Possibilities of Local Energy Production in Tertiary Institutions in Ghana: Accra Technical University as a case study.
ABSTRACT

Lappeenranta University of Technology
LUT School of Energy Systems
Degree Programme in Environmental Technology
Sustainability Science and Solutions

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Possibilities of Local Energy Production in Tertiary Institutions in Ghana: Accra Technical University as a case study

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The study examines the possibilities of local energy production of Accra Technical University in Ghana in order to meet the increasing energy demand of the institution. The increasing population of the students, staffs and high energy consumption equipment being use in the institution are some of the key factors leading to high electricity consumption in the institution. A proposed hybrid system which comprises of solar PV and battery storage were considered as the system configuration for Accra Technical University. The results show that solar PV-battery hybrid system dominates electricity supply share with 93%, while the remaining 7% is supplied by the grid. The hybrid energy system model achieved a cost savings of about 192 000 $ each year in electricity bill.

Investment costs of the system were calculated to be around 1,5 million USD. This resulted in annual costs of 158 000 $ during the 15 years of the project lifetime. The annual cost includes yearly investments due to maintenance and purchase of new battery capacity due to degradation factor in the battery storage banks.
ACKNOWLEDGEMENT

I thank God for giving me the strength to complete the thesis. I would like to express my sincere gratitude to my supervisors Prof Risto Soukka and Associate Prof Mika Luoranen. I am grateful for their continuous support, patience motivation and knowledge share during my master’s study.

I would also like to thank the experts who were involved in the modelling for this research project: [Sandy Kyei and Solomon Ayobami]. Without their passionate participation and input, the modelling could not have been successfully conducted.

Last but not least, I would like to thank my family my parents and siblings for supporting me spiritually throughout the writing of this thesis and my life in general.

In Lappeenranta 4th Nov 2018

Alex Dankwah
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# LIST OF SYMBOLS AND ABBREVIATIONS

## Abbreviations

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<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>CCG</td>
<td>Combined gas cycle</td>
</tr>
<tr>
<td>PV</td>
<td>Photo Voltaic</td>
</tr>
<tr>
<td>SCG</td>
<td>Simple Cycle Gas</td>
</tr>
<tr>
<td>SCO</td>
<td>Simple Cycle Oil</td>
</tr>
<tr>
<td>AC</td>
<td>Alternative Current</td>
</tr>
<tr>
<td>CSP</td>
<td>Concentration Solar Power</td>
</tr>
<tr>
<td>PIA</td>
<td>People in Administration</td>
</tr>
<tr>
<td>PIS</td>
<td>People in School</td>
</tr>
<tr>
<td>Ppv</td>
<td>Output Power of Solar Panel Installation</td>
</tr>
<tr>
<td>NOPIH</td>
<td>Number of People in Hostels</td>
</tr>
<tr>
<td>ESNP</td>
<td>Electric Stove Nominal Power</td>
</tr>
<tr>
<td>TDCF</td>
<td>Time depended coincidental factor</td>
</tr>
<tr>
<td>HAWT</td>
<td>Horizontal Axis Wind Turbine</td>
</tr>
<tr>
<td>VAWT</td>
<td>Vertical Axis Wind Turbine</td>
</tr>
</tbody>
</table>
1 INTRODUCTION

Ghana is a republic country geographically located in the West African region of the continent. The neighbouring countries sharing border with Ghana are Togo to the east, Ivory Coast to the west, Burkina Faso is to the north and to the south the Gulf of Guinea. Ghana’s total land coverage area is about 238 539 square kilometres. Its cardinal coordinates are situated between latitudes 4° 30’ S to 11° N and longitudes of 1° 10’ E to 3° 15’ W. According to the World Bank population censor the national statistical population of Ghana is approximately 28 million. This is estimated with a population growth rate of about 1,822%. (World bank, 2018).

The country is partitioned into ten regions with Greater Accra as the administrative capital. The other nine regions are Western, Volta, Brong-Ahafo, Eastern, Central, Ashanti, Northern, Upper East and Upper West Region. Furthermore, each region is sub-segmented into districts. The purpose of the creation districts is to serve as the fundamental platform for development projects. Most of the industrial and business activities are centred in Accra. Accra has a total land area of 201 square km with an estimated residential population of a little over 2.3 million, a population censor in 2009. (World Bank, 2010). It is estimated that about half a million people commute daily to work in the administrative centre of Accra adding to the residential population (World Bank, 2010).

The insufficient of power generation in Ghana has become a major challenge for many institutions in the country especially educational sectors such as Accra Technical University. This affects administrative activities and academic related matters for students living in the hostels altogether. The power supply is not able to meet the increasing energy demand of the institution’s business activities as well as the growing student population. This has caused problems such as power outages but also affected the growth of gross domestic product in the past years. Energy system of the country is partly relying on imported gas from Nigeria, which was cut-off in 2006. (World Bank, 2010). To make the energy production more secure, the importance of these kind of supply chains should be minimized. This would also help the economic growth of the country.
Thus, in order to enhance power generation stability, fuel pricing should be reasonably price in the power generation sector. However, this is lacking in the energy system. Investments to the energy system have also fallen behind because of inadequate public funding to the sector. The technical knowledge of local energy companies (Electricity Company of Ghana ECG and Volta River Authority VRA) could also be improved. (World Bank. 2010). Therefore, this thesis seeks to address feasible ways by which institution can generate their own electricity to compliment the national grid or in a long term be self-sufficient with their own energy generation.

Figure 1 shows a relationship of the various forms of energy generation and capacities in the country as well as the energy demand between year 2012 to a projection of 2022. From figure 1 it clearly indicates that the current energy production capacity is not meeting the increasing demand. The gap between the production power and demand was almost 20% of the production capacity in 2017. If no new production capacity is added to the grid, clearly the gap would be twice as much in 2018.

![Energy Demand and production in MW](image)

**Figure 1.** Energy demand and production in Ghana. CCG: combined gas cycle, SCG: simple cycle gas, SCO: simple cycle oil (World Bank. 2010).
The power outages cause delayed in meeting academic calendar schedules and reduce the overall performance of the students. In order to meet the demand and solve this situation during power outages a standby diesel power plant become operational automatically. This increases the institution’s expenditure due to the high cost of fuel to run the diesel power plant. However, the adverse effect of using diesel power plant is the emission of particulate matter into the atmosphere and leakage of diesel fuel into the ground leading to environmental and health issues.

Adding more production capacity to the grid would help solve the energy problem. This could be done with smaller power plants near the consumption. With these power plants the location is key. One good place for installation would be near or even inside university campuses, because population tends to gather near them. On site power generation would also increase the reliability of the energy production of the area. For university this would mean stable running computer equipment and other electronic educational devices. Figure 2 shows the map of Ghana with the demarcation of the 10 regions. The case study would be executed in Accra Technical University which is located in the capital city of Ghana.
Using renewable energy source instead of fossil fuel can help in reducing the environmental pollution of the Accra Technical University and the risk which will be caused by the rise in temperature on the earth surface. In this current generation solar energy is one of the best renewable energy sources since the sun can be find everywhere on the globe. Generating power from photovoltaic (PV) technology is green, available, simple, clean and reliable. Notably, PV system efficiency is low, however the PV panel power output is mostly depending on the solar irradiation, array voltage and temperature (Dariush Souri 2016)
1.1 Goal and scope of the study

This study focuses on energy production in the campus of Accra Technical University. The research objective of this study is to design a hybrid system for energy production to meet the energy demand and reduce the cost of energy in the tertiary schools in Ghana. The goal of the study is to find out how practical it would be to have on site power production and gain knowledge of pros and cons of these kind of systems.

This study is about possibilities of local energy production in educational institutions in Ghana with Accra Technical University as a case study. However, the results of the study could be used in similar cases as well. It should be noted that the energy consumptions collated for this study are specific to geographical area and buildings within Accra Technical University.

1.2 Structure of the study

This research would be partitioned into two methods: literature analysis and calculations about the case university and its possibilities. Literature analysis is used to gain information about hybrid energy systems and energy consumption in the area. Literature analysis will form the basis for the calculation part. Calculations part entail accurate numeric information that is essential to the conclusion of this study. Both methods are significant to the feasibility and completion of the research work to ascertain the possibility of self-sufficient energy production by tertiary institutions in Ghana.

