DISTRIBUTED RENEWABLE ENERGY SYSTEMS IN GHANA – A TECHNO-ECONOMIC STUDY OF SOLAR HOME SYSTEMS

By

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MASTER OF SCIENCE – RENEWABLE ENERGY TECHNOLOGIES

DECLARATION

I hereby declare that this submission is my own work toward the MSc. in Renewable Energy Technologies and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgment has been made in the text.

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ABSTRACT

Ghana's urban population in the middle and high-income segments often seek electricity alternate power systems either as a solution in the face of power outages, or as a reliable second option. Some middle- and high-income household users seek to know what options there are, in relation to a second electricity source, and what the techno-economic implications could be. The study sought to assess the technical feasibility and economic benefits of investments in diesel generators and solar PV systems with battery storage. The cost-benefit scenarios of diesel generators were compared to those of Solar-PV systems with battery storage, using a daily base electrical load of 3.3kW peak. Simulations were run with HOMER, comparing options of combined grid and solar home systems, as well as combined grid and diesel generator systems. Running a household solely (considering the base load) on Ghana's national grid offers a yearly operating cost of $839, translating to a monthly electricity bill of $70 (about GHc 330) and a total NPC of $10,732. Investing an initial amount of $1,332 in an SHS for the same household offers a yearly operating cost of $665, translating to a monthly electricity bill of $55 (about GHc 260) and a total NPC of $9,828. The difference between the total NPC of the grid-only system and that of the recommended SHS (i.e. $10,732 - $9, 828 = $904) offers a payback period of about a year and a half on the initial investment. Given the above results, an investment of $2,000 or less in a Solar PV system with battery storage is better than making that same investment in purchasing a diesel generator. The results show that an investment in purchasing a diesel generator to supplement the national grid provides very little or no benefits. Maintenance cost for each kilowatt of solar installation done is an average of USD $4 as compared to an average of USD $40 for a diesel generator system. There are also benefits in the inclusion of a renewable fraction (16% or more) in the energy supply of homes that invest in solar systems, contributing to goal 7 (affordable and clean energy) of the UN's sustainable development goals.

Keywords: Ghana, Solar Home Systems, Hybrid, Diesel, Clean Energy, Sustainable Development Goals

ABBREVIATIONS

AC	-	Alternating Current
ASE	-	Alternate Source of Energy
BOS	-	Balance of System
COE	-	Cost of Energy
DC	-	Direct Current
DG	-	Diesel Generator
ECG	-	Electricity Company of Ghana
GHc	-	Ghana Cedi

IRENA - International Renewable Energy Agency

ISO - International Standardization Organization

kW - kilo Watt

kWp - kilo Watt-peak

LCOE - Levelized Cost of Energy

MW - Mega Watts

MWp - Mega Watt-peak

NPC - Net Present Cost

O&M - Operation and Maintenance

PV - Photovoltaic

RET - Renewable Energy Technology

SDG - Sustainable Development Goal

SHS - Solar Home System

TNPC - Total Net Present Cost

TV - Television

V - Volts

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CHAPTER ONE: INTRODUCTION

1.1 Background

At the end of the year 2012, Ghana's total electricity generation capacity was 2,280 MW, constituting 1,180 MW hydro and 1,100 MW thermal power plants, and giving a national total of 12,024 GWh of electricity. The commissioning of the 400MW Bui power plant in 2013 increased this number to 2,754 MW (Energy Commission, 2016).

Ghana, having a lower middle-income economy, has an increasing demand for electricity and this increase is gauged to stay above 6% per year over the next decade (Energy Commission, 2016). Transmission and distribution losses remain high and are estimated at 23.4% (African Development Fund, 2014). The government recognizes the need for significant investment in generation, transmission, distribution, as well as demand-side management.

Towards a diversified, secure and sustainable energy system, Ghana is keen on taking advantage of the possibilities that renewable energy technologies (RETs) offer. In 2006, the Strategic National Energy Plan (SNEP) proposed a target of 10% renewable-energy-generated electricity by 2020 (Energy Commission, 2006). This target has been adopted and integrated into the National Energy Policy and other documents. In 2011, the Renewable Energy Law (Act 832) was passed to provide a legal and regulatory framework, as well as, support mechanisms to promote RETs in Ghana. Feed-in-tariffs (FIT) for various RETs were published for the first time in August 2013. The publication of the FITs increased the interest of investors, especially regarding Solar PV technology, and the Energy Commission of Ghana had given out about 800 MWp of provisional licenses for utility-scale Solar PV projects by June 2015.

Centralized utility-scale solar PV systems receive more focus globally, but distributed Solar PV technologies need to be exploited, as they hold great potential in managing load growth (International Energy Agency, 2010). Renewable energy technologies offer additional benefits when operated in a distributed mode, aside their trademark advantages of empowering more use of local energy resources and being environmentally friendly.

In the past decade, peak load in Ghana has increased by 49.8 percent, increasing from 1,393 MW in 2006 to 2,087 MW in 2016. Figure 1.1 records a yearly rise of 4.29 percent from the year 2006 to 2016, with generation capacity more than doubling over the same period.

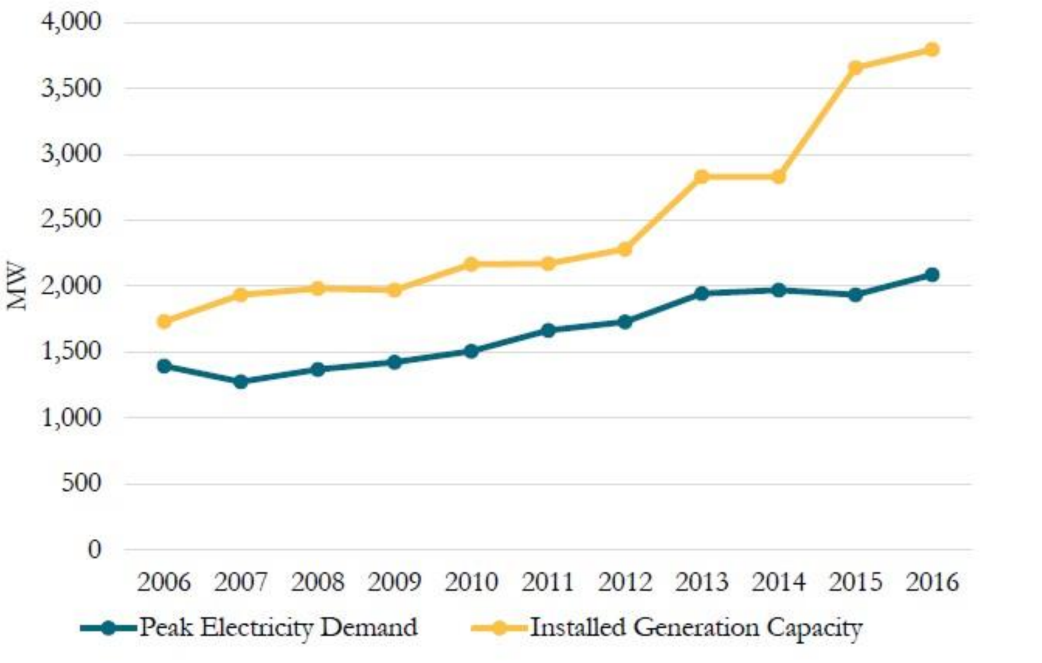


Figure 1.1: Peak Electricity demand versus installed generation capacity from 2006 to 2016

Source: Nyarko-Kumi (2017)

As a result of the fact that the power supply is sometimes unreliable, many businesses and homes have over the years resorted to the use of diesel generators for power backup systems. This thesis seeks to assess the role that distributed (also called decentralized) solar photovoltaic applications could play in building a climateresilient and sustainable energy system in Ghana.

Power-generating technologies are referred to as ‘distributed’ or ‘decentralized’ when they are small or modular, and can be added to energy storage and load management systems, to make the quality and/or reliability of the electricity supply better. Typically, centralized systems are large-scale, remotely-located power plants which generate electricity and transmit power to consumers via power lines. Distributed systems, on the other hand, generate power close to the point of energy consumption, and usually do not require power transmission lines (National Renewable Energy Laboratory, 2012).

While decentralized solutions in Africa tend to be considered mostly in the context of expanding electricity access to un-electrified (mostly rural) communities, it also holds significant prospect in urban and metropolitan areas where the national grid is already present – particularly decentralized PV systems with storage. When distributed solar PV systems are deployed, they present the benefit of on-site electricity production and minimize the need to construct new transmission lines. Decentralized generation makes an existing grid (based on a conventional centralized model) more resilient and offers notable benefits to consumers. Solar Home Systems (stand-alone mode), backup power systems, water pumping and telecommunication systems are few examples of applications of distributed generation. Ghana has large, centralized power plants which supply a bulk of the nation’s power but has also explored some form of distributed generation in the area of providing electricity from solar PV to off-grid island and lakeside communities. Distributed renewable energy systems include electricity from wind turbines, small-hydro power plants in communities, and these systems generate clean, renewable electricity on-site.

While increased use of renewable energy technologies such as solar PV addresses one of the important legs of energy sustainability, its deployment in distributed mode simultaneously addresses in some way, energy efficiency, since it is accompanied by reduced transmission and distribution losses. These in turn strengthen the resilience of energy systems to climate variability and climate change.

Solar PV, as a renewable energy technology, is growing rapidly and is projected to play a significant role in the global electricity generation mix in the future. One feature of solar PV which makes their systems favourable is their modular size. Solar PV also offers the benefit of making end-users have more access in controlling their own generation. Other advantages of solar PV are listed below:

- In every part of the world solar power is an available renewable energy resource.
- Components of the solar PV systems are usually small, modular in size and are easily usable anywhere.
- Users of solar-powered PV systems have no fuel cost, providing a huge advantage in comparison with fossil-fuel-powered systems, considering how volatile fossil prices are, globally.
- There are usually minimal costs spent on the operation and maintenance of solar PV systems.

When either direct of diffuse solar irradiation is present, solar PV systems work. Solar resources are expressed as annual mean figures in kWh/m^2/day or as kWh/m^2/year. In areas that have high solar resources, the cost of electricity from installed solar PV systems is decreased. Worldwide, the amount of solar resource available is expansive, with about 885 million TWh worth of solar radiation reaching the surface of the earth annually (International Energy Agency, 2014). Largely, local meteorological conditions are the main factors that cause significant daily, weekly and monthly variations in the available solar resource. Regarding annual variation of the available solar resource, the geography of the earth correlates most.

Africa is greatly endowed with high amounts of available solar radiation, mostly greater than 5kWh/m²/day. In Ghana, yearly figures of solar radiation lie between 4.5 and 5.6 kWh/m^2/day, placing the nation in an advantageous position for solar electricity projects (UNEP, 2015).

Table 1.1 indicates that Accra on an annual basis receives 64% more radiation than Berlin (which is a world leader in the deployment of Solar PV), 51% more radiation than Tokyo, 21% more radiation than Beijing, and 18% more radiation than New York (RETSCREEN Software, 2017).

Table 1.1 Average Daily Radiation of Major Cities in the World, kWh/m2

	kWh/day						
Month	London	Berlin	New York	Tokyo	Rome	Accra	Beijing
January	0.64	0.79	1.76	2.16	1.98	4.10	2.15
February	1.19	1.48	2.64	2.63	2.92	4.59	3.00
March	2.16	2.41	3.61	3.12	4.32	5.21	3.94
April	3.37	3.75	4.68	3.56	5.48	5.08	4.90

May	4.37	4.77	5.44	3.91	6.78	5.02	5.48
June	4.75	4.80	5.98	3.45	7.64	3.97	5.19
July	4.55	4.77	5.79	3.83	7.67	3.70	4.59
August	3.98	4.18	5.20	3.85	6.71	3.84	4.38
September	2.83	2.76	4.11	2.90	5.08	4.59	3.93
October	1.66	1.61	2.99	2.30	3.40	5.19	3.10
November	0.84	0.85	1.92	2.11	2.11	4.79	2.23
December	0.50	0.61	1.57	1.93	1.69	3.86	1.82
Annual	2.58	2.74	3.81	2.98	4.66	4.49	3.73

Data Source: (RETSCREEN Software, 2017)

Solar home systems (SHS) are stand-alone PV systems that aid in providing a second technology of supplying electricity to lights and appliances used in households. SHSs could be an alternate source of energy that meets the basic electricity needs of a home. The use of energy-efficient appliances in SHSs serve as a plus, helping to limit the size of the solar array. Usually, SHSs consist of one or more PV modules, a charge controller which distributes power and shields the appliances and batteries from damage, an inverter to convert the DC from the batteries to AC, plus one battery (at the minimum) to store energy for use during no-sunshine periods.

