a total capacity of about 10.2 kilowatt-hours, which costs around 6,000 GBP per unit (CCL Components, n.d.). Batteries are the most expensive part of renewable energy generation project. Batteries usually have a recommended discharge limit to prolong their life. For a lithium battery

this is about 20%. So, the watt-hours actually provided by the battery is 80% of the total which is 8.16 kilowatt-hours.

$$10.2 \text{ kWh} \times 0.8 = 8.16 \text{ kWh}$$

The energy generated by 60 solar panels in one day is 114 kilowatt-hours.

$$60 \times 1.9 \text{ kWh} = 114 \text{ kwh}$$

The number of battery packs required is simply, the energy generated divided by the usable watt-hours of the battery rounded up to the next whole number, in this case 14 battery packs are required.

$$114 \text{ kWh} \div 8.16 \text{ kWh} = 13.9$$

For 108 solar panels, that generate a total of 207 kilowatt-hours a day, the number of batteries required would be 26.

$$207 \text{ kWh} \div 8.16 \text{ kWh} = 25.4$$

3.2.3 Cost

The current tariff for electricity from the grid is around 15.6 Kenyan Shillings (KES) per kilowatt-hour (kWh) (Regulus, 2018), which is approximately 0.12 British Pounds (GBP). Given that the college currently uses 22.6 megawatt-hours of electricity a year, they are currently spending approximately 2,700 GBP.

$$£ 0.12 \times 22600 \text{ kWh} = £2712$$

The price of a cheap 280 watt solar panel is about 100 GBP (CCL Components, n.d.), and assuming the British rates for labour installation costs are about 600 GBP per 15 panels (MyJobQuote.co.uk, n.d.) (this would be a lot cheaper in reality due to low labour costs in Kenya). The cost of 14 battery packs is 84,000 GBP and for 26 battery packs the cost is 156,000 GBP.

$$14 \times £6,000 = £84,000$$

$$26 \times £6,000 = £156,000$$

So, installation of 60 solar panels and 14 battery packs would roughly cost 92,400 GBP and installation of 108 solar panels would cost around 171,000 GBP.

$$60 \div 15 = 4$$

$$4 \times £600 = £2,400 \text{ (Labour for 60 panels)}$$

$$(60 \times £100) + £84,000 + £2,400 = £92,400$$

$$108 \div 15 = 7.2$$

$$7.2 \times £600 = £4,320 \text{ (Labour for 108 panels)}$$

$$(108 \times £100) + £156,000 + £4,320 = £171,120$$

As there is no cost of generation, a saving of 2,700 GBP per year is made, excluding inflation and interest, the payback period of 60 solar panels and 14 batteries is just over 34 years and the payback period for 108 solar panels is about 63 years.

$$£92,400 \div £2,700 = 34.2 \text{ years}$$

$$£171,120 \div £2,700 = 63.4 \text{ years}$$

The payback period is the amount of time it takes for the installation of the solar panels to, essentially, pay for itself based on savings made. This also includes no down time due to power losses, and the whole system is more environmentally friendly than the current means of electricity generation.

As this seems quite expensive and the payback period is quite long, there are other options that can be considered, i.e. the use of solar panels without batteries or the use of a limited number of solar panels and batteries.

Considering that no batteries were to be installed, 60 panels and their installation would cost about £8,400 giving a payback period of about 3 years. The installation of 108 panels would cost about £15,000 giving a payback period of just under 6 years.

$$(60 \times 100) + (4 \times 600) = £8,400$$

$$£8,400 \div £2,700 = 3.1 \text{ years}$$

$$(108 \times 100) + (7.2 \times 600) = £15,120$$

$$£15,120 \div £2,700 = 5.6 \text{ years}$$

If only 30 panels were used, daily generation would be 57 kilowatt-hours. Installation would cost £4,200. Savings made would each year be £2497, and the payback period would be 1.7 years.

$$(30 \times 100) + (2 \times 600) = £4,200$$

$$£4,200 \div £2,497 = 1.7 \text{ years}$$

In the case of not using batteries, if there is a point in time where the amount of energy required is greater than the energy generated, the supply would come from the grid, assuming that the college will remain connected. In the scenario where only 30 panels were installed the remaining requirement would have to come from the grid. These two

options are viable but, as mentioned earlier, the college requires an uninterrupted power supply to avoid disruption, as there are power cuts while connected to grid.

