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# Buturi Solar

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Department of Electrical Engineering

I HEREBY RECOMMEND THAT THE THESIS PREPARED
UNDER MY SUPERVISION BY

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ENTITLED

# BUTURI SOLAR

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Department Chair date

# BUTURI SOLAR

By

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**SENIOR DESIGN PROJECT REPORT**

Submitted to
the Department of Electrical Engineering

of

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in Partial Fulfillment of the Requirements
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**Abstract**

The village of Makongoro in the Buturi community of Tanzania lacks the resources to bring any form of energy to power the local school. The most reliable source of energy we could bring to the school is in the form of a photovoltaic system, as the climate of Buturi provides an ideal location for the implementation of such system. We have designed a solar microgrid specifically for Buturi and the needs of the school, that has the capability to power laptops, cell phones, and lighting throughout the school building. The system is fully detailed and explained in this report, with the final goal of implementation in the near future.

**Acknowledgements**

We would like to thank our advisor Dr. Tim Healy for the help and guidance along the way in our design. Additionally, we would like to thank the Frugal Innovation Hub in partnership with the Buturi Project for presenting this project to us, and helping us work towards implementation. Lastly, we would like to thank eIQ Energy of Santa Clara, California for the expertise and resources that helped finalize and mirror our design.

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## Background Information

We partnered with the Santa Clara University School of Engineering Frugal Innovation Hub and with Judith Smith of The Buturi Project. The Frugal Innovation Hub works towards connecting students and faculty with technical and humanitarian projects, and The Buturi Project is one of several organizations that is connected with the Frugal Innovation Hub. The Buturi Project is a foundation working to empower the impoverished in the village of Buturi[1]. Our group accepted the project proposal of designing and implementing a solar project in their recently built school building. This made The Buturi Project our client while the Frugal Innovation Hub acted as the liaison between our group and the organization.

As we began our initial research we found that more than 1.2 billion people across the world live without access to electricity, and another billion have unreliable access. In Tanzania, only about 15.5% of its population of 55.57 million people[2] have access to electricity. Buturi is comprised of six remote villages, and is located off the shore of Lake Victoria in North-west Tanzania as shown in Figure 1. In the village of Makongoro, one of the six villages, most residents are fishermen and subsistence farmers living in mud huts without electricity or water. This means that the people of Makongoro are in dire need of sustainable energy to power their basic needs. We saw this community as a place in need of serious support and as a great place for our group to make an impact.

1 http://www.buturi-project.org/

2 https://www.google.com/publicdata/explore?ds=d5bncppjof8f9_&met_y=sp_pop_totl&idim=country:TZA:KEN:UGA&hl=en&dl=en


**Figure 1**: Map of Tanzania (Buturi as red dot)

Buturi is located near the equator at a latitude of -1.4166700° and a longitude of 34.017. This location has about 12 hours of daylight from 6am to at least 6pm on most days, meaning that there is significant potential for energy to be harvested through the use of solar panels. The area has values of insolation varying from 5.7 to 6.5kW-hr/$m^2$/day according to data provided by NASA.[3] This is an ideal location for a low cost infrastructure to generate power leaving a significantly reduced carbon footprint.

The original project proposal looked to power a refrigerator, blender, 50 lights, and up to 74 laptops inside their recently built school building. However, with our time and resources, we decided to focus on introducing a solar microgrid to the school for lighting and the charging of phones and laptops.

[3] https://eosweb.larc.nasa.gov/sse/

## Project Objectives

Our main objective with this project is to design a solar microgrid system for the school building in Buturi, Tanzania to be implemented in the future. We plan to produce enough solar energy each day to power 50 light bulbs for about 6 hours, a single full charge for 25 laptops, and a single full charge for 10 cellular phones. This will provide lighting and charging for all of the classrooms and the library of the school. Upon completion, the system should have the capability to store enough energy for up to two days in order to allow for cloudy days when the sun isn't radiating as strongly. This solar microgrid system will be installed in the school building of Makongoro.

## Implementation Alternatives

Before going into our design we needed discuss whether we wanted to created a system that used AC (Alternating Current) or DC (Direct Current) power. We saw three possible answers to this question: a system with only AC, only DC, or a combination of the two.

### *AC vs DC*

After researching into the different techniques, we initially decided that keeping the power in AC will be the easiest and most effective way to implement our system, primarily because we would have easier access to other components that utilize AC power. Most phone chargers, laptop chargers, and appliances utilize AC power connections. This meant that we could just add typical outlets in each room of the school building. Also, there is less losses over long distances with AC power.

On the other hand, having a DC system avoids the need for an inverter in order to convert the DC power coming from the panels into AC power to the outlets. This option is more cost effective and avoids having losses due to the conversion.

***Dual Inverters vs. Single Inverter***

So with our initial decision of doing an AC system, we then had to decide whether we wanted to use dual inverters rather than just one to make it easier to upscale at a later date. Rather than paying for a more expensive inverter that can withstand higher power values, we can use more than one inverter in order to divide the amount of current/power passing through each one. Also, this will allow us to avoid having just one point of possible failure.

