THE POTENTIAL OF HYBRID SOLAR-WIND ELECTRICITY GENERATION IN GHANA

BY

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DECLARATION

This thesis is my original research work I carried out at the Department of Physics, University of Ghana, Legon under the supervision of the undersigned.

References made to other research works and publications are duly cited within the text.

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DEDICATION

To my caring wife and daughter Dorcas Atanga Apoka and Anne Aniweh Ayirewura respectively.

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The compilation of this thesis could not have been effectively and successfully done without the support of some dedicated people. I therefore wish to take this opportunity to thank some individuals who have contributed in diverse ways to making the work a success.

I am grateful to the living God for granting me his mercy and wisdom to complete this work successfully. Praised be the lord! Amen.

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ABSTRACT

In this work the potential of harnessing electricity from solar and wind sources in Ghana is evaluated both quantitatively and qualitatively. In this regard solar, wind and other relevant data were collected (over a period of one year) from various parts of Ghana. Detailed assessment of the capacity or potential of power production from hybrid solar-wind sources is done with the use of empirical mathematical formulae and the PRO VITUS model incorporated in the 'ENERGY X' software. The various characteristics of wind, solar and available energy resources for the five locations over a one year period have been studied too.

The annual mean wind speed at a height of 10 m above ground level for five locations namely Accra, Kumasi, Takoradi, Sunyani and Tamale are 2.38 $ms^{-1}\pm0.05$, 2.39 $ms^{-1}\pm0.05$, 2.38 $ms^{-1}\pm0.06$, 2.18 $ms^{-1}\pm0.05$ and 2.47 ±0.05 ms^{-1} respectively and their corresponding annual mean solar radiations are 228.71 $Wm^{-2}\pm9.81$, 187.69 $Wm^{-2}\pm9.60$, 236.58 $Wm^{-2}\pm10.39$, 200.99 $Wm^{-2}\pm9.88$ and 231.63 $Wm^{-2}\pm11.13$. Thus, the five sites hold potential for hybrid solar-wind energy exploitation.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AM	Air mass
AM0	Air mass 0
AWP	Available Wind Power
B.T.U	British Thermal Unit
ECG	Electricity Company of Ghana
EWP	Extractible Wind Power
GW	Gigawatt
GWh	Gigawatthour
GDP	Gross Domestic Product
Gmet	Ghana Meteorological Agency
H_o	Extraterrestrial Radiation
HOMER	Hybrid Optimization Model for Electric Renewables
HAWT	Horizontal Axis Wind Turbine
ISSER	Institute of Statistical, Social and Economic Research
kW	Kilo Watt
LCO	Light Crude Oil
LPG	Liquidified Petroleum Gas
MW	Mega Watt
PV/WT	Photovoltaic/Wind Turbine
PV	Photovoltaic
RPT	Renewable Energy Premium Tariff
RCEER	Resource Centre for Energy, Economics and Regulation
SNEP	Strategic National Energy Plan
TOE	Tonnes of Oil Equivalent

VALCO	Volta Aluminum Company
VAWT	Vertical Axis Wind Turbine
WECS	Wind Energy Conversion Systems
WT	Wind Turbine

CHAPTER ONE

INTRODUCTION

1.0 Overview

Energy is the mainstay of any industrial society. As the population of the world increases and people strive for a higher standard of living, the amount of energy necessary to sustain our society is ever increasing. At the same time, the availability of nonrenewable sources, particularly fossil fuels, is rapidly shrinking. Therefore, there is a general agreement that to avoid future energy crisis, the sources of energy needed to sustain society will have to be well-managed, as well as extended to include renewable sources. As a consequence, conservation techniques and renewable energy technologies are increasing in importance and reliability. However, reliable information about the availability, efficiency, and cost of renewable energy sources and systems, necessary for planning a secure and sustainable energy supply, is not readily available.[1]

The timing of this research coincides with a new impetus for the use of renewable energy being championed by many governments and policy-makers around the world. In Ghana, the Renewable Energy Act 2011, Act 832 seeks to encourage the use of renewable energy.[2] The renewable energy act requires that a percentage of energy generated and used be derived from renewable resources.