1.2 Problem Statement

The inconsistent nature of Ghana's electricity supply has forced many institutions, businesses and individuals to resort to diesel systems, candles and other polluting and more expensive energy alternatives. Additionally, with the increasing uptake of mechanized boreholes in urban and peri-urban areas in Ghana, water supply is also adversely affected. Over-reliance on centralized power generation and supply systems largely based on large hydro and fossil-fired plants have the multiple disadvantages of jeopardizing energy security and being vulnerable to extreme climate events.

Ghana's need to manage demand on centralized power supply system, diversify its power supply sources and strengthen resilience to climate variability and climate change, makes an enhanced understanding of the interplay of factors crucial. In a nation abounding so much with solar resource, an understanding of the crucial roles of distributed solar PV (and necessary actions) is, particularly, valuable. Ghana receives over 2000 kWh of solar radiation per square meter annually, compared for example to about 1350 kWh/m2/year in Germany (which is a world leader in deployment of Solar PV).

Whenever Ghana faces a power crisis (the most recent one having lasted for about three years – 2012 to May 2015) with its attendant load shedding and load management schedules by the Electricity Company of Ghana (ECG), there is the question of why the country does not explore the use of solar energy since this is an abundant resource. The answer mostly given to this question has to do with solar systems being more expensive, but not much is said about the actual cost variations and the actual market figures that make this true or otherwise. There is, therefore, a lack of knowledge and/or information about the techno-economic pros and cons of the usage of solar systems in place of (or as an addition to) the utility's electricity supply.

This thesis seeks to explore the use of stand-alone solar PV systems in buildings and to use actual market numbers to analyze the cost of solar home systems in comparison to electricity taken from Ghana's grid or diesel-fired generators.

1.3 Aim and Objectives

The aim of this thesis to find out what the techno-economics of distributed solar PV applications are in Ghana, and the support mechanisms needed to spur the rapid uptake of such systems.

The objective of this work would be to generate some numbers on exactly how much it costs on a life-cycle basis to own solar home systems designed to meet the needs of a typical Ghanaian home. The project would contribute to increased knowledge of how to take some electrical load off Ghana's centralized electricity system via solar home systems, and enhance understanding of the contribution that distributed solar PV technologies could make to the sustainability of Ghana's power sector.

Specifically, this study will seek to:

a. Determine the cost of electricity from SHSs in Ghana and compare it to other technologies (national grid and diesel)
b. Study the projected gains to be expected from SHSs, and
c. Determine conditions under which SHSs are competitive with other technologies in Ghana.

1.4 Overview of Report

Chapter One contains a general background of the work including stating the objectives and a justification. Chapter Two contains a review of literature on the subject of distributed generation and solar home systems in particular. Chapter Three contains a discussion of the methods and materials used for this thesis. Chapter Four looks at the actual sample scenarios of comparison of the national grid, solar home systems and diesel generators installed in typical urban homes in Ghana. Chapter Five concludes with recommendations and observations from the study.

CHAPTER TWO: LITERATURE REVIEW

Following the identification of the alternative energy technologies in Chapter One, this chapter reviews literature on sustainable access to electricity for consumers towards growth and poverty reduction in Ghana.

2.1 Relevant definitions and formulae

2.1.1 Photovoltaic (PV) System

As a basic unit, a PV system is built from a PV cell; a semiconductor element which converts solar energy to into DC electricity. PV systems convert solar energy directly into electricity and comprise of PV modules and inverters, batteries and other electrical components which are mainly dependent on the particular application of the specific system. PV modules, some ranging from about 50 to about 330 Watts, are formed from linked PV cells. Depending on the use of PV systems, modules are often linked together to provide electrical power ranging from a few watts to hundreds of megawatts (International Energy Agency, 2014).

PV systems are described as 'standalone' when their function is independent of the electricity utility grid, and they supply DC or AC to electrical appliances based on the system's design and size.

PV systems which are 'grid-connected' or 'utility-interactive' typically function in parallel to the utility grid in an interconnected mode. Primarily, grid-connected PV systems have their main component as an inverter or a power conditioning unit (PCU). The function of the inverter is to convert the DC power produced by the PV array into AC power compatible with the power quality and voltage requirements of the utility grid, and is conditioned to stop supplying power to the grid once the grid is not energized. All grid-connected PV systems have this safety feature and this ensures that when the grid is down for service or maintenance, the PV system does not continue to work and feedback electrical power to the grid.

2.2 Net Metering

During peak solar radiation hours of a day (from about 11am to 2pm in Ghana), there could be over-production of electricity. Net metering is a billing mechanism that credits solar PV system owners for the electricity they add to the grid. For example, if a residential customer has a PV system on the home's rooftop, it may generate more electricity than the home uses during daylight hours. The usage of net-metering allows customers who produce renewable energy on a small scale to “bank” or “store” their electricity in the national grid whenever they have excess power (Pacudan, 2018) This excess electricity which is sold out to the national grid is bought back during times of under-production or no-production (e.g. during the night and in the morning in the case of solar energy). Net metering promotes small-scale investments in renewable energy and consumers get to save on electricity bills. Net metering gives room for additional power to be generated into the national grid, without necessarily having the utility or conventional Independent Power Producers (IPP’s) make investments in new systems.

In a net-metered household that has a renewable energy source as an alternate to the grid, the electricity meter runs in the opposite direction to provide a credit against the electricity consumed from the utility grid. The electricity bill in such a scenario is a ‘net’ of the energy use, avoiding the incremental tariffs related to electricity units taken from the utility grid. The higher the cost of the energy in kWh, the more attractive net-metering might be (Jacobs, 2018).

2.3 Major system components of solar PV systems

The design of a solar PV system considers different components that are selected according to the location and type of system, as well as its intended applications. Generated electricity from solar PV systems can be stored in batteries, used in conjunction with other electricity sources, or fed back to the utility grid. A PV module, a solar charge controller, an inverter and a battery bank form the major components of a solar PV system, which together supply power to electrical loads (appliances). The PV module serves as the item which converts sunlight into DC electricity. If left unregulated, the PV module could send too much voltage to the batteries, leaving the battery overcharged (IRENA, 2016). The solar charge controller regulates the current and voltage from the PV modules to the batteries. The inverter is the component which converts the DC electricity from the solar panels to AC electricity. Some appliances could use DC electricity directly but the appliances mostly used in Ghanaian homes require AC electricity. In a solar PV grid-connected system, the inverter is the most significant component because it enables the system to interface with the AC-based national utility grid. Electricity produced in solar PV systems could either be used directly or stored in one or more batteries for demanddriven usage. An electrical load is any appliance which requires electricity to function, such as TVs, lights and laptop computers. Installation accessories are all the items that ensure that the major components are properly and securely fixed, such as mounting structures for solar panels and racks for battery banks.

2.4 Trends in cost reduction of solar PV systems

Governments, organizations, policy-makers and individuals often require information regarding the costs and advantages of RETs to enable them make informed choices and decisions of what suits a particular situation. The Global Market Outlook for Solar Power (2016-2020) reports that the costs associated with solar PV systems are reducing faster than most experts predicted – and this trend will continue (Solar Power Europe, 2016). Globally, accurate data on the average cost of PV is difficult to obtain. Balance of system (BOS) and cost of installation usually make up 55% to

60% of total PV system costs for small-scale and residential systems (International Renewable Energy Agency, 2012). Installation costs for SHSs in the United States have significantly declined since 2010 as shown in Figure 2.1; reflective of costs worldwide. In quarter one (Q1) of 2017, the total costs for SHSs were $2.80 per direct current watts (Wdc), recording a 61% decline since 2010 (National Renewable Energy Laboratory, 2017).

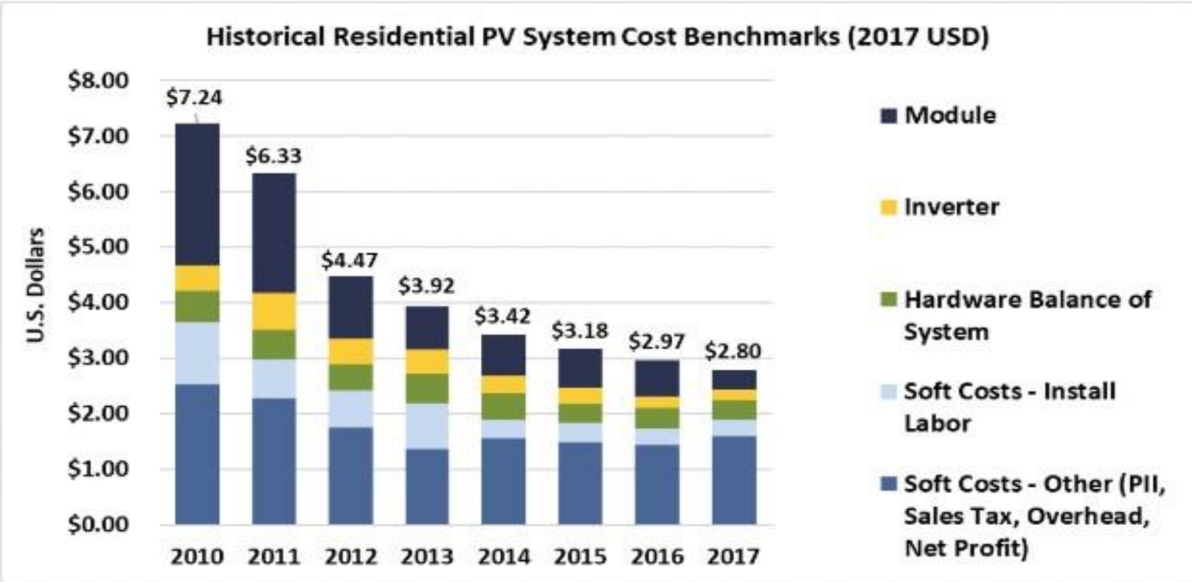


Figure 2.1: Historical Residential PV System Cost Benchmarks (NREL, 2017)

2.5 Country policies increasing the uptake of SHSs

Many developing countries have recorded increasing numbers in installed SHSs but there are still data gaps which do not enhance reliable analysis of these systems. In Africa, however, Kenya is noted to have a market annual growth of about 10% for SHSs, with 320,000 units cumulative installed capacity at the end of 2010 (Ondraczek, 2013).

Though Africa's solar industry has made significant commercial progress, some challenges include the skill gaps for roles of electrical engineers and technicians, the quality of imported solar PV panels and the affordability of SHSs (International Renewable Energy Agency, 2014).

2.5.1 A review of SNEP (2006-2020) and NEP (2010-2015)

It is important to state that changes in the rainfall regime, which is associated with climate change have long affected electricity supply in Ghana. In 1983/84, 1998 and 2007, Ghana experienced a major drop in the rainfall pattern, which resulted into power rationing and frequent power outages that in turn affected the performance of the national economy. These periods are often used to accentuate the claim that hydroelectric power supply in Ghana is threatened by climate change. In view of the increasing demand for energy and the effect climate change poses on electricity generation in Ghana, the Energy Commission in its publication titled "Strategic National Energy Plan 2006 – 2020" argues that the quantum jump in demand for electricity has implications on the nation's balance of payment situation since Ghana imports crude oil to supplement hydro electric power generation (Energy Commission, 2006).