Literature analysis part of the thesis were expounded in chapters 2 and 3. In chapter 2 basic information about energy sector in Ghana are introduced. This entails aspects that affect energy consumption and production in the country. Chapter 3 focuses primarily on energy sources and feasible hybrid energy system configurations that can be deployed.

Chapter 4 highlights on the selected institution for the case study which is Accra Technical University. It gives brief overview of the energy consumption and possibilities for energy
production. Chapter 5 expresses detailed information about the university’s energy consumption. A model design for the hybrid energy system and its possibilities with storage capacity and costs.

Chapter 6 discusses about the results gained from the literature analysis and modelling. Most significant results will be stated in this chapter. It will also discuss about the possibilities and impacts of the hybrid energy system to the university and to the grid. Chapter 7 will be summary of the thesis. Chapter 8 will be the conclusion and the recommendation for the University.
2 OVERVIEW OF GHANA POWER SECTOR

Ghana has about 4000 megawatts (MW) of generation capacities installed at strategic geographical location and mostly to the source. Out of this total capacity, independent power producers (IPPs) generate 551 MW power to compliment the total energy generation. In actuality the available production in Ghana does not exceeds 2000 MW. The available energy production supplies a population of 28 million that is incrementally growing at a percentage of 1.822% per year. (Power African 2015).

The power sector is categorized into three arms, generation, transmission and distribution. In Ghana there are three major organizations in charge of the power generation. These are the Volta River Authority (VRA), Bui Power Authority (BPA) and Independent Power Providers (IPPs). The Volta River Authority (VRA) is a governmental institution responsible for the generation of electricity throughout the southern part of the country. The Northern sector generation is supervised by a Northern Electricity Department (NED) which a subsidiary to VRA. For decades VRA had the monopoly of generation and transmission of electricity in Ghana. However, as population grows and the demand for electricity increases, there was the need for extension of the electricity network. This pave the way for independent power providers to start operations to meet the increasing demand of electricity. This was realized in the late 1990s when the power sector was reformed (Kumi. 2017).

Transmission of electricity from the generation source is executed through the national interconnected transmission system, which is managed by Ghana Grid Company a state-owned entity. The transmission network is inter-connected to the network of Ivory coast and the network of the Togo/Benin as well as the network of Burkina Faso. Figure 3 shows the grid network in Ghana. (IAEA, 2011)

Another governmental institution solely responsible for distribution is the Electricity Company of Ghana (ECG) and Northern Electricity Distribution Company (NEDCo). ECG distributes electricity to the southern part which comprises of 5 administrative regions of Ghana. NEDCo supervises the northern sector in Ghana. Electricity generation in Ghana can be mainly categorized into hydroelectric and thermal power generation. Figure 3 shows the 5 administrative regions in Ghana that ECG distributes electricity to. (ECG, 2016)
Ghana’s energy consumption does not exceed 2400 MW even though the installed generation capacity is about 4000MW. This is due to inconsistency power supply conditions caused by inadequate fuel supplies and obsolete infrastructures. Thus, Power Africa and its partners outlined some reforms across the power sector that would help Ghana to scale-up its private-sector investment which envisages 10% of renewable sources into the energy mix (Power African 2015). Additionally, the reform must focus on the following priorities:
- Building a transparent framework for the management and the development of Ghana substantial natural gas resource.
- Effective allocation and pricing of hydro power
- Initiating a least cost, transparent approach to generation expansion including competitive bidding.
- Expansion of renewable energy sources.
- Integrated resource and resiliency planning among the generation, transmission, and distribution sectors.

### 2.1 Energy sources and production

The proportion of the installed generation capacity in Ghana can be categorized into hydro-electric, thermal plants and renewable energy generation. The share of the dependable capacity of 2400 MW constitutes 41.6% of hydroelectric generation. The remaining 57.8% is largely produced by the thermal plants across the country. There is also a contribution from renewable energy generation constituting less than 0.6% of the total capacity. (GRIDCo 2018)

Table 1 represents the total hydro installed capacity in Ghana. The total capacity of hydro generation in the country is about 1580 MW. Akosombo has the largest installed capacity with about 1000 MW dependable capacity. It is solely owned by the Government and managed by the Volta River Authority (VRA). Bui hydro dam has an installed capacity of 400 MW. The least of the hydro dams has an installed hydroelectric capacity of 160 MW located in Kpong.

<table>
<thead>
<tr>
<th>Installed Plant</th>
<th>Installed Capacity (MW)</th>
<th>Dependable Capacity (MW)</th>
<th>Share of Installed Capacity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Akosombo</td>
<td>1020</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>Bui</td>
<td>400</td>
<td>360</td>
<td></td>
</tr>
<tr>
<td>Kpong</td>
<td>160</td>
<td>148</td>
<td>41.6</td>
</tr>
</tbody>
</table>
There are a number of installed thermal capacity to meet the high energy demand in the country. The main source of fuel for the thermal plants is obtained from the West African Gas Pipeline (WAGP). WAGP is operated by chevron and owned by the West African Gas Pipeline Company Limited. The pipeline has a length of 678 kilometres that transports gas from Nigeria to Benin, Togo and Ghana. The Gas pipeline supply purified natural free of heavy hydrocarbons, liquids and water. This is ideally suited as fuel for power plants and industrial application (WAPCO 2018).

The total of all installed thermal capacity in the country is about 2192 MW with Takoradi Thermal Power Station (T1) having an installed capacity of 330 MW. Takoradi International Company (TICO/T2) has a dependable capacity of 320 MW. Additionally, there are other two (2) installed capacities in Tema. The Tema thermal 1 power plant-T1 (TT1PP) has an installed capacity of 126 MW and Tema thermal 2 power plant (TT2PP) has a dependable capacity of 45MW. The Kpone Thermal Plant has an installed capacity of 220 MW while Karpowership has an installed capacity of 230 MW. Furthermore, the mines reserve plant (MRP), Ameri, Trojan and Genser which are independent power providers have an installed capacity of 80 MW, 250MW,25MW and 30MW respectively. Table 2 represents the number of installed thermal and operational thermal plants in the Ghana. (Kumi. 2017).

<table>
<thead>
<tr>
<th>Installed Plant</th>
<th>Installed Capacity (MW)</th>
<th>Dependable Capacity (MW)</th>
<th>Share of Installed Capacity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thermal</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Takoradi Power Company (TAPCO)</td>
<td>330</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>Takoradi International Company (TICO)</td>
<td>340</td>
<td>320</td>
<td></td>
</tr>
<tr>
<td>Sunon Asogli Power (Ghana) Limited (SAPP)- IPP</td>
<td>200</td>
<td>180</td>
<td></td>
</tr>
</tbody>
</table>
Table 3 shows the number of installed renewable capacity in the country. Thus, with a share of 0,6% of installed renewable capacity in the country’s energy generation mix indicates that more efforts need to be considered to harvest and improve upon the renewable energy sector.

<table>
<thead>
<tr>
<th>Installed Plant</th>
<th>Installed Capacity (MW)</th>
<th>Dependable Capacity (MW)</th>
<th>Share of Installed Capacity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Renewables</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safisana Biogas</td>
<td>0,1</td>
<td>0,1</td>
<td>0,6</td>
</tr>
<tr>
<td>VRA Solar</td>
<td>2,5</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>BXC Solar</td>
<td>20</td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>
Figure 4 depicts the share of the source of fuel use to power the different power plants in the country. Hydro constitute the highest share with 48% and combine gas use to power the thermal plants constitute 42%. Simple gas has a share of 7% while simple oil is 3%.

### Estimated energy production capacity in 2018

<table>
<thead>
<tr>
<th>Source</th>
<th>Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro</td>
<td>48%</td>
</tr>
<tr>
<td>CG</td>
<td>42%</td>
</tr>
<tr>
<td>SG</td>
<td>7%</td>
</tr>
<tr>
<td>SO</td>
<td>3%</td>
</tr>
</tbody>
</table>

**Figure 4.** Estimated energy production capacity in 2018 (GRIDCo 2014).

### 2.2 Major energy consumers in Ghana

Energy demand has significantly increased for residential and commercial facilities over the years. Since 1990s’ demand for electricity has increased rapidly, however, the country has not been able to meet these growing demands with the current power production. Some of the major consumption of electricity in Ghana are Volta Aluminium Company (Valco) and the mining companies. These companies production are highly energy intense activities. Figure 4 shows the share of the various groups of electricity consumers in Ghana (GRIDCo, 2014).
Figure 5. the shares of various groups in electricity use (GRIDCo 2014).