The core details of the Renewable Energy Act encourage renewable technologies and offer an opportunity for the energy industry to compete for the new markets. Thus, to be successful, renewable technologies will have to become more efficient and cost-effective. Although

Renewable energy policies are relatively new in development, they have somehow demonstrated that they can reduce market barriers and stimulate the development of the renewable energy industry. Use of conservation technologies and renewable energy sources can help meet critical national goals for fuel diversity, price stability, economic development, environmental protection, and energy security. They can thereby play a vital role in national socio-economic growth and development.

1.1 Motivation

The demand for energy and its dependent services to meet socio-economic development goals and to improve human welfare and health is increasing. All societies require energy services to meet basic human needs (e.g., lighting, cooking, space comfort, mobility and communication) and to power productive processes. Since global use of fossil fuels (coal, oil and gas) has increased drastically, dominating the world energy supply, it has consequently led to a rapid growth in carbon dioxide emissions into the atmosphere resulting in global warming. All fossil fuels produce significant amounts of carbon dioxide emissions during combustion.[1]

Until recently, there has not been much of a choice but to use the electricity provided by conventional methods. With advances in renewable energy technology and increased consumer awareness, however, solar electricity has now become a very feasible option. So, while one will be lowering the electric bill, one will also be helping to raise the air quality by using solar electricity. Coal-fired power plants are responsible for most of all sulfur dioxide emissions in the world yet they are still operating. Solar electricity produces absolutely no pollution yet very few solar plants are in operation. By using more solar electricity, fewer power plants that produce greenhouse gases would need to be built. Across the world, people are realizing the effects that our actions have on the environment and they are adopting solar to minimize CO_2 production.

Solar installations are done at a fixed cost, and savings increase as utility rates rise in the future. Essentially, one builds a hedge against future rate increases. Rising utility rates are definitely something one cannot avoid. When we switch to solar electricity, we help alleviate our dependence on foreign sources of energy. Solar electricity is used where it is made, so there are no transportation or delivery costs. The price stability of solar is also independent of the effects of natural disasters, wars and civil strife, foreign political instability or trade disputes. The supply chain extends simply from the sun to your roof-top or wherever you have installed your solar panel.

Given the strong correlation between low household incomes and use of low quality fuels, a major challenge is to reverse the pattern of inefficient biomass consumption by changing the present, often unsustainable, use of biomass to a more sustainable and efficient alternative such as hybrid solar-wind electricity. This would provide a more promising future to us especially the poor and the rural dwellers.

1.2 Objectives

The research objectives of this project include the following:

- To measure quantitatively and qualitatively the amount of solar and wind power that can be sourced from five selected locations in Ghana
- To extrapolate the total amount of power available from these local resources to give total power production capacity at district levels.

- To project the Solar-Wind power capacity or potential at national level
- To provide the scientific basis for investors and policy-makers to embark on Solar-Wind energy production.

1.3 World Energy Demand

The world primary energy demand showed a significant increase especially during the last half of the 20th century. In the table below we can see the world energy demand from each source for the last 30 years and the prediction for the next 30 years. [3]

From the table below one can observe that there is a rapid increase in the demand of energy, which during the last 30 years has almost doubled. For the next 30 years until 2030, is observed an increase in the use of renewable energy sources and a small but remarkable increase in the use of fossil fuels. An important role in recent years and especially for the years which are coming, in the world energy balance, is going to be played by nuclear energy. [3]

Table 1.1: World Primary Energy Demand (MTOE)[3]

Sources/Years	1971	2002	2010	2020	2030
Coal	1407	2389	2763	3193	3601
Oil	2413	3676	4308	5074	5766
Gas	892	2190	2703	3451	4130
Nuclear	29	692	778	776	764
Hydro	104	224	276	321	365
Biomass	687	1119	1264	1428	1605
Other Renewables	4	55	101	162	256
Total	5536	10345	12194	14404	16487

Fossil fuels are estimated to cover up to 85% of consumed energy in the developed countries by 2030 and 55% of consumed energy in the developing countries.