***Selected Implementation Method***

In our final design we concluded that it was important to avoid having one point of failure and to provide an efficient system, so we ended up designing a system with a combination of both AC and DC. We chose to make the lighting our DC load and the charging our AC load. That way if the inverter were to fail, the school will still have lighting, thus preventing the single point of failure coming from the battery bank. Having the lights run off DC also meant that we did not have to use 2 inverters or an inverter with a higher rating in order to handle the load. This made our design more cost effective.

## Design Process

The goal of our design specifications was to take into account the worst-case scenario for each of the components. We want our system to operate as desired considering all circumstances. The efficiencies and calculations below reflect this worst-case scenario approach.

*Energy Needs*

The first step we took in designing our solar system was finding the total energy consumption of all loads powered by the system. This was done by calculating total Watt-hours per day for each appliance used. We have listed the devices that we will to power with our system in Table 1 below, along with values for daily energy consumption.

| Item | Quantity | Power rating | Daily Energy Consumption |
|---|---|---|---|
| LED lights | 50 | 6 Watts for 6 hours | 1800 Watt-Hrs |
| Laptops Chargers | 25 | 60 Watts for 1 hour | 1500 Watt-Hrs |
| Nokia Chargers | 5 | 3.38 Watts for 1 hour | 17 Watt-Hrs |
| Smartphone Chargers | 5 | 5.5 Watts for 1 Hour | 27.5 Watt-Hrs |
| Total Power Consumption | | | **~ 3400 Watt-Hrs** |

**Table 1**: Energy Consumption Estimation

Our goal was to hold up to two full days of energy for the school in our system, in case of inclement weather. Therefore, we planned for **6800 W-Hrs** output capability.

*Calculations and Analysis*

Our desired output for our laptops and cell phones requires that we produce an AC output similar to the normal outlets in Tanzania and the surrounding areas. However, we are able to light the school using DC LEDs on another load. Therefore, we separated the 3200W to the inverter for all of the chargers and our LED lights. We planned for our inverter to have a worst case efficiency of 91% and our LEDs to have an efficiency of 95% (expected to be higher upon setup).

Inverter $\frac{3200\ WHrs}{0.91} = 3550\ WHrs$

DC LEDs $\frac{3600\ WHrs}{0.95} = 3800\ WHrs$

DC and AC Load total $3550 + 3800 = 7350\ WHrs$

Using the necessary input to the inverters we then looked at our battery storage capacity. We chose to use deep cycle batteries discharging around 60% each cycle for maximum efficiency. Our A-Hr battery capacity was determined using the equation below taking into account our depth of discharge (DOD) and battery voltage.

$$Capacity\ (A\ Hrs) = \frac{W-Hrs}{voltage \times DOD}$$

$$\frac{7350\ W-Hrs}{12V \times 0.60} = 1025\ A\ Hrs$$

We then looked back to to the output of the batteries at **7350 W-Hrs** divided by two for our daily output back from our two day to determine how much to input considering worst case scenario battery losses of 80%.

$$\frac{7350\ WHrs}{2\ days} = 3675\ W\ Hrs$$

$$\frac{3675\ WHrs}{0.80} = 4600\ W\ Hrs$$

Through these calculations we found that we needed an output of **4600 W-Hrs** each day from our solar panel array. Accounting for an insolation of 5.7 kW*h/($m^2$ day).

$$\frac{4600\ WHrs}{5.7\ Hrs} = 800\ W$$

This determined that we will need a solar panel array of at least **800 W** accounting for all efficiencies in our system.

**<u>Block Diagram and Design Analysis</u>**

The overall goal is to take energy from the sun to power the lighting and charge the devices inside of the school. The conceptual system description is shown in Figure 3 in the form of a simple block diagram. The organization of our solar microgrid system is seen in Figure 4.

We will be taking power in through the solar panels to charge the batteries while being monitored by the charge controller. These batteries will then direct energy to our DC loads and through an inverter which will produce the AC voltage needed to charge the devices.