4 Conclusion

The aim of this project was to research on and how to implement renewable energy generation for a college in Kericho, Kenya. This was to overcome the current problem of an unstable grid connection leading to multiple power cuts a day causing a disruption to teaching and learning, whilst also providing a more environmentally friendly solution for a faith-based organisation.

Research into current renewable energy generation technologies in Kenya, ruled out the use of geothermal power and hydropower due to the size of the project being small. The potential sites for both geothermal power and hydropower generation were too far from the college site to be feasible options.

Research into weather data showed that solar power was the most viable option for electricity generation, rather than wind power. The data showed that there is very little wind in Kericho, and that the potential for generation from solar energy was more favourable and beneficial.

Looking into energy management techniques revealed that wasted energy can be found in different processes and that they can also be reduced by the use of monitoring and targeting.

The energy audit revealed that the college uses 22.6 megawatt-hours per year of electricity. The college may install air conditioning in the future so calculations were also made with this in mind, giving a value of 75 megawatt-hours a year.

Calculations were made using a 280 watt solar panel and a 10.2 kilowatt-hour battery. The number of panels required were calculated as 60 for current energy usage and 108 for when air conditioning is installed, and 14 and 26 battery packs were required respectively. The number of batteries and the price of them seems expensive, but as the college is founded by a faith-based organisation, paying a little extra for the preservation of the planet is considered viable.

5 Suggested further work

Further research is required on the maximum bearable load of the roofs for the college campus. Without this information a true value for the number solar panels that are able to be installed is not possible.

Batteries are currently the most expensive part of a renewable energy project. Further research can be done into finding or even developing a cheaper yet efficient battery for use with renewable energy generation.

It may be an option in the future, if the energy generation exceeds the required the usage demands, to offload the excess, either back to the grid or there may even be potential to provide for some of the local houses and small businesses.

Hopefully the introduction of renewable energy will encourage current and future students to be more environmentally friendly. As the college has a close relationship with the current governor of Kericho, there is a potential conversation to be had regarding the funding for the students of the college to undertake their own projects as part of the development of Kericho.

NSPSI and GNNSJ are currently looking into restoring the local hospital in Kericho. Hospitals have equipment that require constant operation, e.g. all lighting and equipment in operating theatres and fridges for storing medication. With the local grid being unstable the ability to be self-sufficient with regards to electricity supply would be a huge benefit. If this project is successful, the information gathered, and data collected are easily transferable for the implementation of renewable energy for the hospital.

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7 Appendices

7.1 Appendix 1: Energy audit for NSPSI

Appliance	Qty	Capacity /W	Duration in use (per day) /hrs	Energy Consumption per day /kWh	Notes
Lights	295	32	8	75.52	30 rooms + 2 lecture halls
Computers	30	170	6	30.6	
Router	5	10	24	1.2	
Fridge	2	150	7.2	2.16	On 24 hrs but fridges only run 30% of the time
Kettle	2	3000	0.5	3	
Printer	5	800	0.16	0.64	On 24 hrs but on standby, in use 10 mins
			Total kWh per day	113.12	
			MWh per year	22.624	5 day a week, 40 weeks a year

Appliance	Qty	Capacity /W	Duration in use (per year) /hrs	Energy Consumption per year /MWh	Notes
Air con	28	3500	540	52.92	3 hours a day for 6 months
Total Energy usage per year including Air con.				75.544	