Figure 5 shows the shares of various groups in electricity use in Ghana of which residential and commercial consumes the greater share of electricity in the country recording 70% of the total energy share, followed by the mining sector recording 14% of the electricity share. (GRIDCo, 2014).

An allocated fix amount of energy produce in Ghana is exported to the neighbouring countries (Togo, Burkina Faso and Ivory coast) due to the existing contract between them, which also records 10% of the electricity share, and the least, which is 6% of the total electricity share, is the electricity sold to Valco company for its production of iron sheet and other works. (GRIDCo, 2014).

The Volta River Authority (VRA) is responsible for the energy production in Ghana. The Volta river authority controls the energy that comes from Akosombo, Bui, the Northern solar project and the three thermal plants in Ghana. The energy is produced from these various power plants and is been transmitted to the consumer through the grid operator which is called GRIDCO (Ghana Grid Company Limited).

The GRIDCO is in charge of constructing and managing the transmission network in Ghana. In order to promote competition and electricity generation GRIDCO has granted access to power generation companies to join the transmission network. Thus, independent power providers in the country can supply electricity through the transmission network at a fee.
The transmission network is inter-connected to the network of Ivory coast and the network of the Togo/Benin as well as the network of Burkina Faso. The figure 6 below shows the grid network in Ghana. (IAEA, 2011).

Figure 6: The electricity grid in Ghana (Gridco 2011)
Figure 6 shows the grid lines connecting the region together and the transfer of electricity from the source to the consumers.

### 2.3 Climate in Ghana

The climatic transition of Ghana can be characterized into two distinctive seasons. Mainly, the wet season and the dry season. The dry season is experienced with hazy and dusty conditions as a result of dry humidity changes in the atmosphere leading to the dry and dusty wind from the Sahara Desert. This result in reduction in visibility and hazy conditions. The wet season is referred to as the raining season and it is accompanied with heavy downpour of rain. (UN HABITAT, 2009).

Ghana is a tropical country with high average annual precipitation in the southern part of the country. On the other hand, the northern part, experiences dry conditions and the vegetation in the area is extreme savannah. Accra lies within the coastal belt and it experiences an annual low average rainfall of about 810 mm distribution with a span of less than 80 days. A bimodal is observed in Accra. The major season falls between the months of March and June. Observably, the minor season is mostly experienced around October. The average temperatures ranges between +24 ºC in August to +27 ºC in the month of March. (UN HABITAT, 2009).

A critical look at the wind conditions in Accra depicts that, Accra has reasonable amount of wind energy that can be harvested. Figure 7 shows the wind speeds recorded in each month of the year. It can be deduced from the bar chart that during the period between January to April. Conversely the lowest recorded wind speeds are between September to November.
Figure 7 Monthly wind speed recorded for the city of Accra. (Meteoblue. 2018)

Figure 8 exhibits the average temperatures and precipitation extrapolated from Meteoblue weather forecast for Accra per each month in the year. The solid red shows the mean daily maximum temperature and the solid blue line the average minimum temperature.

Notably, monthly precipitations above 150mm are mostly wet seasons and below 30 mm are observed as dry seasons.
2.4 Photovoltaic Power Potential in Ghana

In this thesis, the main renewable energy that would be deployed into the hybrid system is solar energy. Figure 9 shows the photovoltaic power potential in Ghana with an average power range of 3.6-4.4 kWh/kWp. It can be deduced from the map that the northern region has the highest potential, however the country experiences reasonable amount of solar irradiance that can be harvested into the energy mix.

Figure 9. Solar resource map of Ghana. (Solargis. 2108).
Obviously, the solar potential in the capital city Accra is of a reasonable high potential that when harnessed into the energy mix for consumption in Accra Technical University it would help curtail the energy challenges the university is encountering.

3 Opportunities and Challenges in Ghana’s Electricity Sector

The government of Ghana, over the years established structures to help enhance energy production in a more efficient and sustainable way. Thus, in line with the 1990s reformed, policies and regulations were developed by the Ministry of Energy and the Energy Commission to ascertain the pathway to efficient and production in the country. In view of that, the government established regulatory bodies to help with in assessing and monitoring the progress and electricity consumption in Ghana. Public Utility Regulatory Commission which is one of the regulatory bodies established was responsible for fairness and equitable pricing of electricity in Ghana. In addition, the National Electrification Scheme was institutional with a goal to promote and help attain a universal access to electricity to all Ghanaians by 2020. (Kumi, 2017)

Therefore, the government of Ghana in collaboration with other key stakeholders such as the National Energy Policy and the National Energy Strategy established the Renewable Energy Acts 2011, the Feed-in Tariff and the Net Metering Schemes to assist in promoting and implementing renewable energy for electricity generation. However, the energy sector still faces major challenges in meeting the increasing demand in spite of all these measures put in place. These challenges can be related to poor tariffs structure which has diverse effects leading to financial instability of utility organizations. In addition, high level of losses in the distribution systems and lack of diversity in the energy mix generation. Therefore, the government seeks intrinsic measures in implementing demand side management to assist in promoting effective consumption of electricity through sustainable energy efficiency and renewable energy source such as mini-hydro, solar and wind (Kumi, 2017).
3.1 Losses in Electricity Distribution System in Ghana

It is interesting to note that, a country that its energy production cannot meet the demand has more losses throughout its electricity distribution system. Invariably, the losses can be attributed to inefficiencies of some of the equipment as most of them are obsolete. Additionally, power theft and loss of revenue as a result of non-payment of electricity bills by consumers. In the Energy Commission annual report 2017, it accounted that approximately 21.7 percent of gross electricity was lost through transmission and distribution over the last decade. Figure 4 depicts a decade losses of electricity distribution in Ghana.

![Figure 10: Transmission and distribution losses (Energy Commission of Ghana, 2017)](image)

It can be deduced from the figure 10 that ECG has the largest share of losses in its distribution system and this can be attributed to low efficiencies of equipment, power theft and bad management. One of the major implemented measures by ECG to avert these challenges is the introduction of prepaid metering system for residential and commercial consumers. Additionally, replacement of those obsolete equipment would enhance efficient transmission and distribution. (Kumi, 2017).
3.2 Tariff Framework

The governing body in charge of electricity tariffs in Ghana is the Public Utilities Regulatory Commission (PURC). In Ghana, electricity tariffs are partitioned into 6 groups; residential, commercial, special load tariff (SLT)-low voltage. Furthermore, special load tariff (SLT)-medium voltage, special load tariff (SLT)-high voltage and mines. (Energy Commission of Ghana, 2016b). Commercial and residential consumers are classified based on a range consumption matrix as follows: below 50 kWh, 51-300 kWh, 301-600kWh and consumers above 600 kWh. However, PURC has established some irregularities in the subsidy’s government remits to all residential consumers whose energy first energy consumption is 50 kWh. PURC advocates that the subsidies should be given to consumers whose total monthly consumption is less than 50 kWh. It has established the Automatic Adjustment Formula (AAF) that helps to sustain real value of tariff in proportion to determine variables such as inflation, foreign exchange and fuel price increase (natural gas, crude oil etc). Additionally, PURC has established lifeline tariffs to help alleviate financial burdens on consumers with low income. This is in alignment with the government poverty alleviation plan under the scheme Poverty Reduction Strategy. As stated above, one of the determining factors for increasing tariffs is exchange rates. Thus, figure 11 represents how the Ghanaian cedis performs against the US dollars in relations to end user tariff in Ghana for the past a decade with reference point of 2006.

Figure 11: Trend of electricity tariffs of average end user in Ghana. (Energy Commission of Ghana, 2017)
3.3 Electricity Generation mix

For years Ghana has predominantly depended on the Akosombo hydro dam for electricity generation. Obviously, hydro electricity generation is one of the cheapest sources in comparison to thermal generation and other source of electricity generation. However, the over-dependence of rain water to raise the level of the Akosombo dam to sufficiently operate in its full capacity has not be realized for years due to climate change effect. The dam experience one of the lowest water levels in 2006/2007 plunging the country into power shedding (Energy Commission of Ghana 2017). Figure 12 shows the average water levels and electricity generation from the Akosombo dam.