For fossil fuels, demand will reach 16.5 MTOE compared to 10.3 MTOE demand that was in 2002. In the developed countries there is a tendency of reduction in the use of fossil fuels and particularly of oil, with a gradual infiltration of renewable sources of energy. This would be a very good first step in an effort to reduce over dependence on fossil fuels. However the share of renewable energy sources will remain flat, at around 14%, while that of nuclear will drop from 7% to 5% for a while. It is estimated that the existing reserves of fossil fuel sources will suffice for the next, 200 years for coal, 60 years for natural gas and 50 years for oil.[3]

These deadlines show the cruel reality of what is going to happen to our world in the next decades. This remarkable decrease of fossil fuels reserves around the globe creates political and economic tensions. In fact, many wars have already started in the Middle East (e.g. Iraq and Kuwait) and in these countries, every day ordinary people pay sometimes with their own lives, the price for the ***black gold***. On the other hand, each coin has both head and tail sides. Thus, there are alternative predictions for a more sustainable growth in the world. This can become reality only if humanity makes a switch in covering their electricity demands by using renewable sources.[3]

1.4 Energy Demand in Ghana

It is estimated that no more than 20 percent, and in some countries as little as 5 percent, of the population in Africa (excluding South Africa and Egypt) have direct access to electricity. This figure falls to 2 percent in rural areas. Demand is expected to grow by about 5 percent annually over the next 20 years. It is critical, experts say, for Africa to build facilities to provide power to those lacking it, especially in the rural areas where the majority of Africans live. Infrastructural development is not merely about erecting giant structures, but also providing vital services, such as power, to increase commerce, business productivity and enhanced quality of lives of poor families by giving them affordable energy for cooking, lighting, and entertainment.[4]

The total number of households in Ghana was about 4 million in 2000 and is expected to reach between 5 – 6 million by 2020. Urbanisation is expected to increase from the 40 percent in 2000 to about 55 percent in 2015 and eventually 60 percent by 2020. A little more than a third of the urban population lives in Greater Accra and is expected to reach around 40 percent by 2020. About 50 percent of the rural households are found in the forest zone and this is not expected to change significantly by 2020.[5]

Over 90 percent of rural households depend on wood fuel for cooking. Charcoal on the other hand is the dominant cooking fuel used in the urban areas. About 61 percent of urban households use charcoal as their main fuel for cooking. [5]

Energy for lighting purposes is obtained from two sources, kerosene and electricity. About 52 percent of the population use kerosene for lighting. Kerosene is used mainly in rural areas with 82 percent of rural population depending on it for lighting. Nevertheless, its use is associated with high levels of indoor air pollution. Electricity, a high quality lighting source on the other hand, is used extensively in the urban areas of the country where the higher and middle-income groups are the major consumers. About 48 percent of households in the country use electricity for lighting and other purposes in the country. Urban households accounted for 88 percent of electricity usage, whilst rural households accounted for the remaining 12 percent. All the regional capitals have been connected to the national grid. In 2000, the electricity usage in the rural areas was estimated to be higher in the coastal (27 percent) and forest (19 percent) ecological zones, than in the savannah (4.3 percent) areas of the country.[6]

The Industrial sector, especially the Manufacturing sub-sector, is expected to lead in the rapid socio-economic transformation of the Ghanaian economy from that of a low-income to that of a middle-income country by 2015. The industry's share in the GDP formation is projected to increase from about 25 percent in 2000, to 30 percent by 2015; and 32 percent by 2020 under the expected sectoral average growth rate of about 9 percent every year.[6]

The Industrial sector without VALCO had 21-22 percent of total national energy share every year since 2000. With VALCO, the industrial sector of the total energy share increased slightly to about 23 percent per annum. VALCO accounted for 16-17 percent of the industrial energy share until 2003 when its share fell to less than 2 percent due to suspended smelter operations. In terms of electricity however, VALCO accounted for 50 – 60 percent, manufacturing subsector's share was about 14 percent, whilst the mining & quarrying subsector increased its shares to 22 – 23 percent per annum. [6]