**Figure 3**: Block Diagram Level 0

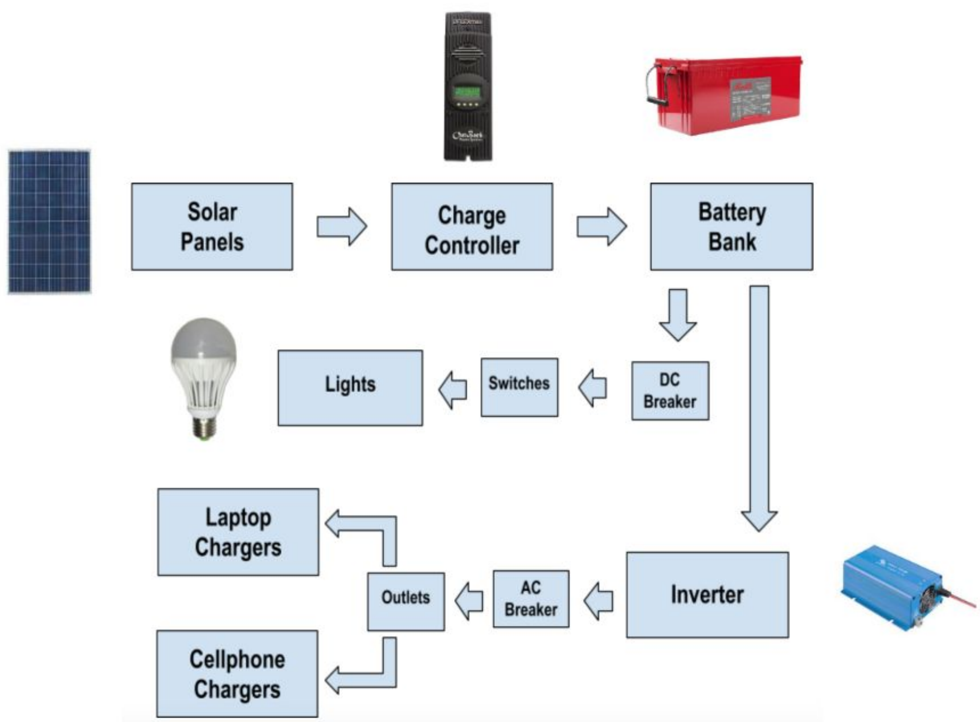


**Figure 4:** Block Diagram Level 1

For the following components we make references to the parts that we will be sourcing from a company called Power Providers in Arusha, Tanzania. This location allows us to have equipment close to Buturi for repairs/accessibility. The specs are shown in the Appendix.

***Overall Design and Equipment Analysis***

All of the equipment in our design  is sourced from a company called Power Providers (http://www.powerproviders-store.co.tz/) which is the cheapest and most reliable solar equipment provider that we could find near Buturi. It is located in Arusha, Tanzania. The solar equipment provider was also the company that we found to have the most reliable equipment found near the target location of Buturi.

**Solar Panels**

Located near the equator, Buturi has insolation values of varying from 5.7 to 6.5kW-hr/($m^2$*day) (see appendix). These values represent the amount of radiation reaching the given area. We will plan for the worst case scenario in the rainy months by planning for an insolation of 5.7kW-hr/($m^2$*day). The solar panels available are 24V 255W panels. As seen in our calculations in the energy needs section our system requires 800W of panels. We will need four 255W panels.

255 W Panels (4)

This will come out to 1020 W of panels connected in series. The series connection allows for a higher voltage and low current to reduce losses. We plan to orient the panels on the north-facing roof at an angle close to 1.5 degrees due to the location of buturi near the equator at a coordinates (-1.4, 34).

We were told by our contact through the Buturi Foundation that the town rarely has cloudy days, so the system will rarely lack sufficient insolation.

**Charge Controller**

The charge controller that we chose is rated at 80 A with a programmable voltage output. We have chose an MPPT (Maximum Power Point Tracking) charge controller because it monitors the panel output for most efficient charging.


**Batteries**

We will be using a battery bank made up of 12V S-220AE AGM Batteries. We have chosen AGM deep cycle batteries because they operate well at high temperatures, have low internal resistance, require the least maintenance, and have a long lifespan. This is typical for our climate without much upkeep. We will need to be able to store 7500W-Hrs of energy for our two days capacity goal. In order for our batteries to be effective in charging and discharging daily we will need to have their depth of discharge at 60% to be most effective. We then plan for 80% efficiency for two years of cycles. With these selected variables, and with a nominal battery voltage of 12V, we obtained the following capacity needed for our battery bank as calculated in the section above. We have chosen our system to have 12V battery parallel combination bank to maximize capacity while easily producing this output to our 12V LED light bulbs.

Battery Capacity = **1025 A-Hrs**

6 batteries connected in parallel will give us 1200 A-Hrs of storage which is sufficient for our two days of storage expectation accounting for losses up until two years of cycles. After two years these batteries will need replacement so that the system works accordingly. The batteries

have capacity of 100% at 77 F and 102% at 104 F. This aligns well with the temperature in Buturi. Their monthly averages are from 73-81 degrees F throughout the year seen in figure 5 below.

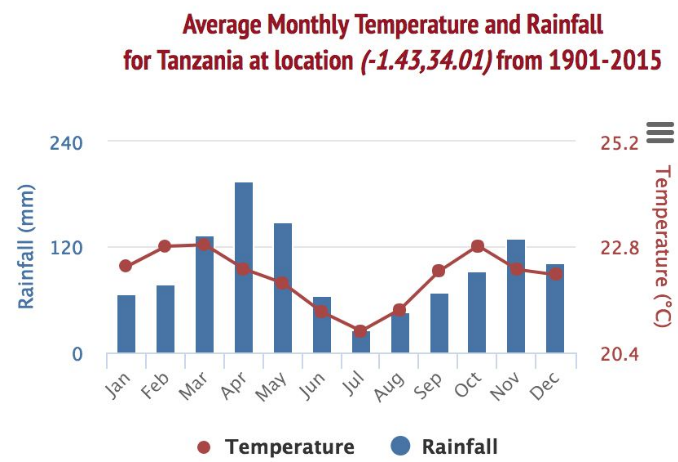


**Figure 5**: Average Temperature for Tanzania[4]

Additionally, in recent years the yearly highs have gone to 105 F which is still keeping the battery at a safe temperature with 102% capacity affected by air temperature.

**Inverters**

We will be using one 12V 800W inverter. Our inverter will produce an output of 230 V at 50 Hz as this is the typical output for outlets used in Tanzania and most surrounding countries. We want the school to have the flexibility of different devices and be able to have standard outlets available for the charging ports they need.