![Figure 12: Average water level compared to electricity generation for Akosombo dam (Energy Commission of Ghana 2017).](image)

3.4 Promoting Energy Efficiency in Ghana

The government of Ghana has adopted measures to tackle the prevalent power crises in the country. It has resolved in building new power plants, but this is associated with high capital investments. On the other hand, the Energy Commission has mapped strategies that is in
alignment with the national policy of energy efficiency and conversion. A campaign that led to replacement of all incandescent bulbs with compact fluorescent lamps (CFL). Admittedly, this project helped in saving about 200-240 MW of generation capacity. (Energy Commission of Ghana 2017) In additional, the Energy Commission in collaboration with Ghana Energy Foundation a non-governmental institution established energy efficiency standards and labelling for a refrigerator, air-conditioner imported into the country. Moreover, the commission sought to replace all second-hand inefficient air conditioners and refrigerators with more efficient one baring the energy efficiency labels. Figure 13 represents the energy efficient standard labels use by the Energy Commission and other energy efficiency organization in Ghana.

Figure 13. Energy efficiency standard label in Ghana (Energy Commission 2016).

4 HYBRID ENERGY SYSTEMS

Hybrid electrical system is a combined system configuration consisting of two different electrical technologies to produce electricity. It is a complete electrical configuration system that
can be configured to meet a power need remotely or at proximity. Also, the combination of two or more electrical components is to eliminate limitations in the system. A hybrid electrical system consisting of two or more components or technologies have an advantage over a single electrical system. This is feasible when considering a standalone PV system with a hybrid system consisting of grid and PV system. In a scenario, where there is not enough sunlight in a particular day, the standalone solar PV system may not be able to meet the energy demand. From another perspective, the hybrid system would be able to supply the energy to the load demand because of the grid system combined with the PV system. Notably, this can be achieved efficiently with a conversion system such as a converter/inverter and battery storage (Energy, Gov. n.d).

This chapter elaborates more about the hybrid energy systems in detail to gain more insight in its operation. Also, the hybrid system would be deployed in the case study of Accra Technical University to envisage its feasibility.

The figure 14 shows a typical hybrid system with combined utility grid, solar, generator, a conversion system and battery storage to produce electricity.

![Figure 14. Hybrid power system. (Symtech. 2018)](image-url)
4.1 Solar power

Renewable energy is obtained from natural processes that are replaced constantly. In its various forms, it is being obtain from the sun. Solar energy is one of the major contributors to renewable energy generation to meet increasing global energy demand. (Haukala 2015). It is environmentally friendly renewable energy generation with innocuous emissions. It also is coupled with low management and maintenance cost with single installation technology. Most essentially, the sun energy can be harnessed globally, and it is available everywhere. Notably, it cannot be retrained by ownership constraint as encountered with convectional energy sources, typically associated with fossil fuel. (Haukkala 2015).

Figure 15 depicts the period in a day when the sun energy can be harvested. The solar irradiance is the power per unit area. There is no solar irradiation before the sunrise and after the sunset. This makes the solar energy received from the sun extremely time dependent. In Ghana the sun begins to rise from morning around 6 o’clock and falls around 6 o’clock in the evening. These times have very little variation throughout the year. Daily irradiation was then calibrated to the known value of 6 kWh /m² day, which is daily average of the year and for horizontal plane. (JRC. n.d).

![Figure 15. Peak sun hours (Munzer S.Y et al 2013).]
In this project, fixed tilted angle solar PV systems would be deployed since all the PV installations are roof top base. Figure 16 depicts the efficiency of single crystal silicon cell over a period. It can be deduced that its efficiency has gradually improved over the years and with advancement in research and development it can be envisaged that its efficiency would further increase. (Axaopoulos and E.D Fylladitakis 2013)

![Figure 16 single crystal Si cell efficiency (%) (Jinyoun Cho, et al, n.d).](image)

The fixed tilted angle considered for the PV Solar panel installation slope is 5.61 degrees. Additionally, a panel azimuth of 0 degree and ground reflectance of 20% would also be considered in order to gain optimum energy output from the PV installations. (Axaopoulos and E.D Fylladitakis 2013)

Installation angles affect collection energy of sunrays hence affecting the energy and power output of a solar system, more importantly if season changes in raining seasons or down in the dry seasons. It’s possible to increase the amount of energy your system can capture during those seasons. (P.J Axaopoulos and E.D Fylladitakis 2013)
Solar systems installations are reliable and have proven to be one of the dependable sources of energy for residential, commercial and industrial facilities. Maintenance cost depends on the type and size of solar system installed. Maintenance plays a vital role in sustaining a reliable and efficient structured solar panel in operation. In comparison to generators that have movable components that require lubrication at high maintenance cost, solar panels operations do not incur high maintenance cost (Axaopoulos and Fylladitakis 2013).

Photovoltaic panels are a good option of energy source because it provides clean green energy during electricity generation with negligible harmful emissions. Thus, deploying solar photovoltaics to the university would enhance green energy generation on the campus. Solar energy has a higher promising future and it is both economically viable and environmentally sustainable. Photovoltaic panels are cheaper energy source compared to power plant generation source and thus reducing electricity energy bills and reduced dependability on national energy grid system. Photovoltaic panels are good option for the university because they are a perfect solution for noise control and sustainable energy supply to the University’s learning environment (IRENA 2012). The cost of the crystalline solar panel selected for this model was estimated to be $0.7 for 1 Watt with an efficiency of 20%. (Alibaba, 2018).

Observably, solar panels are easily broken when excessive load is exerted on it. Thus, to safeguard these fragile panels, insurance would be an ultimate option. Notably, insurance costs would add to the PV investment cost, thereby soaring the initial capital cost. In this project rooftop mounting PV panel installation would be considered because Accra Technical University has scarce land area for land mounted PV projects. Thus, roof top is the best option for the PV installations in the institution (IRENA 2012).

4.2 Diesel power generation

A diesel power generator comprises of storage tank, pump, injection pumps and strainer. Typically, the uses of a diesel fuel to generate electrical energy is accompanied with emissions of heavy metals. Usually, there are two main fuel oils: heavy fuel oil and low fuel oil. Normally, the heavy fuel oil needs to be treated with a separator before been pumped into the heavy fuel tank. (Hanania et al 2015).
For low fuel oil, it is normally stored in the main tank without separate treatment mechanism. (Hanania et al 2015). Figure 17 shows a typical diesel generator incorporated into energy system configuration.

![Figure 17. Diesel generator (Caterpillar 2018)](Image)

The internal combustion engine sets (gensets) normally consist of pipes for fresh air intake into the engine in order to obtain efficient compression ratio. It is essential that the compressed air component operates continuously to avoid air lock. It is critical to remove excessive heat from the generating system as heat can damage the component in the engine. Thus the radiator component plays that important role to remove heat from the engine (Armstrong & Proctor 2018).

The diesel power plant starts very fast compared to other power plants, it can also be stopped when required, a small size diesel power plant station is even easier to start, as these diesel power plant can start and stop when required, there will not be any standby loss in the system, Its cooling is very simple and also requires less amount of water as compared to other power plant Also the thermal efficiency of the diesel power plant is higher than most of the power
plants. It is simple in construction (design point of view), it requires small space finally it can be designed for portable use.

4.3 Battery storage

In hybrid energy systems, batteries store energy produced by PV-array system. Batteries are also used in standalone power system configuration. One useful attributes of a hybrid system integrated with battery is that loads can be supplied with efficient energy at any given time. It is important to note that with batteries integration into the energy system anytime there is power outage from the grid, the entire system will shut down before the generator starts. Thus, storage battery serves as a back-up to maintain electricity connection for all or most of the important equipment in the university. Notably, a system configuration with a battery storage fortifies the system in such a way that anytime there is power outage from the utility grid it may not be realized because of the back-up system. In this project, the stored energy would be utilized anytime sun radiation is low and the power output from the panels are low, but demand is high (Madziga et al 2018).