Manufacturing had been the dominant subsector accounting for about 74 percent of industrial energy share since 2000, followed by Mining and quarrying (9-10 percent). Utilities had been taking just about one to one and half percent, whilst Construction has accounted for less than one percent of energy share per annum.[6]

The Commercial and Services Sector also referred to as the tertiary sector is regarded as the facilitator of economic growth. It has been the fastest growing sector of the economy over the past decade and continues to increase its share in the nation's gross domestic product (GDP). Sectoral share in the GDP and the annual growth rate between 2000 and 2004 have averaged 32.1 percent and 5.0 percent respectively. The Information Communication Technology (ICT) subsector is one of the three main targets identified by the government to drive the GPRS high economic growth.[6] Most of the energy used in this sector had come from wood fuels (over 65 percent in 2000). Electricity follows with about 30 percent share, and then petroleum products, about 9 percent share. Electricity demand in the Commercial & Service sector could exceed 1,500 GWh by 2008, 3000 GWh in 2015 and reach about 4,000 GWh by 2020.[6]

The existing installed electricity generating capacity of 1,760 Megawatt would have to be at least doubled by 2020 should the nation be assured of secure electricity supply. The total energy demand would grow from 6.2 million TOE in 2000 to about 22 million TOE by 2020.[6] This is shown by the figure below.

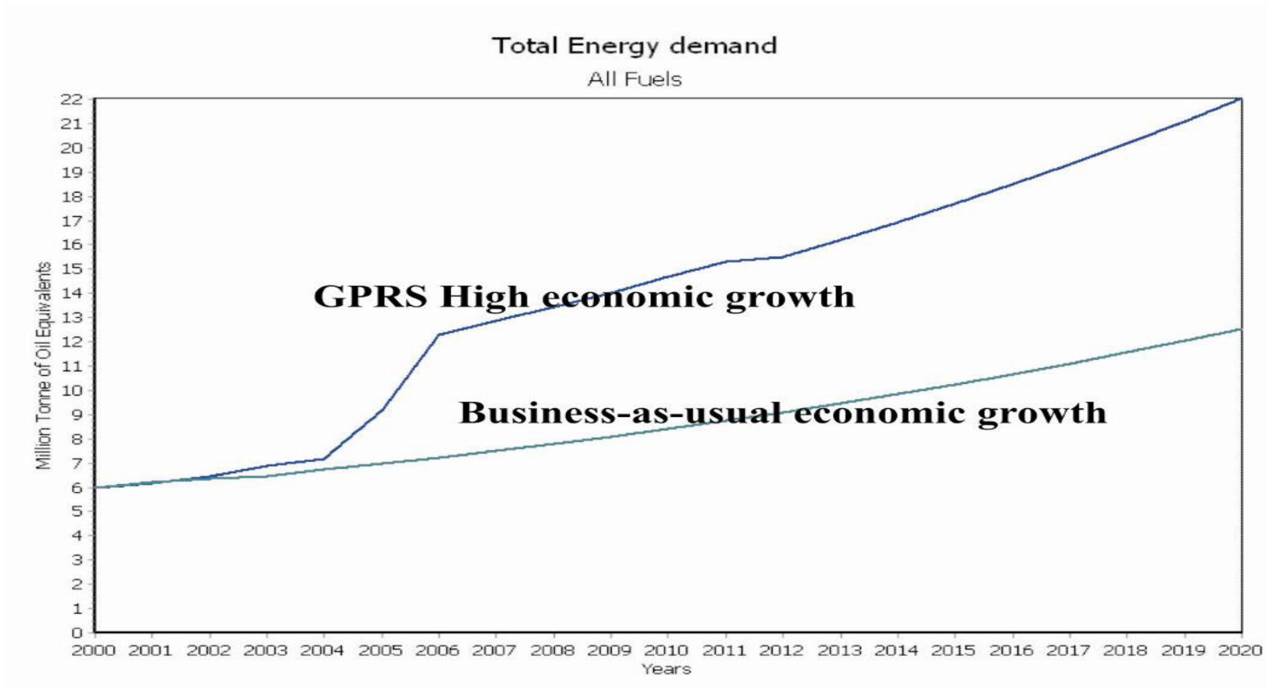


Fig. 1.1 Total Energy Demand of Ghana.[6]