**End Result**

Overall, our project will need to produce 3400 W-Hrs of energy each day to the school. This output will need to be at 230V and 50Hz in order to comply with the electric grid in Tanzania. It will need to effectively monitor and distribute energy from the batteries, and have

[4] http://sdwebx.worldbank.org/climateportal/index.cfm?page=country_historical_climate&ThisCCode=TZA

the capability to be scaled up at a later time to produce and store more energy for the school. The system architecture is shown in Appendix B.

**eIQ Setup**

Due to our lack of funding and ability to travel, we created our own proof of concept microgrid system with a local solar company. The local solar company eIQ allowed us to oversee a microgrid install as well as use their equipment in building our own scaled down system. We created a system that closely mirrored the components in our Buturi design as a proof of concept.

We looked to mirror each of the components in a similar manner to our Buturi design as best we could with available materials at eIQ. As a result, we used a solar panel array, charge controller, battery bank, to an inverter. With the help of the eIQ team we made each of the connections and successfully built a working system that mirrored our design for Buturi.

***Solar Panels***

Our solar setup consisted of four solar panels rated at 175W and 35V in a two by two parallel and series combination. These were connected using MC4 connectors that snap into place.

**Figure 6:** Four 175 W solar panels (left) and the MC4 connectors used (right)

***Charge Controller***

We then used a 60A charge controller with a programmable output set to 24V. We needed this 24V to power our 24V batteries and then the 24V inverter. The connections with the solar panels and battery are labeled in the figure below.

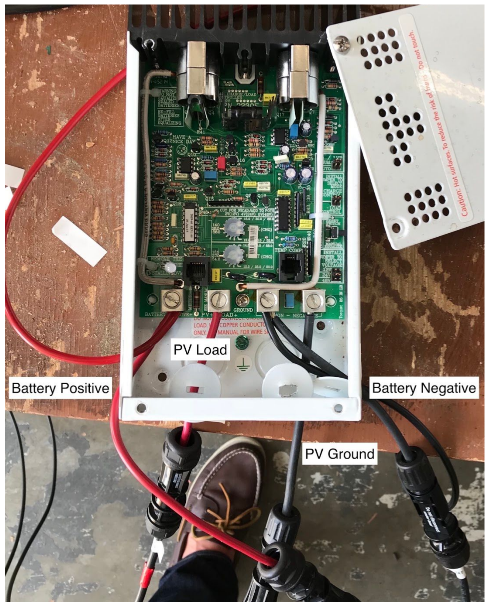


**Figure 7:** 60 A Charge Controller programmed to output 24V.

***Batteries***

For our battery bank we connected four 6V batteries in series to get 24V. The batteries used were 6V Trojan T-105 Deep Cycle Lead Acid Batteries. Each with a 185 A-Hr capacity.

**Figure 8:** Four 6V Trojan Deep Cycle lead acid batteries in series to make a 24V battery bank.

***Overall Setup***

Our 24V output from the batteries connected into our inverter. We used a 24V 800W inverter with an output of 120V AC at 60 Hz. (This is the standard outlet output in the United States.) The image below displays the system as a whole excluding the batteries and solar panels which are out of the frame. The inverter has an LED screen which indicated our input of 22.8V (around our desired 24) as well as our output of 119V AC (around our desired 120V). As a result our system then powered the flood light seen on the left in figure 9.

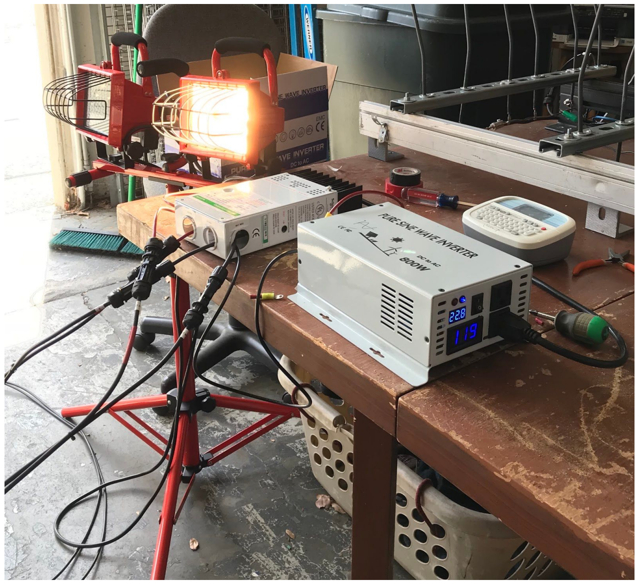


**Figure 9:** Overall setup with the 24V 800W inverter, powering a flood light

**<u>Risk Analysis</u>**

In order to avoid any issues with the high voltage, we have decided that we need to designate one room as the power room. Only a person that is certified to look after the system will have access to the power room. Having a designated power room will help in keeping the students away from the components that can impose a hazard. We will also make sure that any wires that are exposed will be well insulated so that there is the least amount of risk of someone being hurt.