Following from the above, the solution to the precarious energy situation of the world lies in the exploitation of clean alternative sources. Thus, "green" technologies are neither affected by climate change nor high prices of fossil fuels. Based on this premising, the next section of the chapter examines the extent to which Ghana's energy policies consider the non-conventional sources of energy.

2.6 Alternative Sources of Energy in the SNEP (2006-2020) and NEP (20102015)

The Strategic National Energy Plan (SNEP 2006-2020) and the National Energy Policy (2010-2015) aim to develop alternative sources of energy especially for communities inaccessible to the national electricity grid. Increasing energy coverage in the policy documents is justified by the fact that energy sector interventions can provide energy services to support micro, small and medium scale income generating activities thereby elevating individual incomes, improving employment opportunities and reducing poverty (Energy Commission, 2006). However, increasing the energy coverage is only possible through increased investment in the energy sub-sector. Additionally, the investment must go into technologies that provide reliable and sustainable supply of energy. Based on these arguments, SNEP and NEP aim to exploit alternative sources of energy which are considered “green”. In consonance with the vision of the Ministry of Energy, SNEP and NEP do not only aim to ensure that energy consumers (both within and outside Ghana) have access to adequate and affordable energy, but also to clean and efficient sources of energy.

Conventional sources of electricity have proven to be unreliable and expensive due to climate change and increasing cost of fossil fuel exploitation. Attention, therefore, ought to be concentrated on renewable energy sources (Energy Commission, 2006).

SNEP and NEP do not only justify the need to exploit renewable energy resources and technologies, especially, for remote off-grid areas, but also justifies their use as a means of reducing Ghana’s contribution to global warming. Thus, the “green” alternative source of energy, if well developed, can ensure energy reliability and sustainability for a well meaningful poverty reduction agenda.

2.7 Renewable Energy Technologies identified in SNEP and NEP

2.7.1 Wind Energy Generation

Wind resources are available in Ghana but most of the potential is around the coastline. Globally, renewable energy is going through exciting times with increasing investment in many countries. Solar PV capacity increased from 3.1 GW in 2005 to
227 GW in 2015. Within the same period, wind power capacity increased from 59

GW to 433 GW (United Nations Environment Programme, 2015).

2.7.2 Agro Biofuel Wastes and Wood Fuels Power Generation

Biomass is another renewable energy source promoted by both SNEP and NEP.

The policy on biomass aims to ensure that the energy share of traditional biomass (wood fuels) in the national final energy mix is reduced from about 60 per cent at present to 40 per cent by 2020. A dedicated national agency for wood fuel production and marketing issues would be set up, along the same lines as VRA and ECG for Electricity, and Ghana National Petroleum Commission (GNPC) and Ghana Oil (GOIL) for petroleum issues. A SNEP review has also revealed that electricity generation from biomass is still at the first stage of planning whilst specific actions are yet to be implemented. This implies that electricity generation from biomass is a long-term objective.

2.7.3 Small and Mini-Hydro Power

Small to mini-hydro sites, totalling about 25 MW, are dispersed over 70 sites in Ghana. Small to mini-hydro dams could be grid-tied to serve as supplementary power units. The small hydro power proposed for development is the Dayi River cascades which could be developed and connected to the national grid. The review of the energy policies has revealed that the generation of electricity from small and mini hydro dams is a medium to long term policy target. The Ministry of Energy and Power reports that there are about twenty-one small/mini-hydro sites (with a total capacity of about 840MW) yet to be developed (Ministry of Energy, 2012).

2.7.4 Grid Electricity

Most developing countries continue to see an increase in energy demand predominantly due to improved economic conditions, population growth and urbanization. In many of such countries, the expansion of national energy production lags behind current demand, causing shortages and break downs frequently
(Electricity Company of Ghana, 2016).

Ghana's industrial sector constitutes the major consumer of electrical energy, closely followed by the residential sector. Owing to growth in the residential demand, right policies and incentives are able to help make important strides in the electricity sector.

Table 2.1 Electricity Consumption by Customer Class (GWh)

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015[1]
Residential	2,022	1,997	2,168	2,275	2,483	2,527	2,819	3060	2,772	2,437
Non-residential	790	802	876	924	966	1,199	1,549	1,532	1,529	1,532
Industrial[2]	3,592	2,687	2,963	2,951	3,174	3,901	4,153	4,435	4,681	4,144
Street lighting	108	101	132	144	254	296	369	445	540	534
Total	6,512	5,587	6,139	6,294	6,878	7,922	8,890	9,472	9,522	8,646

[1]Provisional
[2]Special load tariff customers of ECG and NEDCo as well as bulk customers of VRA including VALCO
Data does not include transmission and distribution (commercial and technical) losses
Source: ECG, NEDCo, VRA and GRIDCo

Source: (Energy Commission, 2016)

2.8 Solar home systems and power shortages in Ghana

This thesis focuses on solar home systems in urban and peri-urban communities in Ghana. By the year 2030, Ghana's plan is to have increased its generation capacity with at least 10 per cent renewable energy (excluding large hydropower). Though the programme may be focused on grid-connected system or large solar PV installations, solar home systems could play a significant role both in taking some pressure off the national grid as well as contributing to Ghana's power generation capacity.

Solar home systems have generally been associated with usage in remote or rural areas where there is no access to the grid. However, they also serve a good purpose in cities that have unstable or inadequate power supply systems.

Shortage of power poses a severe threat to Ghana's economy. It is common to find diesel-generators in use in places such as homes and at social events due to the unreliable availability of electricity. The effect of diesel-generator usage on small scale businesses and the environment was analysed in a study by Ikhuosho-Asikhia in the Ondo and Edo states of Nigeria (Ikhuosho-Asikhia, 2014). Results from

Ikhuosho-Asikhia's study revealed the following: 77% of business owners agreed that the usage of diesel-generators was not environmental-friendly, 74% of small-scale businesses were willing to pay more for constant electricity supply that is environmentally friendly, and businesses with lesser income spend 46% of their annual income on the fueling and maintenance of the diesel-generators they used.

2.9 Status of utility scale solar PV in Ghana

As of March, 2017, 90 Provisional Wholesale Electricity Supply Licenses had been issued to potential Independent Power Producers (IPPs) proposing to develop a total of about 5,000 MW of electricity from various renewable energy sources. Sixty out of the ninety provisional licenses issued are for solar photovoltaic (PV) generation totalling about 3,000 MW in capacity. As of the end of 2016, 15 licenses had been issued at a total capacity of 961 MW, as compared to 29 licenses with total capacity of 2,155 MW in 2014 (Energy Commission, 2017).

Table 2.2 Provisional Licenses for RE technologies issued as of February 2015 and their capacities

Type of technology	Proposed Capacity (MW)
Solar	2,155
Wind	776
Waste to energy	430
Biomass	68
Hydro	101
Wave	1,000
Total	***4,530***

Source: Energy Commission, 2015

The figures of proposed capacity in MW, as shown in Table 2.2 exclude smaller systems installed by individual homes and institution. Means of data collection on these systems need to be improved.

2.10 Ghana's initiatives for increasing the uptake of renewable energy

2.10.1 Friendly Licensing-regime

Persons wanting to engage in the production, transportation, storage, distribution, importation, installation and maintenance activity in the renewable energy industry have access to a friendly licensing regime from the Energy Commission, as stated by Michael Opam on behalf of the Commission (Ghana Energy Commission, 2015). The objective is to build a contestable market with strong regulatory safeguards for consumers. Wholesale Electricity Generation and Supply license, Importation license, and Installation and Maintenance licenses are the types of licenses mainly granted.

2.10.2 Net Metering regime

Ghana's Net metering sub-code 2015 enables a customer-generator to export excess generated renewable energy into the grid and to receive a credit for it. This kWh billing system credits customer-generators in kWh, not money, for electricity supplied to the grid. The pilot phase of the Net Metering Scheme in 2015 took the form of a close collaboration between the Electricity Company of Ghana (ECG) and the Energy Commission in the identification of 35 Customer-Generators. Works in the pilot phase included the installation of net meters for customers in series with their existing prepaid and postpaid meters (Etwire, 2016).

Table 2.3: Implementation of most popular RE promotion policies in Ghana

RE Promotion Policy Type		Status
1	Feed-in Tariff	✓
2	Renewable Portfolio Standard/quota, REPO	✓
3	Capital subsidies, grants, rebates	✓
4	Investment or other tax credits	✗
5	Sales tax, energy tax, or VAT reduction	✓
6	Tradeable RE certificates	✗
7	Energy production payments or tax credits	✗
8	Net metering	✓
9	Public investments, loans or financing, renewable energy fund	✓
10	Public competitive bidding	✓
11	Mandates for RE Systems in buildings, etc	✗

Table index: '✔' - indicates that the policy type is being implemented and ' ✗ ' indicates a policy type which is not being implemented

Table Source: Energy Commission, 2015

As can be seen from Table 2.3, Ghana is implementing 7 out of the 11 most popular RE promotion policies worldwide.

2.10.3 National 200,000 Rooftop Solar PV Programme

The Energy Commission in collaboration with Public Utilities Regulatory Commission (PURC) rolled out a National Rooftop Solar PV Programme to deploy up to 200,000 solar PV systems in the residential, public, commercial and industrial sectors. The programme provides some amount of capital subsidy for prospective beneficiaries, in the form of solar panels. The Programme is to increase energy security and contribute towards achieving Ghana's RE targets. Upon successful implementation, the programme targets to reduce Ghana's electricity peak load by 200MW and CO_2 emission by 175 kton annually (Opam, 2015)

As at end of 2016, over 2,000 applications had been received and processed, -and approvals have been given to over 800 applicants to install a maximum of 500Wp solar panels each out of which, about 440 installations have confirmed installation.

Also, the Energy Commission in collaboration with the Electricity Company of Ghana (ECG) has successfully piloted 33 net-meters equipped with automatic reading mechanism at various residential and commercial facilities (Energy Commission, 2017).

2.11 Institutional and Regulatory Framework for the Supply of Electricity in Ghana

Having identified that Ghana has policy instruments for the generation of clean energy for consumers, this section provides an overview of the institutional and legislative arrangements for the accomplishment of that purpose. The Ministry of Energy supervises the operations of subsidiary bodies such as the Volta River Authority (VRA) and Electricity Company of Ghana (ECG) under the electricity subsector. Supporting the Ministry of Energy in its operations is the Energy Commission (GEC) established by Energy Commission Act, (Act 541) to develop a competitive energy industry that provides affordable, reliable, efficient and secured energy to consumers. The GEC is mandated to develop a competitive energy industry that provides affordable, reliable, efficient and secured energy economy. The Commission develops, reviews and updates periodically indicative national plans to ensure that all reasonable demand for energy are met in a sustainable manner. Public and non-public companies implement programmes and projects in line with the policy frameworks provided by the Ministry of Energy and Ghana Energy Commission. VRA established by the Volta River Development Act, (Act 46) is mandated to generate electric power and distribute it to the northern and southern parts of Ghana through the Northern Electricity Department (NED) and ECG respectively. Tariffs for the electricity produced by VRA are regulated by the Public Utility Regulatory Commission (PURC) under the Public Utility Regulatory Commission Act (Act 538) (Ministry of Energy and Power, 2017).