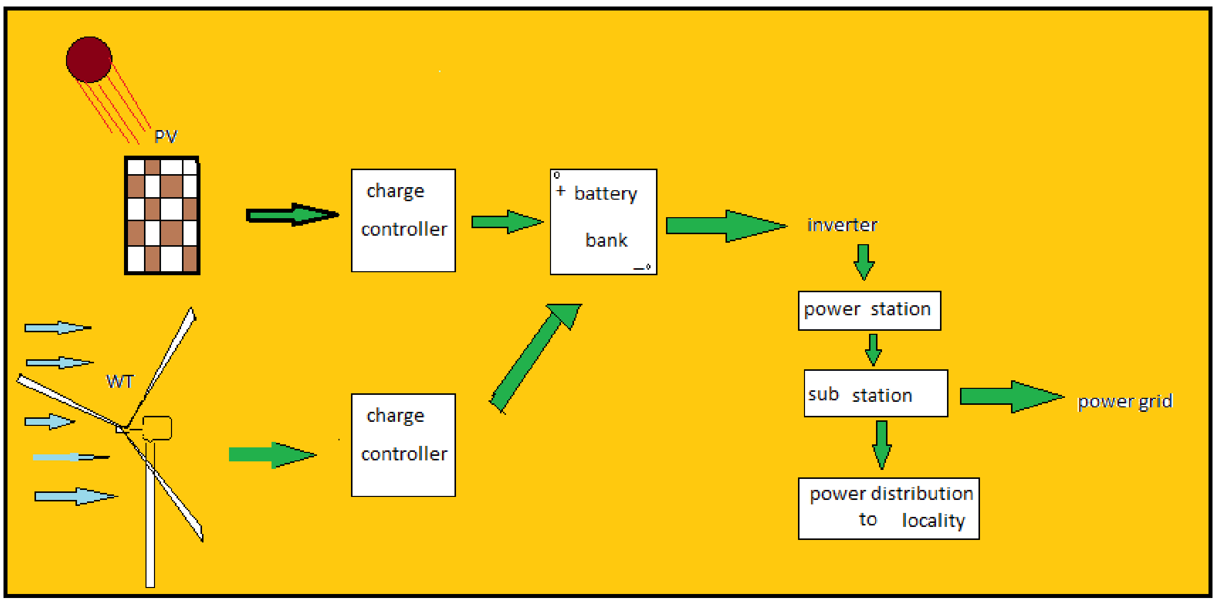
1.5 The need for a Hybrid System

Ghana is endowed with enormous solar energy resource spread across the entire country. Daily solar irradiation level ranges from 4 $kWhm^{-2}$ to 6 $kWhm^{-2}$. Areas of highest irradiation levels are spread across the entire northern belt which represents over 60% of the total national land mass. The annual sunshine duration ranges between 1800 hours to 3000 hours, (an average of 10 hours of daily sunshine) offering very high potential for grid connected and off-grid applications.[2]

The development of wind energy resource for commercial power generation in Ghana is steadily taking centre stage of national discourse. Preliminary wind resource assessments results in selected sites along the coasts and high elevations showed moderate to excellent wind potentials especially, those along the east coastlines.[2]

In recent years, hybrid technology has developed and upgraded its role in renewable energy sources while the benefits it produces for autonomous power production are unchallenged. Nowadays many houses in rural and urban areas use hybrid systems. Many isolated islands try to adopt this kind of technology because of the benefits which can be received in comparison with a single renewable system. The system used in this project is based on a wind turbine (which produces DC power) and PV panels; its function is depicted by the diagram below.