Also, as we learned during the installation of our eIQ system, with high voltages coming from the array of panels, there is a potential hazard called electric arc flashes. This hazard is a release of large amounts of energy in the form of an electric arc that results from the breakdown of the resistance in the air from a line-to-line or line-to-ground fault. Some of the common causes are accidental contacts with connections and conductive dust built up in the connections.[5] Arc flashes can cause serious injury to a person, so whoever will be looking after the system must take special precautions.

## Constraints

The biggest issue we faced with this project was trying to make this design as affordable as possible. We chose to source all of our equipment from Tanzania because if we were to ship all the equipment from the US, we would run into problems as the area of Tanzania has strict laws when it comes to taking equipment across borders. On top of that, the price of shipping would also take up a lot of our budget. By sourcing the equipment from Tanzania, we are able to avoid these issues and if any of the equipment were to fail, the local technician looking over the system can get a replacement locally.

The company Power Providers, based in Arusha, provided a lot of help when it came to selecting equipment because they would actually respond back to us within a day or 2 and they made it clear to us what they had available. On top of that, they also had easy access to all the datasheets that we needed through their website.

The budget shown below is based on the prices given to us by Power Providers. Given that we were not able to get in contact with other solar equipment stores, this was the most cost effective bill of materials for our system.

5 http://solarprofessional.com/articles/design-installation/calculating-dc-arc-flash-hazards-in-pv-systems#.Ww-KnFMvwWo

| **Item** | **Cost** |
| --- | --- |
| 255 W 24V Solar Panel (260 $ per panel) | $1040 |
| Surrette 12V S-220AE AGM Battery (6) | $2640 |
| 50 x LED bulbs ( $8 per bulb) | $400 |
| Charge Controller | $1000 |
| Circuit Breaker | $50 |
| Victron Energy 12V 800W Phoenix Inverter | $440 |
| Wire, junctions boxes, disconnects, breakers | $400 |
| **Total** | **$5970** |

**Table 2**: Bill of Materials

**Gantt Chart**

| Original Predicted Timeline | | | | | | |
|---|---|---|---|---|---|---|
| | December | January | February | March | April | May |
| Drive Funding | | | | | | |
| More Specific Design Work | | | | | | |
| Finalize Full Budget | | | | | | |
| Complete Funding | | | | | | |
| Design Finalized | | | | | | |
| Trip Finalized | | | | | | |
| Trip Accepted | | | | | | |
| Gain Familiarity with equipment (eIQ Energy) | | | | | | |
| Order Equipment | | | | | | |
| Final Design | | | | | | |
| Trip to Buturi | | | | | | |
| Presentation Preparation | | | | | | |
| | | | | | | |
| | | | | | | |
| Incomplete: | | | | | | |
| | | | | | | |
| Completed: | | | | | | |

| Accomplished Timeline | | | | | | |
|---|---|---|---|---|---|---|
| | December | January | February | March | April | May |
| Drive Funding | | | | | | |
| More Specific Design Work | | | | | | |
| Finalize Full Budget | | | | | | |
| Complete Funding | | | | | | |
| Design Finalized | | | | | | |
| Trip Finalized | | | | | | |
| Trip Accepted | | | | | | |
| Gain Familiarity with equipment (eIQ Energy) | | | | | | |
| Order Equipment | | | | | | |
| Final Design | | | | | | |
| eIQ Proof of Concept Setup | | | | | | |
| Trip to Buturi | | | | | | |
| Presentation Preparation | | | | | | |
| | | | | | | |
| | | | | | | |
| Incomplete: | | | | | | |
| | | | | | | |
| Completed: | | | | | | |

## Ethical Analysis

Our goal is to provide electricity not only to a school, but to empower a community with a more indepth, efficient education through technology. Upon completion, students will have more access to light, deeper learning through computer programs, and increased telephone communication. The lighting will also aid in allowing evening workshops to be held for vocational training for Buturi's adults. Our motivation is to get this system working effectively for the benefit of the people of Buturi.

As mentioned, there is a significant need for off-grid projects to aid those without electricity. With solar power gaining ground fast, it is the perfect technology for off-grid applications, and it may soon replace the current energy sources in use across the world. Creating the first microgrid in this village helps move the community towards clean energy, which will definitely make a great impact to the community as it increases the scope of their education to further benefit the people. This system also promotes the use of sustainable energy, which in turn will promote neighboring villages to do the same as they see the countless benefits that energy brings.

## Science Technology and Society

Although the environmental impact of solar energy overshadows a lot of its other benefits, many social benefits can result from the use of solar energy in the targeted area. Examples include, but are not limited to the economy, the health of the people in the area, and less dependence on fossil fuels.

With the creation of our solar system design in the community of Buturi we are not only directly helping the community, but also hoping that our system influences the surrounding communities to work toward a similar goal and better living conditions. For instance, workers are needed to plan the project, develop and implement the project, build the solar energy system, and manage the equipment. Thus, many new jobs can be fulfilled by workers as a result of a village or community using solar microgrid systems to generate electricity for the area, and this would in turn help increase the possible career paths for these people with vocational training more readily available.

There are many ways in which the use of solar energy can help stimulate the economy of the affected area. With more people able to find employment as a result of the increased number of jobs created by the sales and operation of solar energy panels, more people would have money to contribute to the nation's economy. Also, manufacturing solar energy is less expensive than burning fossil fuels, which is the traditional method of generating electricity.