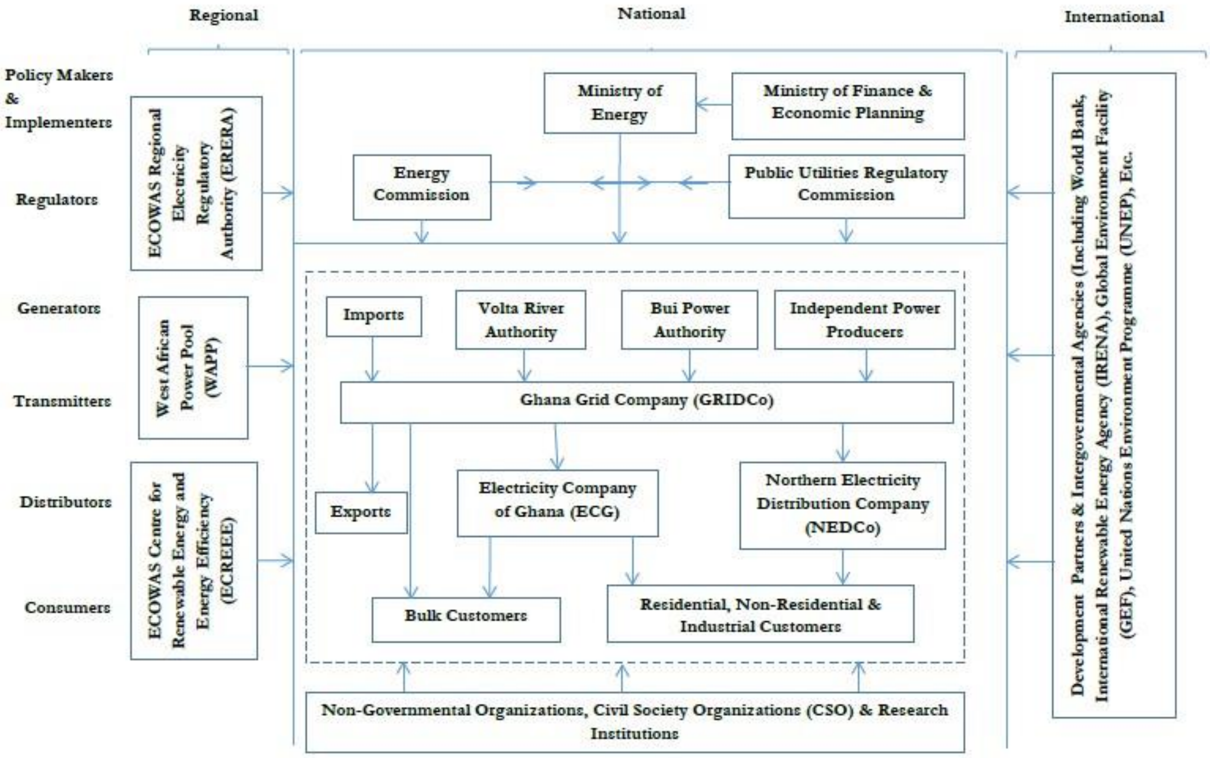


Figure 2.1: Stakeholders in Ghana's Power Sector

Source: Nyarko-Kumi (2017)

2.12 Private Sector Participation in Renewable Energy Promotion

The private sector is considered to be efficient in the production of economic services. Due to this efficiency, SNEP and NEP have made provisions for the production of renewable energy with the active involvement of the private sector. Subsequently, several private manufacturing firms have undertaken investments in the energy subsector to produce clean energy to meet the needs of consumers.

CHAPTER THREE: METHODOLOGY

3.1 Research Design of the Study

The overall research design approach adopted is a case study. Within the case study simulation was used as a tool to analyse data. The software selected to undertake this study is called Hybrid Optimization Model for Electric Renewables (HOMER). Dr. Peter Lilienthal is the original developer of the HOMER® software and founded HOMER Energy in 2009. The version used is the freely-available one, which is appropriate for optimization, sensitivity and pre-feasibility analysis for hybrid renewable energy systems. The wide variety of tables and graphs generated from HOMER simulations allow for comparison of different configurations and evaluation of varied system combinations based on technical and economic merits. One limitation of HOMER is that it cannot do detailed financial analysis (that is, HOMER does not evaluate projects and budgets to determine their performance and suitability, and is not used to analyse whether an entity is stable, solvent, liquid or profitable enough to warrant a monetary investment); it is however able to calculate Net Present Costs, Cost of Energy, Operating Cost and Initial costs (Sinha, 2014). HOMER's ability to present results in order of least Cost of Energy (COE) makes it suitable for this work, providing a visual platform on which to assess electricity generated from the grid, solar PV and/or diesel generators.

Table 3.1: Some merits and limitations of HOMER

MERITS	LIMITATIONS
Simulates a list of real technologies, as a catalogue of available technologies and components	Quality input data needed (sources)
Very detailed results for analysis and evaluation	Detailed input data (and time) needed
Determines the possible combinations of a list of different technologies and its size	An experiences criterion is needed to converge to the good solutions
It is fast to run many combinations	HOMER will not guess key values or sizes if they are missed

Results could be helpful to learn system configuration and optimization	Could be time consuming and onerous

Source: (Okedu & Uhunmwangho, 2014)

A study reviewing nineteen software tools used for hybrid energy system analysis found HOMER to be the most widely used tool as it has maximum combination of renewable energy systems and performs optimization and sensitivity analysis, which makes it easier and faster to evaluate the many possible system configurations (Sinha, 2014).

The questions that HOMER will help to answer in this thesis are:

- What is the cost of electricity from SHSs in Ghana, compared to other technologies (grid and diesel) - $$/kWh.
- If initial cost was the main deciding factor for a client, which option would be a better choice – a diesel generator or a SHS?

3.2 Inputs required by HOMER

One feature of HOMER which can be limiting sometimes is that the software thrives on detailed input data to generate simulations and outputs that are as close to real as possible. Inputs for this work include solar radiation data for location, grid prices for electricity, diesel cost and trends, load profiles for homes in categories (middle income and high income), assumptions (economics and constraints), technology costs (diesel generators, SHSs). Making use of various literature reports, journal articles, documents authored by RE organizations, information from websites of companies and governmental bodies, and statistical data from institutions and authorities facilitated the simulation method.

3.3 Techno-Economic Assessment

A techno-economic assessment was conducted to find the cost of electricity for medium and high-income households mainly with the application of the Discounted Savings Model (DSM) and Levelized Cost of Electricity (LCOE)

3.4 Discounted Savings Model

The Discounted Savings Model (DSM) presents Net Present Value (NPV) of the savings from a renewable energy source, per kWh. A positive NPV or DSM value indicates that a system is beneficial, and utilizing the single value obtained could be used to analyze policies and compare effective applications.

General formulae which can calculate savings per kWh is as shown in equations 1 and 2:

$$NPV of Savings\left(\frac{\$}{kWh}\right) = \sum_{t=0}^{N} \frac{\left[\frac{\text{Annual Household Electricity Bill without PV system} - \text{Net Bill with PV system}}{\text{Consumption}}\right]}{(1+d_n)^t} \quad -(1)$$

Denoting using variables

$$NPV\ Savings\left(\frac{\$}{kWh}\right) = \sum_{t=0}^{N} \frac{\left[\frac{A-B}{C}\right]}{(1+d_n)^t} \quad -(2)$$

Where,

A=Net Bill without PV system = Annual Electricity Consumption per household

* Retail Electricity Price

B=Net Bill with PV system = Net Cost of Buying Electricity from the Grid (BB) – Net Cost of Selling Electricity to the Grid (BS) dn= Nominal Discount Factor (%)

N= Lifetime of the solar system

C= Annual Household Electricity Consumption

3.5 Levelized Cost of Electricity

LCOE is a technique which aids in comparing a wide range of technologies plus different systems within the same technology range. LCOE includes accurate costs distributed over the entire lifetime of a system, unlike the simple 'cost per watt' calculations. Basically, LCOE is represented as shown in equation 3:

$$LCOE = \frac{\text{Total Life Cycle Cost}}{\text{Total Lifetime Energy Production}} \quad - (3)$$

Equation 3 can be mathematically defined as shown in equations 4 and 5:

$$TLCC = \sum_{t=0}^{N} \frac{Ct}{(1+d)t} \quad - (4)$$

$$LCOE * TLEP = \sum_{t=0}^{N} \frac{LCOE}{(1+d*)Qt_t} \quad - (5)$$

Where,

TLCC= Total Life Cycle Cost

TLEP= Total Lifetime Energy Production

LCOE= Levelized Cost of Electricity

Ct= Annual Cash Flow in year t

Qt= Energy generated by the system in kWh in year t d=

Annual discount factor (%)

N= Lifetime of the project

Equations 4 and 5 signal that the cash flow and energy for each is being discounted; this is the reason why LCOE is assumed to have a constant value over time (Walter Short, 1995).

3.6 Ghana's Grid Electricity Tariff

As of the time of concluding this thesis, Ghana's Public Utilities Regulatory Commission (PURC) had published a new single-year electricity tariff, listing rates to be charged end-use consumers, starting on 8th March, 2018. However, simulations were done in between the last quarter 2017 and February 2017, during which time the previous tariff shown in Table 3.2 was valid. Ghana's tariff structure for grid electricity to residential facilities (EUT Tariff category) as shown in Table 3.2 is what was used for the simulations.

Table 3.2: Ghana's Tariff Structure - Grid electricity to residential facilities

EUT TARIFF CATEGORY (Residential)	EFFECTIVE 14TH DECEMBER, 2015
0 - 50 (Exclusive)	33.5586 (GHp/kWh)
51 – 300	67.3273 (GHp/kWh)
301 – 600	87.3777 (GHp/kWh)
600+	97.0864 (GHp/kWh)
Service Charge	633.1717 (GHp/month)

Source: (Electricity Company of Ghana, 2016)

The load profiles being considered are mostly in the ‘high grid electricity consumer’ fields (301– 600 and 600+), and the service charge per month is 633.17 GHp. An average electricity tariff of 0.192 US cents (At a conversion rate of 1USD = 4.73 Ghc, retrieved from the Bank of Ghana on 30th August 2017) is used for residential customers (excluding lifeline customers)

An assessment of Grid-charged inverter-battery systems for domestic applications in Ghana (Quansah, et al., 2016) used Table 3.3.

Table 3.3: Electricity tariffs for residential consumers in Ghana

Residential consumption band (kWh)	GHp/kWh	UScent/kWh
0–50	33.56	8.84
51–300	67.33	17.74
301–600	87.38	23.02
601+	97.09	25.58
Average	71.34	18.79

Exchange rate of 1 USD=GHc 3.79 (11 Dec. 2015)

A comparison of the impact of the conversion rate used in Table 3.3 (1 USD=GHc 3.79) and that used in this thesis (1USD = 4.73 GHc) indicates how the exchange rates greatly affects the cost of energy and simulation results. For optimal results at all points, the most current inputs should be used to guarantee best outputs.

3.7 Basis for selection of households and their load profiles

The load profiles for this thesis focus on middle income and high-income households of Ghana, in particular, those situated in the urban areas of the country.

The selection of households in urban areas was based on numbers from the Ghana Living Standards Survey (GLSS6) as shown in Table 3.4. Table 3.4 shows that the mean annual income of a household in an urban locality is GHc 20,930.05. Ghana's urban households have a mean annual income of GHc 20,930.05, representing 69.2 percent of the total national income.

Table 3.4 Mean annual household income, per capita income and estimated total income by locality in Ghana

Locality	Mean annual household income (GHc)	Mean annual per capita income (GHc)	Estimated total annual income (Million GHc)	Percentage share of total income
Urban	**20,930.05**	**7,019.72**	**74,893.45**	**69.2**
Accra (GAMA)	17,023.71	5603.23	19,191.11	17.7
Other Urban	22,726.77	7671.23	55,702.34	51.4
Rural	**11,408.01**	**3,302.83**	**33,406.63**	**30.8**
Rural Coastal	11,351.13	3,681.58	4,381.49	4.1
Rural Forest	12,102.59	3,816.30	20,257.47	18.6
Rural Savannah	10,094.73	2,144.97	8,767.67	8.1
Ghana	**16,644.59**	**5,346.91**	**108,300.07**	**100**

(Ghana Statistical Services, 2017)

Baseline simulations for this thesis were done to include households with these specifications:

- Household is in an urban area
- At least one occupant in the household is gainfully employed and falls in the category of earning an average annual income of GHc 20,930.05 (average monthly income of about GHc 1,700) as per Table 3.1.