It is important to avoid overcharging and deep discharging of the batteries, this helps to enhance its life span usability. Thus, a controller is an important device of the energy storage in the solar PV-arrays systems. The charging pattern would be monitored to avoid under charging and over charging, as these practices can damage the batteries. The use of a bi-directional converter would be integrated into the system. Typically, DC/DC type to allow charging of the battery when there is enough generation from the solar PV-arrays. A controller would also be installed to discharge battery when there is more demand of energy or less supply from battery storage. (Miriam Madziga et al 2018). The cost of the battery selected for this model was estimated to be $200 with a capacity of 1.28kWh. (Alibaba, 2018).

A photovoltaic charge controller is an important part of a hybrid power systems configuration with battery back-up. Its’ main function is to prevent overcharging of batteries irrespective of the power source. Additionally, a photovoltaic charge controller is simple to operate and has low voltage disconnect to prevent over discharge. Photovoltaic charge controller is selected base on the PV array voltage and current. (Madziga et al 2018).
An inverter is a device which is used to convert direct power (DC) output coming from the PV array or storage battery bank into alternating current (AC). The inverter must be incorporated with maximum power point tracking features to ensure maximum power output. It also ensures that voltage fluctuations are reduced before fed into commercial electrical grid AC frequency cycles in synchronization to 60 cycles per second. The selection of the inverter would be based on the voltage of the battery storage or incoming DC current from the solar module. Additionally, the inverter must be of high efficiency with good voltage regulation and frequency. The cost of the solar inverter selected for this model was estimated to be $250 with a power of 3000W. (Alibaba, 2018)

4.4 Pros and cons of hybrid energy system

Hybrid energy configuration reduces the size of diesel engine generator utilization and enough saving is made on fuel as well as reduction in pollution. Thus, hybrid energy system reduces environmental impact associated with only diesel only generation. Additionally, hybrid system improves the load factor and cut expenditure on maintenance and replacement cost. From another perspective, there is reduction in cost of electricity with the integration of renewable energy system. The lifecycle cost of a hybrid energy system is affordable in comparison with standalone PV system or diesel generator system. Moreover, with hybrid system configuration, reliable and stable power supply is observed. (CER 2014).

Conversely, hybrid energy system attracts high initial capital, though it provides reliable power supply and has a payback would be realized in a couple of years. The high initial capital cost seems to be an impedance to adopt this system (CER 2014).

Furthermore, for future expansion of the hybrid energy system project which comprises of diesel generator and battery storage; structural, space and technical feasibility need to be considered. Thus, expansion of the energy system configuration might make the system complex to handle. Moreover, for a hybrid system configuration reliability constraint plays vital role. This implies that a share of the peak demand must be reserved. (CER 2014).
5 ACCRA TECHNICAL UNIVERSITY

In this chapter, the Accra technical university is presented from the hybrid energy system point of view. Main focus of this chapter is on energy production potential and current consumption. Energy production potential will be addressed mostly by finding out what is suitable area for solar panel installation. Addressing of energy consumption will use the electricity bill of the campus as a basis but also try to go deeper with known behaviour. This chapter will provide most of the basis for later simulation. (ATU 2018).

Even when the scope of this thesis is limited to one university the consumption behaviour is versatile and consumed energy amounts are quite huge. Now, the institution has about six hundred personnel that comprise of administration staff, teaching and non-teaching staff. It also has about twelve thousand students who are taking various Degree, HND, Diploma and other certificate courses. (ATU 2018). This amount of people will need a lot of space in case all of them should come to the school campus at the same time, which can be seen from the satellite image of the campus below.

![Satellite image of the campus](image)

*Figure 18. Satellite image of the campus. (Google Maps, 2018)*
As it can be seen from the figure 18, the campus has many buildings and those are tall. The high building volume and the need of AC rises the electricity consumption remarkably. The versatility to the consumption comes from the dorms that are also in the campus. This adds some effect of living habits to the mix.

### 5.1 Campus buildings and roof areas for PV installations

The Accra Technical University has two big storey building used for student hostels. The old building has 96 rooms’ whiles the new building has 121 rooms. In total there are 217 rooms and it rooms has 6 students so in total the school hostel can accommodate 1306 students in the school hostels. (ATU 2018).

The administration block is where all administration works such as printing of transcripts are executed. The Engineering block with high energy consuming equipment for practical trainings. In addition, the engineering block is furnished with projectors for presentations. The lecture halls are fitted with lighting and computers in the ICT lab. Science Laboratory and technology block the classrooms over there uses lighting, projector and computer unit. Fashion and designing block use lighting, projector and computer unit as well.

The university hostel is place where students lives, and it has fridge, television set, microwave, blenders, irons, water heater, cookers and lighting system. University lecturers flat it is a place where lecturers live, and these are some of the devices used in the lecturer’s flat fridge, television set, microwaves, blenders, irons, water heater, cookers and lighting system (ATU 2018).

### 5.2 Energy consumption of the campus.

The energy consumption of the campus was found out from the actual electricity bill. The bill was missing information of November. Missing data was filled with average of October and December (linear approximation). Consumption graph is shown in figure 19.
Figure 19. Energy consumption in kWh

Figure 18 shows the annual energy consumption of the Accra Technical University. The energy consumption of the Accra Technical University increases when population increases due to a lot of energy consuming activities such as use of electronic appliances like computers, mobile phone. Thus, increase in population is directly proportional to high energy consumption. During the school hours the Administration block, lecturer halls and offices consumes more energy because of the air conditioning, computers as well as office machines are being used. When it is evening time students moves to their hostel and start cooking with their electric cooking stoves, which also consumes more energy during the evening around 6pm to 8pm. On weekends where the lecturers and the administration are not working, the total energy consumption will be less compared to the normal working hours.

Between January to March, the consumption is higher because the temperature drops as a result of the harmattan season. The harmattan season is characterized by very cold-dry and dusty wind. The temperature sometimes falls to +19 degrees Celsius and most students use hot water for bathing in the hostels. Thus, the use of electric heaters and stoves contributes to the increase in the energy consumption. During the wet or rainy season that is from June to somewhere September the temperature is mild, and students reduce the rate of using hot
water, so it automatically reduces the total consumption of the school. Furthermore, the institution goes on recess between June to August school and most students moves to their various homes and hence the consumption is reduced drastically. However, the consumption begins to increase from September when studies and the school commence.

5.3 Proposed hybrid energy system for the case university

Accra Technical University which is located in the capital city of Ghana experiences a lot of power outages due to the high energy demand in the university. Hence the University must get alternative electricity source which will compensate in case the electricity company of Ghana could not supply the needed energy to meet the demand of the University.

The hybrid system configuration proposed for Accra Technical University consist of solar PV, the utility grid with a standby diesel generator. In addition, conversion system that is convert/inverter to convert AC to DC and versa vice would be integrated into the system with battery storage capacity.

Roof areas of each numbered building were calculated using measurement tool from Google Maps. Pitch angle of the roof were calculated from Google Street view and the roof area finally using trigonometry. Dimensions are illustrated in the figure 20.

Figure 20. Roof top area calculation
Pitch angle were calculated using the equation 1.

\[
Pitch \ angle = \tan^{-1}\left(\frac{\text{rise}}{\text{span}/2}\right) \quad [\text{Eq 1}]
\]

Where, Pitch angle Angle of the roof as presented in figure 16 [degree]
Rise Rise of the roof [m]
Span Width of the roof’s projection to flat surface [m]

From pitch angle the rafter of the roof were calculated with the following equation 2.

\[
\text{Rafter} = \frac{\text{span}/2}{\cos(\text{pitch angle})} \quad [\text{Eq 2}]
\]

Where, Rafter Real width of the roof side [m]

Finally, the area of the roof was calculated with the equation 3.

\[
\text{Roof area} = 2 \cdot \text{rafter} \cdot \text{length} \quad \text{Eq 3}
\]

Where, Roof area Roof surface area [m²]
Length Length of the roof [m]