Generating the electrical energy from solar panels does not emit pollution into the air, and thus solar energy is a much cleaner source of energy than the burning of fossil fuels. Solar energy does not damage the atmosphere or cause global warming. Areas that decide to use solar energy to power their structures would thus enjoy a cleaner quality of air in the region, which in turn would benefit the health of the citizens and workers in the region. Furthermore, studies indicate that burning fossil fuels helps facilitate global warming. Thus, if areas decide to use solar energy to generate electricity, the shift will help diminish the effects of global warming, such as the sea levels rising and storms intensifying.

## Civic Engagement

The only agencies that we found could possibly be problematic with such an install is the government of Tanzania and more specifically the government agency known as The Energy and Water Utilities Regulatory Authority (EWURA) in Tanzania (**http://www.ewura.go.tz/ **). Our initial intention with the system was to merely provide a source of energy to use for the people, but there is no way to profit monetarily from it in our design. For this reason the government could very likely try to get involved with the system and find a way to distribute the energy and charge the people of the community for using it which could be both bad and good for the people. We saw that there was a Small Power Purchase Tariff implemented in 2016, but our system doesn't qualify for the specific tariff because our system power output isn't high enough. The power output required to fall under this category was written as 100kW to 1MW. However, we were told by a former resident of Tanzania that it could be a possibility that they could try and take ownership of it because there is no telling with the government there. They deal with all of the pricing for utilities which includes the use of energy. If this were to happen, we would want to prepare the people there to have the skills and abilities to sustain an economy and contribute to it in different ways.

In order to help influence the approval of our system being used for the village without monetary profit, we would put strong emphasis on what this could mean for the future of the village and its people. We would inform the government of our intention to provide energy so that the people of the village could attain greater education and expand their opportunities in life. As mentioned before, the older generation of the community would also benefit strongly as they would be receiving vocational training for different skills that they wouldn't have had access to without the solar system providing the energy to light up the building. Also, we would put great emphasis on the fact that hopefully with the installation of this system, nearby communities will be influenced to do the same for energy purposes. If this were to influence more villages then that is when I would pitch for the governmental agencies to get involved as they could then begin to plan for a grid with a main facility and substations across the area, which they could monitor and use to bolster their economy.

**Health and Safety**

Workers in the solar energy industry are potentially exposed to a variety of serious hazards, such as arc flashes (which include arc flash burn and blast hazards), electric shock, falls, and thermal burn hazards that can cause injury and death. Workers may be exposed to electric shocks and burns when hooking up the solar panels to an electric circuit. In order to avoid such hazards when installing the system as well as avoiding the hazards that arise after installing, we would have to take precautionary measures and teach these techniques to the people of the village that plan to maintain the system after it is installed. There is not much worry about the hazards that would arise after the installation as we plan to keep all high voltage wires hidden or out of reach for the people there. Since solar panels generate electricity, we plan to adhere by the Electric power generation, transmission, and distribution standards and, therefore, plan to implement the safe work practices and worker training requirements of OSHA's Electric Power Generation, Transmission and Distribution standard, 29 CFR 1910.269.

**Sustainability**

It is very important for us to consider how exactly our project is going to provide a benefit and create a value for the people of Buturi. By considering this we can make sure that we will be able to successfully develop our system as a sustainable product and service. So we made sure to analyze and consider the three important components of product sustainability: environmental, social, and economic sustainability. We made sure to look at these three different categories with entrepreneurial thinking in mind.

Our project will involve a variety of different components for a solar microgrid system. These components include: solar panels, batteries, inverters, LED bulbs, wiring, and sockets. This equipment in the end will take solar energy (sunlight), store it in the batteries, and power light bulbs and functioning power outlets. Our solar microgrid will be located in Buturi, Tanzania just below the equator allowing for 12 hours of sunlight year-round. Therefore the sun will be powering the school completely.

So overall our project appears to be environmentally sustainable, however, there are a few components who's production and disposal is not as friendly to the environment, such as the production of photovoltaic cells which requires the use of hazardous materials and chemicals.[6] It is a similar situation with the batteries. Even though they are used in systems that fall under renewable energy, there are some negatives about the components; however, at the end of the day the pros definitely outweigh the cons. These components will be integrated in a system that will provide electricity to a village that has been living without it for many years. Also as technology advances, the way in which they are produced advances as well, and there are policies in place so that the hazardous materials are disposed of properly.

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6 https://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/environmental-impacts-solar-power.html#.WqIlrpPwbPA

The product life of our system is mainly dependent upon our batteries. We have sized our system to be effective for at least two years. After that time, the batteries will need to be switched out due to losses in storage. Additionally, our solar panels will need to be cleaned at minimum once every six months. This needs to be done with a light brush and purified water. If the panels are kept clean their lifespan will be long. It is said that solar panels only lose around 1% efficiency each year. Dependent upon the effectiveness of the system (measured by our monitor), the school will be able to decide when the panels will need to be switched out.

The village of Mokongoro is in desperate need of a form of energy. Currently they do not have access to electricity nor clean water. Our project seeks to satisfy the need of electricity. Electricity is taken for granted around the world, and these people don't have any sort of access to it. With access to electricity, and devices that need electricity to be powered, the amount of knowledge these people will receive is endless. They will have access to the internet, which is our greatest teacher nowadays. Not only will having access to the internet educate them, but it can also be used for vocational training amongst the older crowd of people as they will now have extended days due to the lighting provided by our system.