Some of these households already have diesel generators as a back-up to the grid. The load profile of each type of household determines the sizes and costs of SHSs and diesel generators to be used as an alternate source of energy. The classification of homes as either 'middle income' or 'high income' is assumed as per author's survey of some urban homes in Accra, Kumasi and Takoradi, their electricity bills and the electrical loads used.

3.8 Applications of Electricity from PV SHS

The study perceived that the application of solar energy at the household level is also widening to include the use of 16-inch Television set, medium-sized refrigerator and high-end cassette players (Table 3.5). However, a higher capacity panel would be more useful for other appliances like a refrigerator, irrigation pumps and for running enterprises like hair saloon, barbering shops and others. Table 3.5 presents a list of wattages (electricity consumption) for commonly used household appliances used among middle-income and high-income households, indicating the capacities of PV SHS currently in use. Whereas grid electricity is being used for all household energy needs, PV SHS was mostly applicable to appliances that require less than 100watts. Thus, appliances including high end refrigerators and electric irons are not often used with PV SHS (Table 3.5).

Table 3.5 :Type of Electric Appliances and Their Use

Appliance	Electricity use (watts)	Usage in Grid Electricity systems	Use in PV systems
15 watt Incandescent light bulb	15	Often	Often
Radio/cassette player	10	Often	Often
Mobile phone	5	Often	Often
Television	60	Often	Often
Electric Iron	1,500	Sometimes	Not applicable
Small size refrigerator	80	Often	Sometimes
Electric Cooker/stove	1,500	Sometimes	Not applicable

Source: Author (2017)

3.9 Solar Resource

HOMER accepts hourly or monthly solar radiation data. There are many sources of solar radiation data but the one used is imported directly by entering Ghana's GPS coordinates (7.9465° N, 1.0232° W) into HOMER, and NASA's Surface Solar Energy Data Set provides monthly average solar radiation data. HOMER uses the latitude value to calculate the average daily radiation from the clearness index and vice-versa, and the solar resource inputs are used to calculate the PV array power for each hour of the year. Ghana's irradiation map shows that the northern part of the country has a higher irradiation data than the southern part. Depending on the particular location of a prospective site for an SHS installation, the data used in this paper may vary.

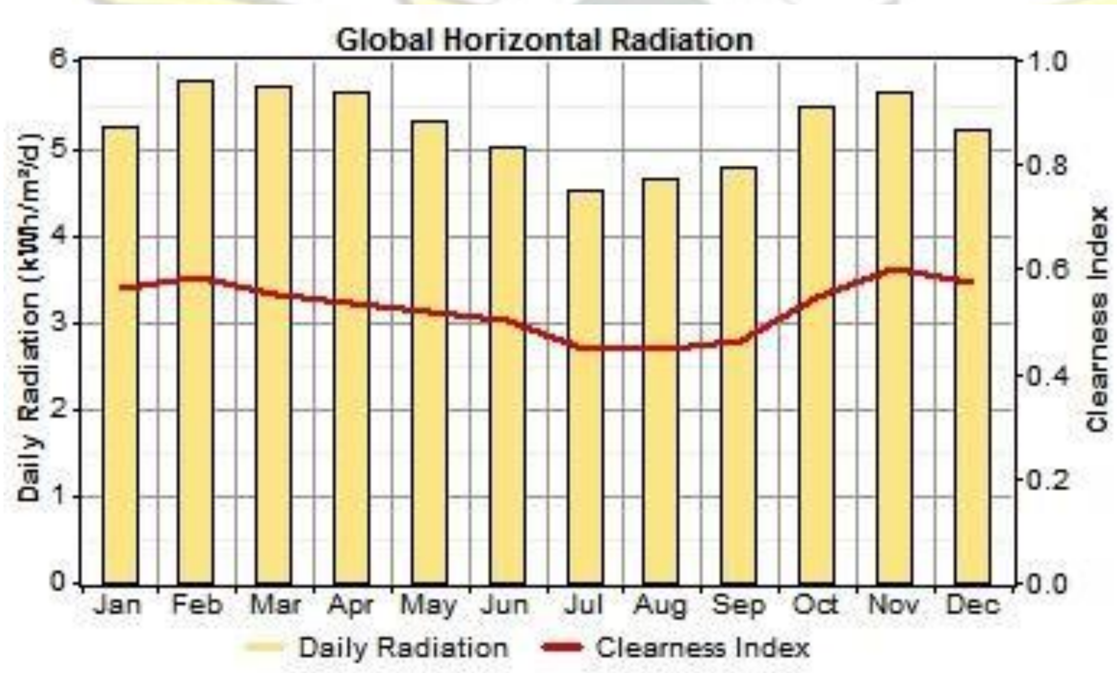


Figure 3.1- Graph of monthly solar radiation data of Accra, Ghana, and the clearness index as imported from HOMER

3.10 Technology cost data for components

Cost data inputs for solar PV modules, inverters, batteries and diesel generators are average figures based on a market data collection from selected installers and suppliers in Accra, Ghana, as of August 2017. Costs obtained were in GHc but needed to be converted to US dollars to enable usage in HOMER, at an exchange rate retrieved from the Bank of Ghana on 30th August 2017 (1 USD = 4.73 GHc). A conversion rate of 1USD = 4.73 GHc is used for this work. (Bank of Ghana, 2017) A 10% margin on component cost accounts was added to account for material and installation costs, based on an average margin author gathered from installers.

3.11 Diesel Price

As of 30th August 2018, one litre of diesel cost GHc 4.90 in Ghana, translating to USD 1.04 per litre based on the exchange rate of GHc/$4.73, while 29th May 2017 recorded diesel in Ghana costing GHc 3.84 per litre, translating to USD 0.89 per litre based on the exchange rate of GHc/$4.3 (Global Petrol Prices, 2017). This confirms, as shown in Figure 3.2, that the trend of diesel prices in Ghana over the past years has been on an increment level (2009-2015); the trend has not been any different from 2015 to 2018.

A margin of 1% (based on the least of the percentages mentioned by most fueldelivery companies) was added to the diesel price to account for delivery cost, making it USD 1.05 per litre.

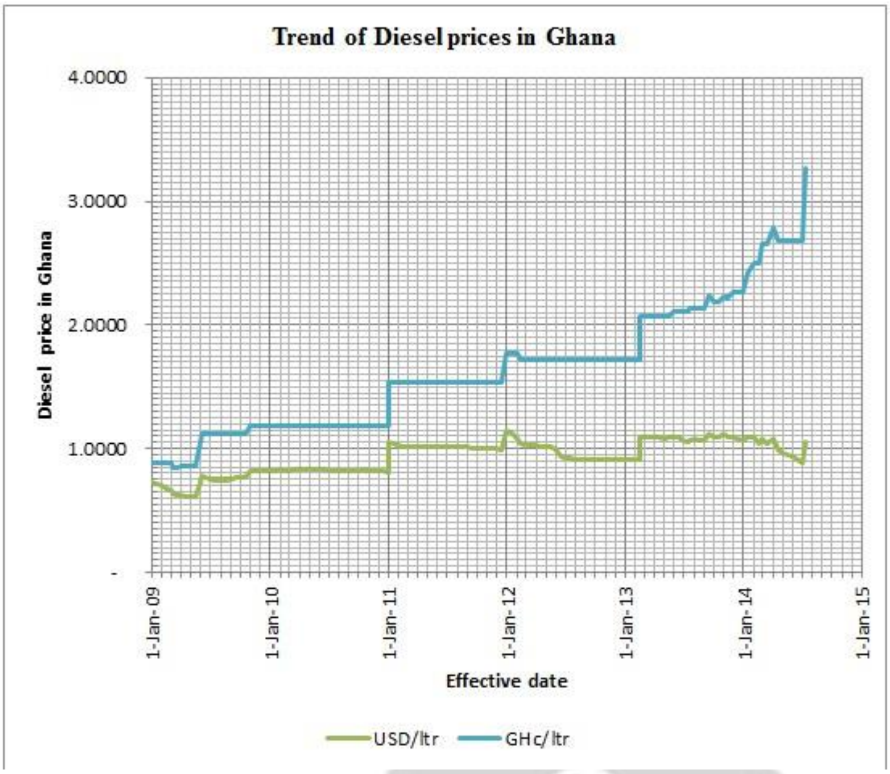


Figure 3.2: Trend of Diesel prices in Ghana from 2009 - 2015 (Woangbah, 2015)

Sensitivity analysis was considered for a 10% increase and decrease rate in cost of diesel.

3.12 Economics and constraints

The interest rate entered as HOMER's input is the annual real interest rate, a discount rate used to convert between one-time costs and annualized costs. The annual real interest rate is set at 8%. This definition of the interest rate factors inflation out of the economic analysis. All costs in HOMER, therefore, become real costs.

To allow HOMER to consider a system that has only a diesel generator, the minimum renewable fraction is set at 0%. Regarding emissions, it is assumed that there are no constraints.

3.13 Diesel Generator

Operation and maintenance (O&M) costs for diesel generators depend on the type and size of the generator. Diesel generators (DG) are serviced approximately every three months in Ghana, though the servicing depends largely on the number of hours the DG runs. Typically, first servicing happens after the first 50 hours and the next, after 200 hours of running the DG. Minimum load ratio of 30% is used based on average figure from DG suppliers. For example, Cummins Power Generation does not recommend running generator sets at less than 30 percent of rated load (Camelotech, 2017).

Table 3.6: Details of 5kVA, 10kVA and 20kVA Diesel Generators

Component	**Capacity**	**Initial cost (USD)**	**Replacement cost (USD)**	**O&M cost (USD/year)**	**Warranty**	**Life time**	**Noise Level of Diesel Generator**
Diesel generator	5kVA (4kW)	2,000	1,000	250	1 year/700 hours	15000 hours	79dBA @7 metres
	10kVA (8kW)	11,800	10,900	450	1 year/1500 hours	20000 hours	67dBA @7 metres
	20kVA (16kW)	13,900	13,000	570	1 year/1500 hours	20000 hours	67dBA @7 metres

3.14 Inverter (Converter)

The installation and replacement costs of the converter (inverter) are as displayed in Table 3.7. An efficiency of 95% is assumed. The operation and maintenance (O&M)

cost is taken as US $ 40 per year. The cost of charge controllers for the SHSs is incorporated in the inverter cost.

Table 3.7 : Capacities and prices of inverters

Supplier	**Capacity (W)**	**Price (GH₵)**	**USD**	**USD/Watt**
1	800	850	198	0.25
2	1000	1250	291	0.29
	1200	1400	326	0.27
	3000	3300	767	0.26
3	800	900	209	0.26
	1200	1380	321	0.27
	1500	1700	395	0.26
	2000	2200	512	0.26
4	1000	1400	326	0.33
	2000	2100	488	0.24
	3000	3500	814	0.27
	5000	5500	1,279	0.26
5	500	580	135	0.27
6	800	900	209	0.26
	1000	1280	298	0.30
	1200	1390	323	0.27
	1500	1640	381	0.25
	3000	3340	777	0.26
7	5000	5600	1,302	0.26
8	1200	1420	330	0.28
Average				**0.27**
Plus installation cost (5%)				**0.32**
Plus cost of Charge Controller (20%)				**0.52**

Source: Author

3.15 Energy Storage (Batteries)

Energy storage is needed for SHSs in the urban areas of Ghana because most potential clients need electrical energy at night, when the solar system is unable to convert solar radiation directly due to darkness. Battery and charge controller costs currently account for around a third of total SHS costs in Africa (International Renewable Energy Agency, 2016). The installation and replacement cost for the battery is estimated at USD2.35/Ah and USD 2 /Ah (see Table 3.8). Requiring very little or no maintenance at all, an assumed cost of USD 4 per battery per year is stated as cost of maintenance.