**Table 4.** Roof area of the buildings in campus. Dimensions are taken from Google Maps.

<table>
<thead>
<tr>
<th></th>
<th>Orientation</th>
<th>Span [m]</th>
<th>Length [m]</th>
<th>Pitch angle [°]</th>
<th>Rafter [m]</th>
<th>Area [m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building 1</td>
<td>West-East</td>
<td>10</td>
<td>59</td>
<td>12</td>
<td>5</td>
<td>605</td>
</tr>
<tr>
<td>Building 2</td>
<td>West-East</td>
<td>11</td>
<td>60</td>
<td>11</td>
<td>6</td>
<td>672</td>
</tr>
<tr>
<td>Building 3</td>
<td>West-East</td>
<td>14</td>
<td>70</td>
<td>12</td>
<td>7</td>
<td>988</td>
</tr>
<tr>
<td>Building 4</td>
<td>North-South</td>
<td>13</td>
<td>44</td>
<td>12</td>
<td>7</td>
<td>585</td>
</tr>
<tr>
<td>Building 5</td>
<td>North-South</td>
<td>13</td>
<td>60</td>
<td>16</td>
<td>7</td>
<td>780</td>
</tr>
<tr>
<td>Building 6</td>
<td>West-East</td>
<td>12</td>
<td>39</td>
<td>20</td>
<td>6</td>
<td>498</td>
</tr>
<tr>
<td>Building 7</td>
<td>West-East</td>
<td>5</td>
<td>38</td>
<td>20</td>
<td>3</td>
<td>202</td>
</tr>
<tr>
<td>Building 8</td>
<td>NW-SE</td>
<td>9</td>
<td>79</td>
<td>20</td>
<td>5</td>
<td>752</td>
</tr>
<tr>
<td>Building 9</td>
<td>West-East</td>
<td>10</td>
<td>33</td>
<td>12</td>
<td>5</td>
<td>337</td>
</tr>
<tr>
<td>Building 10</td>
<td>West-East</td>
<td>14</td>
<td>41</td>
<td>20</td>
<td>7</td>
<td>611</td>
</tr>
<tr>
<td>Building 11</td>
<td>West-East</td>
<td>6</td>
<td>62</td>
<td>0</td>
<td>3</td>
<td>369</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>116</td>
<td>584</td>
<td>155</td>
<td>60</td>
<td>6399</td>
</tr>
</tbody>
</table>

6  CALCULATIONS OF THE HYBRID ENERGY SYSTEM

The calculation consists of the consumption modelling, peak load, energy production and storage modelling as well as the cost analysis and scenarios.

The number of people in the university were taken into consideration, the type of appliances and the number of appliances were added into the calculation modelling. Also, the number of classrooms and the number of rooms for lectures and administration staff were taken into account in the modelling of the consumption, production, peak load and battery energy storages.

6.1  Consumption modelling and peak load

When designing a power production system of any sort, there are many aspects that need to be taken into account. Two of the most important ones are peak load and total energy demand from the system in a given time period. Peak load is the maximum amount of power being drawn by all the components (appliances, machines, etc.) at the same time. Peak load is usually very short-lasting spike in energy demand but the system need to still be able to provide that to avoid blackout. For a grid-connected system, it is not as critical to be able to handle the peaks.
The energy demand from the hybrid energy system were modelled from the basis of the campus electricity bill. The campus electricity consumption model was created by estimating number of different types of devices in the campus, location of the population of the campus and most probable time schedule to use each device. For the modelling, January were used as a base for the total energy consumption as it had the highest total energy consumption.

There are 12000 students and out of that, 30 percent will be in lectures at the same time whiles out of 600 workers, assuming 80 percent of them showed in the working hours. Base on this assumption am estimated amount of 8400 students will be on campus, 450 workers at the administration block and at least 300 students will be staying in the hostel during the day. Figure 21 shows the number of students in the school during school hours, the workers and staffs in the administration during working hours and the students who stays in the hostel during school hours.

![Graph showing movement of people](image)

**Figure 21**. Movement of people in the school.

The students in the hostels consume energy during the morning period since they live in the main campus. From 7:30 onwards they migrate from the hostels to the campus. While the
Day student and staffs who live outside the campuses come to the university and study during the working hours and the teachings hours respectively. On the other hand, the spike drop entails the break periods for the administration workers. Since during these periods a lot of activities lessen.

There are also 1309 student’s living in the hostel and out of that, 90 Percent of the student will be present in the case scenario. Which means 1175 students living in the hostel will move from the hostels to the school campus for lectures.

To get the amount of people in each location to power usage values some key appliances were added to the model. These appliances and their rated powers are shown in the table 2 below.

**Table 5. Electricity devices in the simulation**

<table>
<thead>
<tr>
<th>Device</th>
<th>Amount</th>
<th>Power [W]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACU</td>
<td>60</td>
<td>1100</td>
</tr>
<tr>
<td>Electric stove (hot plate)</td>
<td>320</td>
<td>2000</td>
</tr>
<tr>
<td>Lights</td>
<td>X</td>
<td>2 W/person in campus</td>
</tr>
<tr>
<td>Computers</td>
<td>1900</td>
<td>90</td>
</tr>
<tr>
<td>Fridge</td>
<td>320</td>
<td>100</td>
</tr>
<tr>
<td>Other appliances</td>
<td>x</td>
<td>1000 (total and constant)</td>
</tr>
</tbody>
</table>

For each of the appliance listed in the table above, utilization scenarios were created. For air conditioning units (ACU) the usage were approximated to be depended on the solar irradiance curve, but the dependence was offset by couple of hours. All of the 60 ACUs were set running on maximum power on 1 and 2 pm giving total consumption of 66 kW. The consumption before and after that would raise and lower following the shape of solar irradiation curve. The curve is presented in the figure 22.
Electric stove usage was estimated to be depended on the time of day and location of the people. Since dining habits affect a lot of the usage of these devices, specific utilisation scenario was needed. Total power of electric stoves was calculated with the equation 4.

\[
P_{\text{stove}} = \text{NOPIH} \times \text{ESNP} \times \text{TDCF} \quad [\text{Eq 4}]
\]

Where, Pestove  Total power demand of electric stoves [W]
NOPIH    Number of People in Hostels [-]
ESNP     Electric Stove Nominal Power [W]
TDCF    Time depended coincidental factor [-]

Time depended coincidental factors are not presented separately in this thesis. The factor has three spikes for one day. These spikes are 0.09 at 7 am, 0.17 at 11 and 12 o’clock and 0.205 at 6 and 7 pm. These spikes were set to illustrate typical dining times. The results are shown in figure 23.
Figure 23. Electric stove power demand curve

Power demand of lighting were calculated allocating 2 W of power for each person in the campus starting from 6 am and ending in 11 pm. Power demand curve of lighting formed from the people coming to the campus from outside because those inside the campus were already added up.

For computers the demand was calculated from the computer nominal power and the number of computers in use at a given time. The number of computers at use in any given time were calculated with the equation 5 below.

\[ N_c = (PIA + PIS) \cdot \frac{1400}{40800} \]  \hspace{1cm} \text{[Eq 5]}

Where, \( N_c \) Number of computers in use \hspace{1cm} [-]

\( PIA \) People in administration \hspace{1cm} [person]

\( PIS \) People in school \hspace{1cm} [person]

The factor 1400/40800 were used to get the utilisation of computers close to the total number of these electronic devices in the campus. 40800 is equal to the maximum number of people
in the school at the same time. The power demand of computer equipment was then calculated multiplying the nominal power of 90 W with the number of devices in use. Summed up, these devices would produce a load of 170 kW in the mid-day.

Fridges were the easiest devices to model, as they would run constantly. At the power consumption of 100 W, these 100 fridges would form a constant load of 32 kW to the system. Other appliances were added in the form of constant load of 1 kW. All of the power demands are shown in the figure 24. Electric stoves created the most significant spikes to the power demand while all the rest of the appliances create more even load to the system. The role of electric stoves come from their highest nominal power and the time depended use scenario. Computers create the second biggest demand to the system.

This model resulted in a peak load of 534 kW between 7 and 8 pm when most of the cooking is happening. According to the campus electricity bill, the peak demand of the campus was 542 kW and that was in March. The modelling using estimations of usage and device numbers got remarkably close to the actual peak load of the campus.

Figure 24. Power consumption model of the school
With this model the energy consumption of one day is 5317 kWh which means a total consumption of 165 000 kWh in January. The campus electricity bill had 160 000 kWh as January’s consumption and the model got very close on that too. For the hybrid energy system design, this model is accurate enough to carry out further analysis.

For the rest of the modelling the load curve was set to maintain the same form. Variation from 70 % to 130 % was added on top of that. Monthly variance of consumption was also taken into account January being the baseline with factor of 1. Rest of the factors were determined with the consumption data from the electricity bill as shown in equation 6.

\[
\text{Demand factor}_i = \frac{\text{Energy consumption}_i}{\text{January energy consumption}} \quad \text{[Eq. 6]}
\]

Where, Demand factor\(_i\) Month \(i\)’s demand factor [-] Energy consumption\(_i\) Month \(i\)’s energy consumption [kWh]

Calculations whit the equation 6 gave the following results shown in table 6.