Our plan is to make the upkeep of the system as simple as possible by creating an instruction manual for a technician that we will train while installing the project in Tanzania. The system will be self-sufficient unless the batteries are being overused. This can easily be done as we plan to have an LED monitor that will display the energy stored in the batteries and notify the user whether they are being used properly. We plan to have a simple system that displays a green light if the storage in the batteries is nominal, yellow if it needs to send a warning to the user that the battery storage is becoming low, and red if the batteries are reaching a threshold near our depth of discharge. Ideally we would hope that the system never sends a red signal to the user, but one cannot account for every possibility of error. This system is of great value to the entire village as mentioned before because it is connecting the people of this village to the rest of the world, and giving them an opportunity to help benefit their community/world with vocational training and education. Our solar system will be constructed on top of the school building in the village, which is used as the main place to meet. Access to the electricity will be given to all which will be life changing for these people. Children will now be able to have education that they did not have access to before which will open up an immense amount of opportunities such as a college education.

We designed the system to avoid any safety issues with the high voltage wiring. The only health hazard that could possibly happen is if the people of the village tampered with the system and were shocked, or if the panels weren't installed correctly and fell off the roof to injure someone. We have already constructed a risk analysis with all the possible hazardous situations and have created solutions to mitigate each risk. Also, misuse of the solar energy could result in a negative effect on the general welfare of the village. For this reason and for upkeep we plan to have a technician to watch over the system to make sure that the energy produced is being used in such a way that the entire village is benefiting.

When it comes to the economic sustainability aspect of our project, we are not looking to make any profit at all. However, the original investment in the system lays the foundation for energy for years to come. This will continue to benefit the community with minimal cleaning and replacement of components over the years. As a result, the "profit" of our system will be the education and opportunity that our technology and extra time for education will bring to the people. This impact is exponential for the people of Buturi.

**Environmental Impact**

The sun provides a tremendous resource for generating clean and sustainable electricity without toxic pollution or global warming emissions. The potential environmental impacts are not associated with the generation of solar power, but with the manufacturing of solar equipment. The main impacts that we looked into are land use and habitat loss, water use, and the use of hazardous materials in manufacturing. The actual impact that it has on the environment can vary greatly depending on the technology, which includes two broad categories: photovoltaic (PV) solar cells or concentrating solar thermal plants (CSP). The size of the system which can range from a small, distributed rooftop PV array to a large utility-scale PV and CSP project, also plays a significant role in the level of environmental impact.

Solar PV cells do not use water for generating electricity. However, as in all manufacturing processes, water is used to manufacture solar PV components. Concentrating solar thermal plants require water for cooling. The amount of water used depends on the plant design, location, and type of cooling system utilized. CSP plants that utilize wet-recirculating technology with cooling towers use between 600 to 650 gallons of water per megawatt-hour of electricity produced. Those that use once-through cooling technology have higher levels of water use at a time, but they have lower total water consumption because water is not lost as steam. Dry-cooling technology can reduce water use at CSP plants by approximately 90 percent. The tradeoffs to saving such amount of water however are higher costs and lower efficiencies. In addition, dry-cooling technology is significantly less effective at temperatures above 100 degrees

Fahrenheit, which limits the locations that can be used for the factory unless the company chooses to pay more for cooling the actual factory.

The PV cell manufacturing process includes a number of hazardous materials, which for the most part are used to clean and purify the surface of the semiconductor. These chemicals, include hydrochloric acid, sulfuric acid, nitric acid, hydrogen fluoride,1-trichloroethane, and acetone. The amount and type of chemicals used depends on the type of cell, the amount of cleaning that is needed, and the size of the silicon wafer.  Workers in the manufacturing industry also face risks associated with inhaling silicon dust. Thus, PV manufacturers must follow laws enforced by the U.S. to ensure that workers are not harmed by exposure to these chemicals and that waste products from the manufacturing process are disposed of properly. Thin-film PV cells are much more harmful to create as they contain a number of more toxic materials than those used in traditional silicon photovoltaic cells, including gallium arsenide, copper-indium-gallium-diselenide, and cadmium-telluride. If they are not handled and disposed of properly, these materials could pose serious environmental or public health threats. However, manufacturers have a strong financial incentive to ensure that these highly valuable and often rare materials are recycled rather than thrown away.