Table 3.8 : Capacities and prices of batteries for SHSs in Ghana

Supplier	Capacity (Ah)	Price (GH₵)	Price (USD)	USD/Ah
1	100	950	221	2.21
2	200	1800	419	2.09
3	100	970	226	2.26
	200	1920	447	2.23
4	100	990	230	2.30
	200	1760	409	2.05
5	100	1000	233	2.33
6	200	1855	431	2.16
7	100	970	226	2.26
8	200	1320	307	1.53
9	100	790	184	1.84
	200	1790	416	2.08
11	200	2000	465	2.33
	100	935	217	2.17
	200	1955	455	2.27
13	200	1800	419	2.09
14	100	980	228	2.28
15	200	1960	456	2.28
	100	899	209	2.09
Average cost				**2.15**
Plus Installation and accessories (20%)				**2.35**

Source: Author

3.16 PV Panels

PV module cost is an important component of the PV system initial cost. Since 1998, installed PV system prices have fallen by 6-7% per year on average (National Renewable Energy Laboratory, 2014).

Table 3.9: Solar PV Module sizes and prices

Suppliers	Module size (W)	Price (GH₵)	Price USD	USD/W
1	100	650	151	1.51
	150	860	200	1.33
	250	1100	256	1.02
2	100	550	128	1.28
	200	1200	279	1.40
3	100	630	147	1.47
	200	1050	244	1.22
	250	1300	302	1.21
4	250	1200	279	1.12
5	150	770	179	1.19
6	100	630	147	1.47
7	150	880	205	1.36
	200	1050	244	1.22
	250	1250	291	1.16
	300	1500	349	1.16
8	50	480	112	2.23
9	100	690	160	1.60
	150	842	196	1.31
10	200	1180	274	1.37
	250	1430	333	1.33
11	200	1120	260	1.30
12	50	280	65	1.30
Average price				**1.35 USD/W**
Plus installation (10%)				**1.45 USD/W**

Source: Author

A one kW PV system combined with 400Ah battery capacity is estimated to cost USD2390 with a replacement cost of USD2140 and an O&M cost of USD10 per year (for removing dust from the surface of the panels, and minimal maintenance of batteries).

Inputs in HOMER are summarized in Table 3.10.

Table 3.10 Author’s Input parameters for HOMER simulation

Parameter definition		Value	Remark/Reference
Battery life (years)		3	Based on average life given by installers and IRENA (IRENA, 2016)
Inverter (Converter) life (years)		10	Based on highest warranty period given by installers in Ghana
Solar PV module life (years)		25	Typical warranty period from manufacturers
Days of autonomy of battery		1	Authors’ assumption
Cost of electricity from grid, (USD/kWh)		0.20	Based on average published tariff for residential buildings
Unit installed cost of inverter (converter), (USD/W)		0.52	Based on market data. Charge controller cost is incorporated. Refer to Table 3.7
Unit installed cost of batteries, (USD/Ah)		2.35	Based on market data. Refer to Table 3.8
Discount rate, %		24%	(Bank of Ghana, 2017)
Array derating factor		80%	Authors’ assumption
PV module cost, (USD/W)		1.45	Based on market data. Refer to Table 3.9

Source: Author

3.17 SCENARIOS

The African Development Bank estimates that nearly one in five Ghanaians has a per capita daily consumption of between USD4 and USD20, which is in the bracket of lower or upper middle class by its definition (Riley, 2013).

The middle-income households in this paper have been placed in two categories; those at the lower end of that bracket and those at the higher end. Middle income (lower) – minimum of one distinct room in the household, spending

USD4 - USD20 daily. Examples of such units are described as a ‘chamber and all’ or as a single bedroom apartment. The load profiles being considered are mostly in the ‘high grid electricity consumer’ fields (301– 600 and 600+), and the service charge per month is 633.17 GHp. An average electricity tariff of

0.192 US cents is used for residential customers (excluding lifeline customers) Ref. Appendix 1: PURC tariff

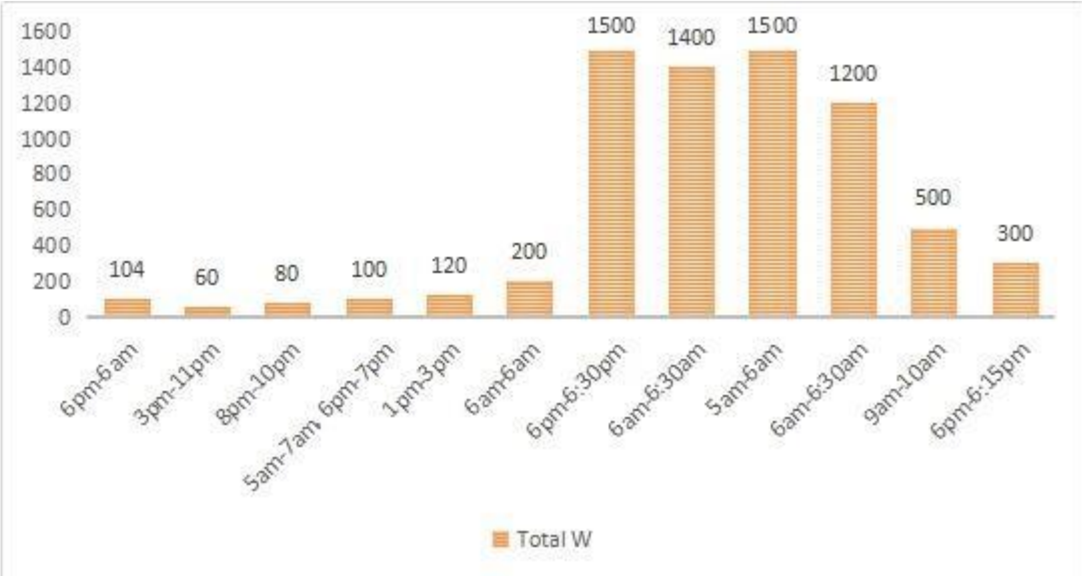


Figure 3.3 Graph showing load profile for a middle income household

Source: Author, (2017).

The results from data collected from middle and high-income urban homes that own diesel generators as a back-up to the national grid indicate that the most common sizes used are 5kVA, 10kVA and 20kVA. These sizes were also confirmed by vendors in the diesel generator space in Ghana; although there are still a few users who purchase used diesel generators that are below 5kVA in rating, the stated sizes would be considered for the purposes of this work.

Appliances and the duration of their usage for the base load are as shown in Table 3.11.

Table 3.11 Appliances and time of use for Base Load

No.	Components /Appliance	Watts	quantity	Time of Use	Total W	Total h	Total Wh
1	Television (CRT)	100	1	6pm-11pm	100	5	500
2	Radio	50	1	6pm-6am	50	12	600
3	Ceiling Fan	20	1	6pm-7am	20	13	260
4	Electric Iron	1000	1	5am-5:30am	1000	0.5	500
5	Lights	20	3	6pm-6am	60	12	720
6	Blender	300	1	6pm-6:15pm	300	0.25	75
7	Refrigerator	200	1	6am-6am	200	16	4800
8	Electric Kettle	1200	1	6am-6:15am	1200	0.25	300
	TOTAL				**2930**		**7755**
					2.93kW		7.76kWh

Table 3.11 shows an electrical load of 2.93kW and a daily electricity consumption of 7.76kWh. However, depending on the consumption behaviour of household occupants, the total electrical load for the appliances listed in Table 3.11 ranges from about 2kW to about 4.5kW, with electricity consumption ranging from about 6.1kWh to about 13.8kWh but for the purpose of this thesis, an electrical load of 3.3kW and a daily electricity consumption of 11kWh is used for the base case scenario (also enabling a comparison of a suited SHS with a 5kVA diesel generator). All systems are designed to run for twenty-four hours every day, for which reason the SHS options used need to have batteries to enable the PV systems to be functional during nosunshine periods.

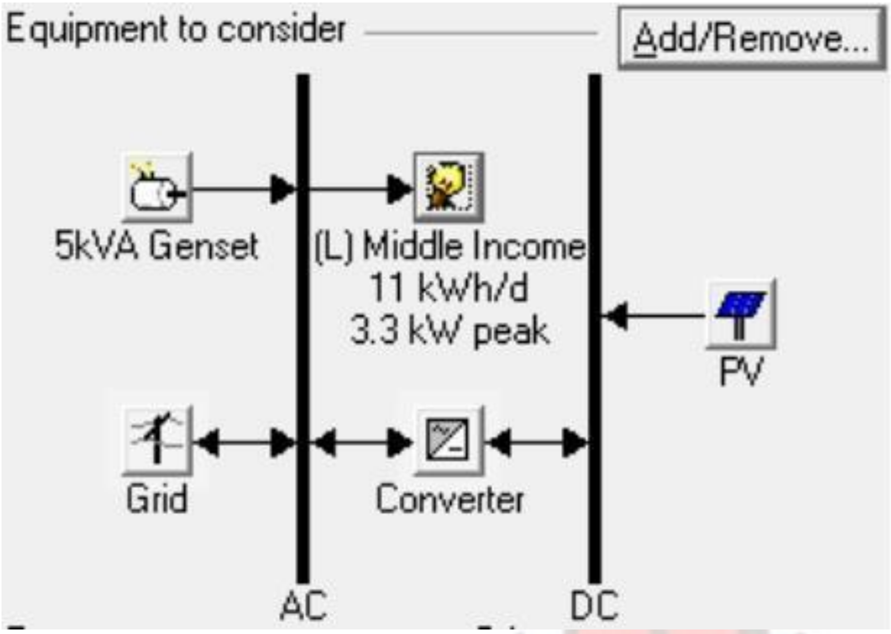


Figure 3.4: HOMER -extracted schematic diagram showing simulation components for the base load

The scenarios to be run are as follows:

Scenario 1: Base Case – Running the Base Load on one technology (Grid only, Diesel Generator Only and Solar PV Only)

Scenario 2: Running the Base Load on a hybrid system (Grid and Solar PV Combined)

Scenario 3: Running the Base Load on a hybrid system (Grid and Diesel Generator Combined)

CHAPTER FOUR: RESULTS AND DISCUSSION

This chapter presents the results and discusses the findings from the research based on the stated objectives of the study. In this chapter, the energy use patterns in urban households are characterized and the cost benefit analysis for solar energy use or Solar Home Systems (SHS) presented as observed in the study area. Lastly, it indicates the willingness and ability of middle-income and high-income households to pay for solar energy as well as the level of environmental alertness as indicators of the potential environmental significance of energy transition.

4.1 Scenario One: Base Case- only, PV only and Diesel Generator only

The Base Case Scenario considers costs of grid power for low- and middle-income households based on a particular demand over a month, projecting into the year.

The base case scenario run is of a middle-income household with an average electricity consumption of 11.5kWh/day and an average peak load of 3.3kW daily. The average peak load of a daily 3.3kW is being used for the simulation because that is the maximum applicable load (load acceptance) when running a 5kVA (4kW) diesel generator. Typical load acceptance on a diesel generator is in the range of 50-

80% (Well and Power, 2015).