Table 6 Demand factor for each month

<table>
<thead>
<tr>
<th>Month</th>
<th>Demand factor [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>1,00</td>
</tr>
<tr>
<td>February</td>
<td>0,91</td>
</tr>
<tr>
<td>March</td>
<td>0,94</td>
</tr>
<tr>
<td>April</td>
<td>0,91</td>
</tr>
<tr>
<td>May</td>
<td>0,86</td>
</tr>
<tr>
<td>June</td>
<td>0,65</td>
</tr>
<tr>
<td>July</td>
<td>0,64</td>
</tr>
<tr>
<td>August</td>
<td>0,53</td>
</tr>
<tr>
<td>September</td>
<td>0,61</td>
</tr>
<tr>
<td>October</td>
<td>0,60</td>
</tr>
<tr>
<td>November</td>
<td>0,72</td>
</tr>
<tr>
<td>December</td>
<td>0,83</td>
</tr>
</tbody>
</table>
6.2 Energy production and storage modelling

There are two energy production alternatives in the modelled hybrid energy system: solar panels and diesel generator. Since the generator’s role is only to backup production during grid blackouts and cloudy days, the only production method modelled as this point is solar panels.

As presented in the chapter 3, solar energy is very time depended. This was illustrated in the figure 10. For modelling purposes solar irradiation values were extracted from the figure using Web Plot Digitizer. This resulted in the figure 25.

![Solar irradiation at given time [kW/m²]](image)

**Figure 25** Solar irradiation

Between sunrise and sunset, the irradiation follows closely equation 7.

\[
I = -3 \cdot 10^{-5} t_i^3 - 0.0287 t_i^2 + 0.703 x - 3.2047 \tag{Eq 7}
\]

Where, 
- \(I\) Solar irradiation \([\text{kW/m}^2]\)
- \(t_i\) Time value in hours between 6 AM to 6 PM \([-]\)
Solar irradiation at given time of day were calculated using the formula visible in the equation 6 above. The irradiation was set to start from zero at 6 am and end to zero at 6 pm. Between those times, the formula was used, and other times were set to zero. Daily irradiation sum was then calibrated with a factor to daily average of each month for horizontal plane. Variation to the value were added later in the modelling. In the table 7 monthly averages of daily irradiation sums and irradiation curve factors for each month are represented.

Table 7. Daily average solar irradiation sum for one square meter in Ghana (JRC n.d).

<table>
<thead>
<tr>
<th>Month</th>
<th>Average daily irradiation sum [kW/m²]</th>
<th>Irradiation curve factor [-]</th>
</tr>
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<tr>
<td>January</td>
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<td>0,73</td>
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<td>February</td>
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<td>April</td>
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<td>0,75</td>
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<tr>
<td>May</td>
<td>5,93</td>
<td>0,71</td>
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<tr>
<td>June</td>
<td>5,37</td>
<td>0,64</td>
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<tr>
<td>July</td>
<td>4,93</td>
<td>0,59</td>
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<tr>
<td>August</td>
<td>4,7</td>
<td>0,56</td>
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<td>0,58</td>
</tr>
<tr>
<td>October</td>
<td>5,72</td>
<td>0,69</td>
</tr>
<tr>
<td>November</td>
<td>5,97</td>
<td>0,72</td>
</tr>
<tr>
<td>December</td>
<td>5,76</td>
<td>0,69</td>
</tr>
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</table>

To calculate the electricity output of solar panel, it is needed to take into account the efficiency and the area of the solar panel. The electricity output was calculated with the following equation 8.

\[ P_{pv} = Irradiation \cdot area \cdot eff_{pv} \cdot eff_{dcac} \cdot variable \]  

[Eq 8]

Where, Ppv
- Output power of solar panel installation [W]
- Irradiation Solar irradiation to surface [W/m²]
- Area Panel area of the installed system [m²]
For this model, the total roof area calculated in the chapter 4 were used. This step could have offset the results a little since it is not horizontal area, but this is on the other hand compensated always with the other side of the roof and also due the location near equator as the track of the sun is quite straight from East up and then West. Daily irradiation were then calibrated to the known value of 6 kWh/m^2*day, which is daily average of January and for horizontal plane (JRC n.d).

Hybrid system battery storage was modelled with the efficiency of 80% in charging. For simplicity reasons the inverter efficiency was set the same. Any PV production that was not used to meet the demand, were stored in the batteries. To find the storage capacity needed. The model was made for one day. Energy in storage was set to start from 0 kWh. and was allowed to go negative. Production and demand variation were not used in this model. The difference between the lowest and highest energy state in the storage would show the needed battery capacity. Results of this model are shown in figure 26.
Figure 26. Energy consumption, production and storage.

Figure 26 show the storage capacity of about 4000 kWh between the lowest and highest energy state. The model used the total energy consumption data collated for the university with the month of January showing the highest energy consumption. The production curves show that the amount of energy which the solar energy will produce is enough to meet the demand of the school during the day and also charge the batteries. This is as a result of good solar irradiation experience within the geographical location. Figure 25 also shows that the energy which will be stored in the batteries will be enough for the school during the night when the solar irradiation is not all that good to supply the school with enough energy. The lower limit of storage was set to 1000 kWh (25 %) to increase the lifetime of the instalment.
This limit would increase the grid dependency, as the curve in figure 25 is just above 1000 kWh in the end but went negative in the beginning.

Energy in battery storage was modelled as follows:

- Battery has maximum charge state was 4000 kWh and minimum 1000 kWh
  - Battery would not get any charge if it was at the maximum state
  - Battery would not give any power out if it has reached minimum state
  - Energy transfer is only allowed between the states

- If production from Eq. 6 was over the demand, battery would gain the energy from over production it is not fully charged already.
  - Production from equation 6 already included 80 % of efficiency, no other reduction would affect the charge.

- If production from Eq. 6 was not able to fulfil the demand, the battery would supply energy to meet the demand taking into consideration an efficiency of 80 % of dc to ac conversion indicating that the efficiency was 80 % both ways.

Energy balance of the system was calculated each hour for the whole year. The balance was calculated at the ac level after the inverter:

- Energy from solar panel has highest priority. Production from solar panels was the first one to be reduced from the demand.
- Energy from storage was set to second highest priority. If production from the panels did not meet the demand, the rest was taken from storage if it was available.
- If energy from the panels and storage was still not able to fulfil the demand, the rest was taken from grid.
  - Every hour that has energy taken from the grid was counted and monthly sums of these counts can be seen in the results.

For reality reasons fluctuations were added to production and demand on each hour:

- To meet the real peak irradiation from the average irradiation sums from January to May, the variation of solar energy production was set from 70 % of the average to 130 % of the average each hour randomly
- Variation of demand was also set from 70 % to 130 %
Electricity price of $0.19/kWh was used in the calculations. The price was calculated dividing the total annual cost with energy used. With these rules the model gave following results shown in the table 8 and figures 27-28.

Table 8 shows the modelling results of energy consumption and source supply throughout the year with their electricity savings.

<table>
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<tr>
<th>Month</th>
<th>Energy demand [kWh]</th>
<th>Energy from inverter [kWh]</th>
<th>Energy from grid [kWh]</th>
<th>Solar hours [h]</th>
<th>Grid hours [h]</th>
<th>Savings in electricity bill [$]</th>
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<td>9457</td>
<td>656</td>
<td>88</td>
<td>29747</td>
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<td>8307</td>
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<td>152168</td>
<td>7696</td>
<td>642</td>
<td>78</td>
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<td>8658</td>
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<td>103068</td>
<td>7762</td>
<td>998</td>
<td>350418</td>
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</table>

95 % 5 % 89 % 11 %
Figure 27 depicts the total energy demand and the production capacity of both solar and the grid to meet the demand.

![Energy demand and source [kWh]](image)

**Figure 27. Energy Demand and Source Supply**

Figure 28 represents the yearly duration and contribution balance of both the solar and grid when to the load.