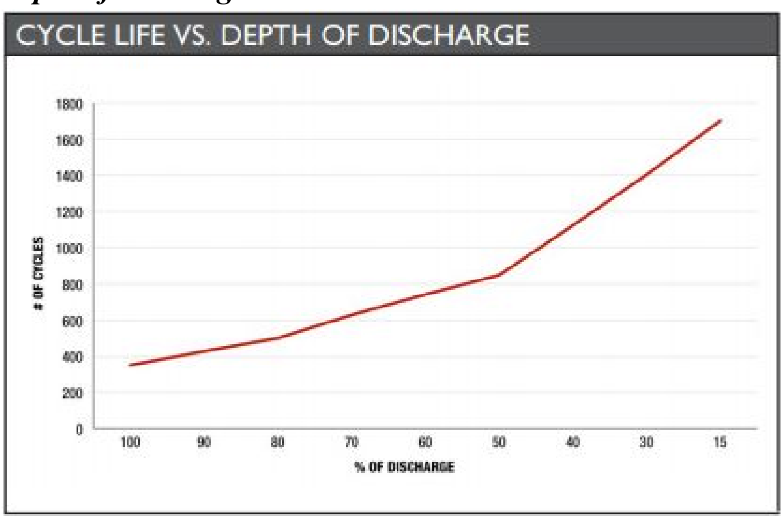
While there are no global warming emissions associated with generating electricity from solar energy, there are emissions associated with other stages of the solar life-cycle, including manufacturing, materials transportation, installation, maintenance, and decommissioning and dismantlement. Most estimates of life-cycle emissions for photovoltaic systems are between 0.07 and 0.18 pounds of carbon dioxide equivalent per kilowatt-hour. Most estimates for concentrating solar power range from 0.08 to 0.2 pounds of carbon dioxide equivalent per kilowatt-hour. In both cases, this is far less than the lifecycle emission rates for natural gas (0.6-2 lbs of CO2E/kWh) and coal (1.4-3.6 lbs of CO2E/kWh).

## Appendix

*Average temperatures*

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| °C | 27 | 27 | 27 | 26 | 24 | 24 | 23 | 23 | 23 | 25 | 26 | 26 |
| °F | 81 | 81 | 81 | 79 | 75 | 75 | 73 | 73 | 73 | 77 | 79 | 79 |

*Depth of discharge*



*Design Equipment Specs*

**Source of equipment:** http://www.powerproviders-store.co.tz/

**Inverter: Phoenix**
Input: 24V
Output: 230V AC at 50/60 Hz
12V 800W inverter
https://www.victronenergy.com/upload/documents/Datasheet-Phoenix-Inverter-180VA-1200VA-EN.pdf

**DC Lights**
8W
http://www.powerproviders-store.co.tz/product/led-bulb-dc-12v-6w-e27-white/

**Batteries (**Connected in series and parallel to produce 24V):
12V S- 220 AE AGM Battery
180 A-Hr capacity (6)
http://www.powerproviders-store.co.tz/product/surrette-12v-s-220ae-agm-battery/

**Charge controller: Outback**
Input: up to 150 V DC
Output: Programmable (12,24,36,48 V), 80 A
https://powerproviderscotz.files.wordpress.com/2016/04/13-341-outback-solar-60a-12_24_48v-flexmax-mppt-charge-controller.pdf
http://www.powerproviders-store.co.tz/product-category/charge-controllers/victron-energy-charge-controllers/

**Solar Panels: Suntech**
Output: 24V connected in parallel (1000W)
255W panels at 24V
https://powerproviderscotz.files.wordpress.com/2016/04/11-020-suntech-255wp-mono-24v-solar-module.pdf

***eIQ equipment specs***

**Inverter**

Input: 24V
Output: 120V AC at 50/60 Hz
24V 800W inverter

**Batteries (**Connected in series to produce 24V)
6V Trojan T-105 Deep Cycle Lead Acid
185 A-Hr capacity (4)

**Charge controller**

Output: Programmable (12,24 V) 60 A

**Solar Panels**

Output: 35V connected in parallel/series combination
175W panels at 35V

***Buturi Hours of daylight***

**Monthly Averaged Daylight Hours (hours)**

| Lat -1.417 Lon 34.017 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average | 12.1 | 12.1 | 12.1 | 12.0 | 12.0 | 12.0 | 12.0 | 12.0 | 12.1 | 12.1 | 12.1 | 12.2 |

***Buturi Insolation***

**Monthly Averaged Insolation Incident On A Horizontal Surface ($kWh/m^2/day$)**

| Lat -1.417 Lon 34.017 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22-year Average | 6.12 | 6.51 | 6.42 | 5.98 | 5.83 | 5.76 | 5.74 | 6.06 | 6.37 | 6.26 | 5.80 | 5.95 |

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Batteries:

"How to Choose the Best Battery for a Solar Energy System." *EnergySage*, www.energysage.com/solar/solar-energy-storage/what-are-the-best-batteries-for-solar-panels/.

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"Battery Bank Tutorial: Joining Batteries Via Series or Parallel for Increased Power." *BatteryStuff.com: We Have The Stuff*, www.batterystuff.com/kb/articles/battery-articles/battery-bank-tutorial.html.

Charge controllers:

"All About Maximum Power Point Tracking (MPPT) Solar Charge Controllers." *Northern Arizona Wind & Sun*, www.solar-electric.com/learning-center/batteries-and-charging/mppt-solar-charge-controllers.html.

Appendix:

*NASA*, NASA, eosweb.larc.nasa.gov/sse/.

"How to Calculate Your Peak Sun-Hours." *Solar Power Authority*, 29 Nov. 2016, www.solarpowerauthority.com/how-to-calculate-your-peak-sun-hours/

"Suntech 305w Polycrystalline Solar Panel (STP-305-24/Vem)." *GadgetroniX.net*, gadgetronix.net/product/suntech-305w-polycrystalline-solar-panel-stp-305-24vem/.