Table 4.1: Scenario One Systems and Details

Name of scenario option (Label)	Scenario Configuration	Initial Capital ($)	Operating Cost ($/yr)	Cost of Energy ($/kWh)	Renewable Energy Fraction of System	Comments

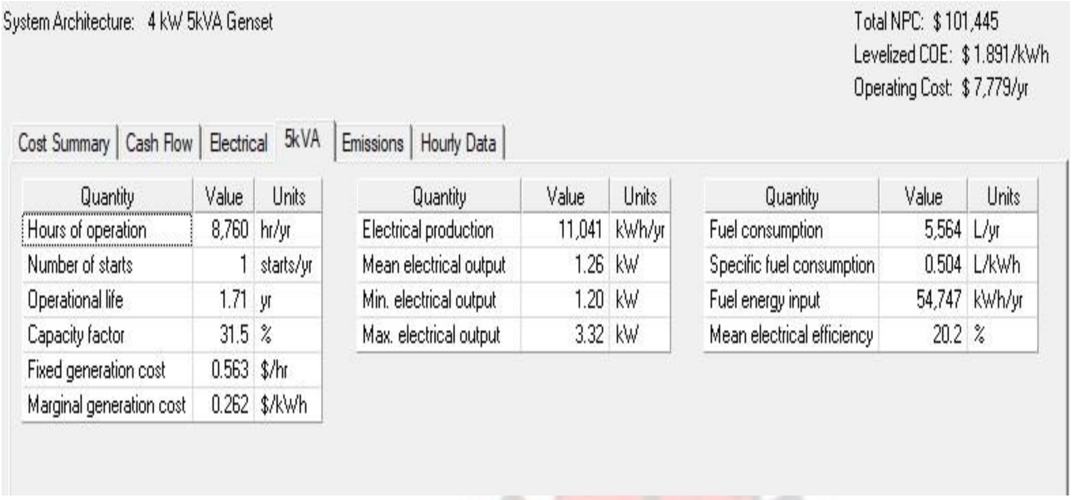
1A	Grid Only	0	839	0.200	0	Ghana's grid has a renewable energy component (hydro) which is not captured by HOMER in this simulation
1B	Diesel Generator only	2,000	7,779	1.891	0	5kVA diesel generator operates for 8,760 hours/yr with a fuel consumption of 5,564 litres of diesel/yr. Though this option does not apply for urban homes in Ghana, it is good to know the actual figures.
1C	Solar PV System only (SHS in a standalone mode)	8,324	396	0.25	1.0	System is not connected to the grid and consists of 12 100Ah batteries, a 4kW inverter, a 4kW solar PV array with all installation accessories. The solar system powers all the appliances.

Source: Author

Table 4.1 offers a grid-only system (1A) as the option with zero initial capital (excluding the initial ECG connection fee charged by ECG in Ghana), an operating cost of 839 USD/year and the least cost of energy (0.20 USD/kWh) for the base load.

Though the initial capital for scenario 1B ($2,000) is lower than that of scenario 1C ($8,324), the yearly operating cost of scenario 1B ($7,779) is about twenty times that of scenario 1C ($396). The COE of running the base load on scenario 1B (1.891

USD/kWh) amounts to nine times doing same on scenario 1A (0.20 USD/kWh), and seven times doing same on scenario 1C (0.25 USD/kWh).



System Architecture: 4 kW 5kVA Genset

Total NPC: $ 101,445
Levelized COE: $ 1.891/kWh
Operating Cost: $ 7,779/yr

Cost Summary | Cash Flow | Electrical | 5kVA | Emissions | Hourly Data

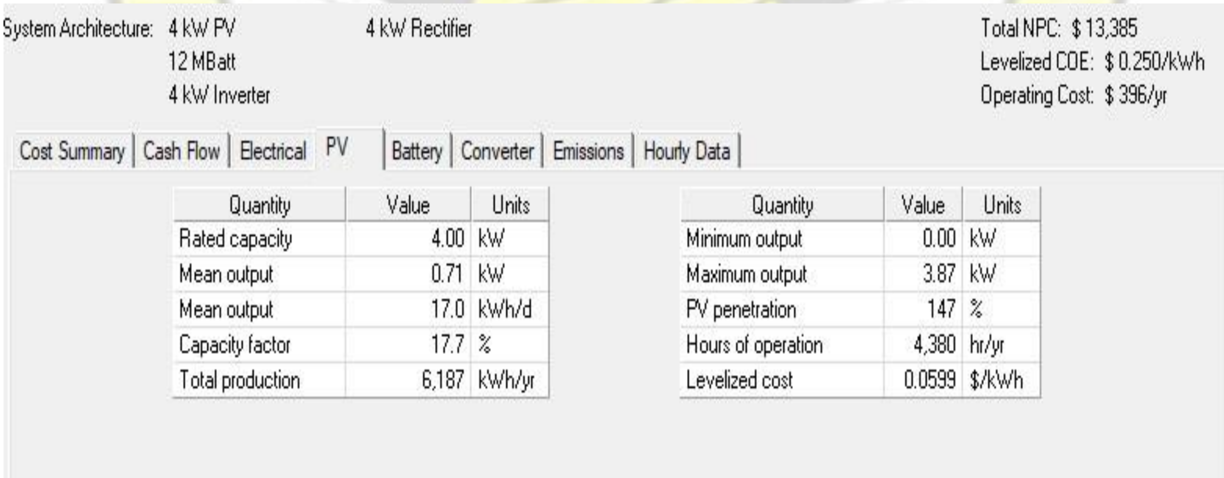
Quantity	Value	Units
Hours of operation	8,760	hr/yr
Number of starts	1	starts/yr
Operational life	1.71	yr
Capacity factor	31.5	%
Fixed generation cost	0.563	$/hr
Marginal generation cost	0.262	$/kWh

Quantity	Value	Units
Electrical production	11,041	kWh/yr
Mean electrical output	1.26	kW
Min. electrical output	1.20	kW
Max. electrical output	3.32	kW

Quantity	Value	Units
Fuel consumption	5,564	L/yr
Specific fuel consumption	0.504	L/kWh
Fuel energy input	54,747	kWh/yr
Mean electrical efficiency	20.2	%

Figure 4.1: Scenario 1B System architecture and details-Running the Base Load on Diesel Generator only

Figure 4.1 shows the system architecture and production details of running the base load on a 5kVA diesel generator only; scenario 1B. The fuel consumption of 5,564 L/yr. for scenario 1B also comes with a noise level of about 79dBA at seven meters and CO2 emissions to the environment.



System Architecture: 4 kW PV
12 MBatt
4 kW Inverter
4 kW Rectifier

Total NPC: $ 13,385
Levelized COE: $ 0.250/kWh
Operating Cost: $ 396/yr

Cost Summary | Cash Flow | Electrical | PV | Battery | Converter | Emissions | Hourly Data

Quantity	Value	Units
Rated capacity	4.00	kW
Mean output	0.71	kW
Mean output	17.0	kWh/d
Capacity factor	17.7	%
Total production	6,187	kWh/yr

Quantity	Value	Units
Minimum output	0.00	kW
Maximum output	3.87	kW
PV penetration	147	%
Hours of operation	4,380	hr/yr
Levelized cost	0.0599	$/kWh

Figure 4.2: Scenario 1C System architecture and PV details - Running the Base Load on Solar PV only (SHS in stand-alone mode)

To run the base load solely on solar PV (scenario 1C), 12 100Ah batteries (or 6 200Ah batteries), 4kW solar panels and a 4kW inverter are required, leading to a COE of USD0.25/kWh. Scenario 1C gives a picture of the investment involved to home users who consider going totally off the national grid, simulating from the base load point.

4.2 Scenario Two: Running the Base Load on a Hybrid System (Grid and Solar PV)

Scenario two looks at running the base load on a hybrid system which has the grid and various solar PV options. Table 4.2 outlines options for a Grid and SHS for the base load and brings out the following:

- Using an SHS together with the grid incorporates a renewable fraction to all systems
- Doubling the PV array decreases the yearly operating cost of the Grid and PV system and increases the renewable energy fraction of the entire system
- The combinations listed offer a cost of energy which is lower than or equal to 0.20$/kWh, which is the COE for an all-grid system as referred to in Table 4.1

Table 4.2: Scenario Two for base load - Grid + PV system options

Name of scenario option (Label)	System Architecture (Plus Grid)	Initial Capital ($)	Operating Cost ($/Yr)	COE ($/kWh)	Renewable Fraction
2A	0.5kW PV array + 2 100Ah Batteries + 1kW inverter	1, 332	665	0.183	0.16
2B	1kW PV array + 2 100Ah Batteries + 1kW inverter	1, 853	641	0.187	0.25
2C	0.5kW PV array + 4 100Ah Batteries + 1kW inverter	1,788	682	0.196	0.16

2D	0.5kW PV array + 2 100Ah Batteries + 2kW inverter	1, 687	723	0.204	0.16

Source: Author

4.3 Scenario Three: Running the Base Load on a Hybrid System (Grid and Diesel Generator)

Scenario three considers a hybrid system which consists of the national grid and a diesel generator. Table 4.3 outlines options for a Grid and Diesel Generator for the base load and shows how high the yearly operating cost and COE are as compared to PV options in Table 4.2. The combinations listed offer a cost of energy which is higher than 0.20$/kWh, which is the COE for an all-grid system as referred to in Table 4.1. Though options 3A and 3B look feasible, they are not viable because diesel generator manufacturers produce specific sizes which do not usually include 1kW and 2kW. Some vendors however sell 1kW and 2kW diesel generators, but these are mostly either slightly used or retrofitted machines. There are petrol generators that could be sized 2kW, but those would have different dynamics unrelated to this thesis paper.

Table 4.3: –Hybrid :Grid + Diesel Generator system options

Name of scenario option (Label)	System Architecture (Plus Grid)	Initial Capital	Operating Cost ($/Yr)	COE ($/kWh)	Electricity Production Breakdown
3A	1kW Diesel Generator	($) 500	1,173 (339 litres of fuel consumed to run DG for 2190 hours yearly)	0.289	16% of electricity production from DG, 84% Grid Purchases
3B	2kW Diesel Generator	1, 000	1,525 (679 litres of fuel consumed to run DG for 2190 hours yearly)	0.382	30% of electricity production from DG, 70% Grid Purchases

3C	4kW Diesel Generator (5kVA)	2, 000	2,266 (1,358 litres of fuel consumed to run DG for 2190 hours yearly)	0.577	51% of electricity production from DG, 49% Grid Purchases

Scenario 3A gives the lowest COE as far as a diesel generator and grid system is considered but the yearly operating cost for this option is more than double ($1173/yr.) the initial capital of USD500.

BEST- AND WORST-CASE SCENARIOS

The HOMER simulations run with various system combinations show that:

The worst option, making projections with the base case load, is scenario 1B where the diesel generator solely powers the electrical load. This option would only apply in the absence of the national grid, which is not the case for most of the middle-income urban homes being considered in Ghana. This option has the highest initial capital and the highest yearly operational cost.

With regards, to making an investment in a power-generating system to supplement the national grid, diesel generators provide very little or no benefits (Ref. Table 4.3). The COE in USD/kWh of scenarios 3A (0.289), 3B (0.382) and 3C (0.577) are all increasingly higher than what the national grid offers (0.20). The yearly operating costs of all diesel-related options (1B, 3A, 3B and 3C) are all more than USD1,000 and are dependent on the prices of diesel, which has shown an increasing trend in the past decade in Ghana (Ref. Figure 3.2).

The best option in terms of an investing in a supplementary electricity source, with the least initial capital ($1,332) is scenario 2A; consisting of a 0.5kW solar PV array, two

100Ah Batteries and a 1kW inverter. Option 2A gives the least COE of USD0.183/kWh, which is lower than what the national grid offers ($0.20/kWh) and provides a system that depends 84% on the national grid instead of the full 100% with a renewable fraction of 0.16. With 16% of a household's electricity consumption being provided by an SHS as illustrated in option 2A, the solar resource available in

Ghana, contributing to a sustainable and climate resilient power generation system.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter considers the conclusions and recommendations arising from the simulations and discussions done in this thesis paper. The overall objective of this thesis, to generate some numbers on exactly how much it costs on a life-cycle basis to own solar home systems designed to meet the needs of a typical Ghanaian home, shows that with an initial amount of USD1,000, a base SHS could be acquired. The general thinking is that solar systems are expensive, but using actual market numbers to analyse the cost of SHSs, and comparing that to costs of other available options shows otherwise, especially over a life-time period. Running a household solely

(considering the base load) on Ghana's national grid offers a yearly operating cost of USD839, translating to a monthly electricity bill of USD70 (about GHc 330) and a total NPC of USD10,732. Investing an initial amount of USD1,332 in an SHS for the same household offers a yearly operating cost of USD665, translating to a monthly electricity bill of USD55 (about GHc 260) and a total NPC of USD9,828. The difference between the total NPC of the grid-only system and that of the recommended SHS (i,e, USD10,732 - USD9, 828 = USD904) offers a payback period of about a year and a half on the initial investment (i.e. USD1,332/$904 = 1.47).