![Balance of source connected hours [h]](image)

**Figure 28. Balance of Solar and Grid**
Figure 29 depicts the production variations of the solar panels. The solar panel efficiency which is used in this monthly modelling is 21%, with roof top panel area of \(5759 \text{m}^2\). This constituted about 90% of the total rooftop area. The variation taken into consideration is 70 - 130% in each hour in other to make modelling real in real life application because of clouds and other irregularities in the weather conditions in Ghana.

The estimated losses from the storage batteries and inverter considered in the modelling is 20%. Consumption were set to vary between 70 % and 130 % of the base consumption model. Figures 30 and 31 shows the energy balance between solar and grid.
Modelling of whole year led to the result that the University would need to be connected to the grid only 16 % of the time (1373 h of 7387 h total) as represented in figure 30. This means that the University would have electricity almost 84 % of the times when there are blackouts in the area. Following figure 31 shows the relating annual energy balance of solar energy constituting 93% of the energy while the grid contributes 7%.

**Figure 30.** Solar and grid hours

**Figure 31.** Energy balance
6.3 Cost analysis and scenarios

The cost of battery was estimated to be 200 $ with a capacity of 1.28 kWh. The total capacity of batteries was set to 4 000 kWh, which meant that the system consists of 1565 batteries. The capacity reduction over time was set to be 2% for each year, which lead to annual costs of 6 250 $. The inverter was estimated to be 1 300$ with a capacity of 20 kW. The peak load of system was set to 600 kW, which lead to 30 inverters needed and total cost of 39 000 $. Solar panel cost was calculated by using price of 0.7 $ and capacity of 1 MW. This led to the total costs of solar panels to be 700 000 $. (Alibaba. 2018)

The total investment of the system was calculated by summing up each component not including the battery capacity renewal. Total investment was 1 294 000 $. The installation cost was estimated to be 10% on top of the investment taking the final sum to 1 423 000 $.

Yearly cost of the investment where calculated with the following equation 7.

\[
A = \frac{(1 + \frac{p}{100})^n \cdot \frac{p}{100}}{(1 + \frac{p}{100})^n - 1} \cdot N \quad \text{[Eq 7]}
\]

Where, 
- A: Annuity [$]
- p: Rate [%]
- n: Number of years [-]
- N: Investment [$]

For the calculation, time was set to 15 years and rate to 5%. Residual value was estimated to be 0.

\[
A = \frac{(1 + \frac{5}{100})^{15} \cdot \frac{5}{100}}{(1 + \frac{5}{100})^{15} - 1} \cdot 1 500 400 \$ = 144 552 \$/year \quad \text{[Eq 8]}
\]

The yearly cost of battery capacity renewal was added to the annuity with maintenance costs of 1 000 $ each year making the total yearly cost to 158 000 $.
The yearly savings calculated earlier was 350 000 $. When the annual costs are subtracted from the savings, the system leads to annual profit of 192 000 $. This saving is however depended on the energy consumption.

![Savings in electricity bill](image)

Figure 32 Savings in electricity bills

7 RESULTS

The hybrid energy system designed for the Accra technical university was dimensioned with the goal to meet the peak load and also energy requirements of January, which had the highest consumption. The system was designed to be grid connected with diesel generator backup. The energy storage was also added to get more benefits out of the solar panels in order to meet the energy demand during the day time as well as the night hours. The modelled system was not able to meet the whole energy demand, thus 5 % of the electricity was obtained from the grid.
Reliability of energy delivery were also found to increase substantially. The share of the utility grid in terms of duration connection to the hybrid system constituted only 10%. During daytime solar panels met more than double of the peak consumption. Even during cloudy days, the system could handle a blackout in the grid during daytime. It can be assumed that most of the power outages in the national grid happen during the day or evening when the consumption is the highest. For the university to lose electricity it would have to be late evening, battery storage empty and national grid in blackout. And even if those happen simultaneously there would be the backup generator.

The hybrid energy system produced 95 percent of the total energy demand, which in turn leads to a savings of 350 000 $ each year in electricity bill. Other savings or possibility to sell excess energy were not taken into account. Other savings would have included things like downscaling the peak energy demand in the contract. The demand could reduce close to 11% before it really starts to affect the savings and when the reduction happens the system will also be more self-sufficient as the energy storage (batteries) would be fully charged.

Investment costs to the system were calculated to be around 1,5 million USD. This resulted in annual costs of 158 000 $ during the 15 years of time. This amount also includes yearly investments to maintenance and new battery capacity as the storage slowly degrades. Calculated profit was 192 000 $ each year.

Solar PV and batteries will evolve as the most important power technologies globally, complemented by wind energy and mainly existing hydropower. In addition, power plant is the most valuable and flexible balancing technology on a time scale of days to months. Solar panel prices have been declining steadily and the efficiency of the panel is going up in the same time. The profitability of modelled system is, with these reasons, going to be better in the near future. This is also backed up with the increasing electricity price in Ghana.

To conclude, the main findings of the modelling were that the system will substantially increase reliability in energy delivery to the campus and that the investment seems to be slightly profitable. The payback of the systems is about 6 to 7 years.
8 CONCLUSION AND RECOMMENDATION

The proposed hybrid configuration system modelled in the case study for Accra Technical University with solar energy as the main source of renewable energy indicated that it is techno-economically feasible and sustainable. The model was executed with the assumption that about 30 percent out of the total student population would be in the lecture hall. Another assumption was infused into the model was that out of a total of 600 working staffs, 80 percent will be actively working during the working hours. Based on these assumptions, an estimated amount of 8400 students were modelled to be on campus and 450 working staffs would be working at the administration block. This implies that 300 students were modelled to be in the hostels during studies period. Additionally, consumption were set to vary between 70 % and 130 % of the base consumption model.

It was deduced that the integration of the Solar PV system into the energy mix 93 percent of the total energy demand was met with solar energy with only 7 percent coming from the grid. Thus, the hybrid energy configuration system contributed largely to each year electricity bill savings of 350 000 $. The university would have become a prosumer if there is a possibility to sell excess energy to the grid.

Moreover, for the project life span of 15 years, a yearly profit of 192 000 $ was calculated. Considering an investment costs to the system to be around 1,5 million USD, an annual cost of 158 000 $ was calculated. In addition, the investment cost included yearly investments of maintenance and new battery storage capacity as the batteries degrade overtime.

To conclude, the main findings of the modelling were that the system will substantially increase reliability in energy delivery to the campus and that the investment seems to be slightly profitable. The payback of the systems is about 6 to 7 years.
9 SUMMARY

The objective of this thesis is to provide and envisage the possibilities of Accra Technical University generating self-sufficient energy to meet the increasing energy demand of the institution. With the student population rising and increment of the working staffs as well as high energy consuming equipment utilization on the campus, there is the need for the institution to deploy hybrid system configuration to meet the high demand. Thus, the hybrid system comprises of solar energy system, the national grid, battery energy storage and a back-up diesel generator. The diesel generator serves as a redundant energy system and only becomes utilized when there is complete power failure from the solar energy system, the national grid and the battery storage.

The solar energy was able to meet the energy demand substantially in a proposed modelled where solar serves as the dominant energy supplier in the system configuration set up. In this configuration it was observed that only 5% of electricity was obtained from the grid. Reliability of energy delivery were also found to increase substantially in a hybrid system connected with the grid. During daytime solar panels met more than double of the peak consumption. Even during cloudy days, the system could handle a blackout in the grid during daytime. According to the modelling results the system lead to savings of 350 000 $ each year in electricity bill.

Investment costs to the system were calculated to be around 1,5 million USD. This resulted in annual costs of 158 000 $ during the 15 years of the project life time. However, this amount includes the yearly investments due to maintenance and purchase of new battery capacity because of degradation factor in the battery storage banks. A profit of 192 000 $ was calculated and envisage each year.
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APPENDICE
APPENDIX 1 (Hostels Buildings)

Hostel Block 1

Hostel Block 2

APPENDIX 2
Machine Shop

Machine shop
APPENDIX 3
Administration Block

Engineering Block
APPENDIX 4

Computer lab
APPENDIX 5

Results on electrical appliances used in the school

<table>
<thead>
<tr>
<th>Fridge</th>
<th>ACU</th>
<th>Lighting</th>
<th>Electric stove</th>
<th>Electric stove power</th>
<th>Computers</th>
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APPENDIX 6

Results on the production, demand, storage power and stored energy

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