5.2 Conclusions

1. Stand-alone solar PV systems are more expensive, as compared to installing SHSs to complement the national grid (Ref. Option 1C in Table 4.1). This is so because the electrical demand at peak hours requires that a high capacity of solar system is installed, causing the excess generated electricity to go waste after the batteries are fully charged. The excess could be beneficial if the SHS is connected to the grid. Grid - connected PV systems in advanced countries usually function without battery storage because a continuous power flow is almost 100% guaranteed. A recommended solution in Ghana would be a grid-connected PV system which has some battery storage for periods after sunshine hours, and in the event of a break in the power flow from the national grid.

2. From the analysis, grid-complementary PV systems are reliable designs that should be promoted. The National Rooftop Solar Programme which was started in 2015 was brilliant and should be continued. Under such a national policy scheme, households are motivated to invest in SHSs, not only as a way to reduce their current electricity bills, but also to strengthen Ghana's national grid in a sustainable manner. Capital subsidy schemes from governments and other national organizations would go a long way to help build a climate-resilient power system.

3. In Ghana's urban locations where the national grid is present, a grid-only system is the best if an alternate source of electricity is not being considered.

Ghana's irradiation map shows that the northern part of the country has a higher irradiation data than the southern part. Accra is located in the south and this makes it have an average solar irradiation data of 5.08kwh/m2/day. This makes installing off grid solar systems at such areas require bigger sizes of panel in order to meet their demand.

4. Upfront investment & payback: Compared to a diesel generator, the upfront investment into a battery-assisted photovoltaic system could be same, lower or higher, depending on the configuration of the system and its usage. After the installation of a solar system, the monthly cost will drop to almost zero, as the energy from the sun is for free. While diesel generators require permanent fuel refill and have significant maintenance cost, a photovoltaic system runs smoothly for many years (about 20 years for the solar panels), with only a minimum cost of maintenance.

5.3 Recommendations

1. Change of consumption behaviour: The daily electricity production of a photovoltaic system starts at sunrise, reaching its peak at noon, gradually decreasing until sundown, at which time the batteries need to be fully charged to provide energy for the night. To avoid an oversized system, it is recommend to use large electrical consumers, like washing machines, preferably at midday when the energy yield is at its peak. Additionally, it is essential to gradually replace electrical devices by lowenergy devices and employ energy efficiency practices in buildings.

2. Contrary to an office building, where the bulk of energy is consumed during the day, a private household requires energy supply at night-time for typical electrical devices like fridge, TV, ceiling fans and light. As a consequence, a solar PV system needs to be designed in such a way, that it produces enough energy during daytime, so

that the surplus can be stored in batteries for overnight use. Furthermore, a system can be configured to automatically switch over to the national grid if the batteries should be empty.

3. As a recommendation, urban households in Ghana should be discouraged from using diesel generator systems as a second option to the national grid, especially because of the noise and air pollution associated with these systems. Beyond a client's ability to purchase a diesel generator for their home, national policies should include clauses that discourage such investments as Ghana's contribution to Goal 3 (Good health and well-being), Goal 11 (Sustainable Cities and Communities), Goal 12 (Responsible Consumption and Production) and Goal 13 (Climate Action) of the SDGs.

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Appendix 1

ANOINTED ELECTRICAL ENGINEERING SERVICES LTD.

The Genset Experts

24 Hour Service:
+233 (024) 348-0334

- Sales, Installation & Servicing of Generating Sets and Spare Parts
- Converting of Manual Key Start to Full Automatic Control System
- Automatic / Manual Synchronizing System
- Automatic Transfer Switches of all ranges
- General Electrical & Mechanical Services

Proforma Invoice

Name / Address
Mawunyo Addo Tema-Comm18

Validity	Proforma #	AS/PF/13121
7 Days	Date	04-Apr-2017
Issued By	Anthony (0243690295)	

Qty	Description	Unit Price	Total
1	5 kVA Diesel Generating Set powered by AEES7000T Engine SPECIFICATION Output voltage: 240 volts Output Power (kVA): 5 kVA Output Current (kW): 4.0 kW Phase: Single RPM: 3000 Frequency: 50Hz Output circuit breaker Noise Level: 79dBA @7 meters Warranty: 6 months or 700 hours from date of Commission whichever comes first. Warranty covers defective parts only and not service and repairs Void of Warranty: Refusal to allow A.E.E.S Ltd to undertake installation, servicing or maintenance during warranty period. Terms of Payment: 100% full payment or as agreed. Delivery period: Ex-stock After sales service: Anointed Electrical Engineering Services Ltd. THE ABOVE PRICE DOES NOT INCLUDE INSTALLATION COST.	7,234.04	7,234.04

Subtotal	GHC 7,234.04
VAT/NHIL (17.5%)	GHC 1,265.96
Total	GHC 8,500.00

Declaration: We declare that this Invoice shows the actual pri ce of the goods described and that all particulars are true and correct.

AEESL is exempted from 5% Witholding Tax

P.O. Box KN 5752, Kaneshie | Location: Anointed House, No. 77, Off Odorkor - Mallam Road

Appendix 2

PUBLIC UTILITIES REGULATORY COMMISSION (PURC)
PUBLICATION OF ELECTRICITY TARIFFS

In accordance with the statutory duty to publish rates approved by the Public Utilities Regulatory Commission under Section 19 of the Public Utilities Regulatory Commission Act 1997 (Act 538) ("the Act"), this publication is made this 26th day of March 2015.

1. The Volta River Authority (VRA) shall charge the rates provided in the First Schedule hereto referred to as "BGC VRA", as the Bulk Generation Charge with effect from 1st April 2015.

2. The rate provided in the First Schedule hereto referred to as "Composite BGC (VRA and IPPs)" is the weighted composite Bulk Generation Charges at which the Electricity Company of Ghana Limited (ECG) shall procure power from producers with effect from 1st April 2015.

3. The Ghana Grid Company Limited (GRIDCo) shall charge the rates provided in the Second Schedule hereto referred to as the Transmission Service Charge with effect from 1st April 2015.

4. The Electricity Company of Ghana Limited (ECG) and Northern Electricity Distribution Company Limited (NEDCo) shall charge the rates provided in the Third and Fourth Schedules hereto referred to as the Distribution Service Charge and End-User Tariffs with effect from the April 2015 billing cycle.

5. The rates are denominated in Ghana Pesewas.

6. These approved tariffs shall remain in force until they are changed by the Public Utilities Regulatory Commission.

7. Until the next major tariff review, electricity tariffs shall be adjusted as per the automatic adjustment (indexation) formula published in Gazette No. 15 of 25th February 2011.

8. The rates approved by the Public Utilities Regulatory Commission as published in the Gazette No. 15 of Friday, 13th February 2015 to take effect from 1st January 2015 are revoked and replaced with the following:

DEFINITIONS

BGC	Bulk Generation Charge
IPPs	Independent Power Producers
TSC	Transmission Service Charge
DSC	Distribution Service Charge
EUT	End User Tariff
SLT-LV	Special Load Tariff – Low Voltage
SLT-MV	Special Load Tariff – Medium Voltage
SLT-HV	Special Load Tariff – High Voltage
kWh	Kilowatt-Hour
kVA	Kilovolt Ampere

FIRST SCHEDULE

Tariff Category	Effective 1st April 2015
BGC VRA - (GHp/kWh)	14.6047
Composite BGC (VRA and IPPs) (GHp/kWh)	23.7408

SECOND SCHEDULE

Tariff Category	Effective 1st April 2015
TSC (GHp/kWh)	4.2958

THIRD SCHEDULE

Tariff Category	Effective 1st April 2015
DSC (GHp/kWh)	16.4575

FOURTH SCHEDULE

EUT Tariff Category	Effective April 2015, Billing Cycle	
Residential		
0-50 (Exclusive) (GHp/kWh)	21.0795	
51-300 (GHp/kWh)	42.2910	
301 – 600 (GHp/kWh)	54.8855	
601+ (GHp/kWh)	60.9839	
Service Charge (GHp/month)	397.7209	
Non-Residential		
0-300 (GHp/kWh)	60.7983	
301 – 600 (GHp/kWh)	64.6959	
601+ (GHp/kWh)	102.0817	
Service Charge (GHp/month)	662.8682	

Tariff Category	Effective April 2015, Billing Cycle	
SLT-LV		
Max. Demand (GHp/kVA/month)	3712.0621	
Energy Charge (GHp / kWh)	63.3702	
Service Charge (GHp / month)	2651.4729	
SLT-MV		
Max. Demand (GHp/kVA/month)	3181.7675	
Energy Charge (GHp / kWh)	49.0522	
Service Charge (GHp / month)	3712.0621	
SLT-HV		
Max. Demand (GHp/kVA/month)	3181.7675	
Energy Charge (GHp / kWh)	45.0750	
Service Charge (GHp / month)	3712.0621	
SLT-HV MINES		
Max. Demand (GHp/kVA/month)	3712.0621	
Energy Charge (GHp / kWh)	71.5898	
Service Charge (GHp / month)	3712.0621	

SIGNED

Samuel K. Sarpong, Executive Secretary
(for) Dr. Emmanuel K. Annan
Chairman, Public Utilities Regulatory Commission

PUBLIC UTILITIES REGULATORY COMMISSION (PURC)
PUBLICATION OF WATER TARIFFS

In accordance with the statutory duty to publish rates approved by the Public Utilities Regulatory Commission under Section 19 of the Public Utilities Regulatory Commission Act 1997 (Act 538) ("the Act"), this publication is made this 26th day of March 2015.

1. The applicable tariffs for Ghana Water Company Limited (GWCL) to take effect from 1st April 2015 are as provided in the Schedule.

2. The rates are denominated in Ghana Pesewas.

3. These approved tariffs shall remain in force until they are changed by the Public Utilities Regulatory Commission.

4. Until the next major tariff review, water tariffs shall be adjusted as per the automatic adjustment (indexation) formula published in Gazette No. 15 of 25th February 2011.

5. The rates approved by the Public Utilities Regulatory Commission as published in the Gazette to take effect from the July 2014 billing cycle are revoked and replaced with the following.

SCHEDULE

Category of Service		Monthly Consumption (1000 Litres)	Approved Rates in GHp/ 1000 Litres Effective April 2015 Billing Cycle
(a)	Metered Domestic	0-20	155.0718
		21 and above	232.4621
(b)	Commercial/Industrial	Flat Rate	331.4978
(c)	Public Institutions /Govt. Departments	Flat Rate	298.2120
(d)	Unmetered Premises-Flat rate per house per month		1009.3122
(e)	Premises without connection (Public stand pipes) per 1000 litres		153.3075
(f)	Special Commercial per 1000 litres		939.66.99

NOTE:

Special Commercial refers to bulk customers who use GWCL treated water as the main raw material for bottling water for resale.

SIGNED
Samuel K. Sarpong, Executive Secretary
(for) Dr. Emmanuel K. Annan
Chairman, Public Utilities Regulatory Commission

MR. STEPHEN AKUOKO	COMMISSIONER	SIGNED
MR. SAMUEL L. ADETOLA	COMMISSIONER	SIGNED
MR. DAVID AMETEFE	COMMISSIONER	SIGNED
MAJOR ALBERT DON-CHEBE (RTD.)	COMMISSIONER	SIGNED
MR. DANIEL OWUSU-KORANTENG	COMMISSIONER	SIGNED
DR. FERDINAND D. TAY	COMMISSIONER	SIGNED
MR. SAMUEL SARPONG	COMMISSIONER	SIGNED