Fig.1.2: Operation diagram of a Hybrid System PV/WT



This specific hybrid system presents many benefits. More specifically for a wind/solar hybrid system the assessment is focused on the wind and solar potential of the region. Therefore it can be operated during the day using the energy from the sun and after the sun has set it can utilise the potential wind energy to continue its function. For this reason, wind and solar systems work well together in a hybrid system and they provide a more consistent year-round output than either wind-only or PV-only systems. Moreover with the use of the appropriate auxiliary systems like batteries you can store energy which will be useful in compensating electrical demands used by the building for periods where there is no sun or wind. Finally, it is economically sound and advantageous to use non finite resources, i.e. solar and wind (hybrid). The investment financially and environmentally in modern technologies will win through the generations to come in the fight for energy efficiency and effectiveness.[7]

1.6 Literature Review

This section will focus on existing work that has been done regarding the renewable energy sources and applications in Africa and the world as well as papers that assess the feasibility of solar and wind production possibilities.

In particular, documents from the Energy Commission of Ghana such as the Strategic National Energy Plan[6] and National Energy Statistics[8] which comprehensively looked at the available energy sources and resources of the country and how to tap them economically and on time to ensure a secured and adequate energy supply for sustainable economic growth now and into the future. It also assesses the renewable energy potential in Ghana to serve as a starting point for determining where the major potential wind sites are and what the proposed projects are that might utilize these sites. Other papers from these state agencies and their consultants , especially The Institute Of Statistical, Social and Economic Research, were also useful in providing background information regarding policy and regulatory plans for promoting the use of renewable resources, however these papers were the most heavily used.

With regards to assessments of solar-wind scenarios, several papers have been written and models developed which examine this topic. A feasibility study of wind energy utilization along the coast of Ghana was carried out by Francis Nkrumah.[9] The main objective of his work was to assess wind energy potential of four selected coastal sites in Ghana using data from the Energy Commission. The four locations were Aplaku, Mankoadze, Warabeba and Oshiyie located along the coast of Ghana. Characteristics of wind regimes and availability of wind energy resources for the four locations were studied. Statistical analysis of the wind speeds measured at 12m above ground level involving fitting of observed cumulative distribution to Weibull function, determination of the Weibull parameters and evaluation of wind power density using JMP statistical package were carried out. The potential of wind power in the coastal sites was further investigated by determining the frequency, wind direction and velocity over one year period using wind data measured at ten minutes interval. The velocity duration curves for the four selected sites were drawn and the power outputs and levelised production cost were estimated for the four selected wind turbines using Wind Power Calculator and Wind Economic Calculator provided by Danish Wind Power Manufacturers Association available at www.windpower.dk.[9] The annual mean wind speed at a height of 12 m above ground level for the four locations namely Aplaku, Mankoadze, Warabeba and Oshiyie were found to be 4.75ms^{-1}, 4.51ms^{-1}, 4.0ms^{-1} and 3.88ms^{-1} respectively and the corresponding annual wind power densities are 103.91Wm^{-2}, 97.78Wm^{-2}, 60.78Wm^{-2} and 77.98Wm^{-2}. The estimated levelised production cost of electricity for the four selected turbines ranges between 6.08-7.32 for Aplaku, 6.6-8.0 for Mankoadze, 8.3-9.9 for Warabeba and 11.0-12.5 cents/kWh for Oshiyie.[9]

In terms of large scale assessments in Africa, Bekele and Palm[10] provides a view at supplying electric energy from solar-wind hybrid resources to remotely located communities detached from the main grid line in Ethiopia. Based on these potentials, a feasibility study for a standalone electric power supply system for a model community of 200 families in a village was conducted. In determining the wind energy potential, a piece of software (HOMER) was used as an aid for the study. From the results, the wind energy potential of one of the sites, Debrezeit, is considerably lower than the other three locations. However, it was concluded that, generallyspeaking, although the potential may not be sufficient for a large, independent wind energy farm, the analysis has shown that wind energy may in some cases be a viable option if integrated into other energy conversion systems such as PV, diesel generator and battery whiles demonstrating the availability of extensive utilisable solar energy at each location. The feasibility study was based on the findings of the wind and solar energy potentials at the particular locations. With the potentials determined, three different approaches were followed in the hybrid system design. In the first approach, system components that were commonly available were included in the design without much regard to their efficiencies. In the second approach, with a thorough market-survey the best technologies available were compared and those with the highest efficiency were selected. A third approach followed to see if cost is minimized by considering a self contained system, i.e., every household having its own supply system. The results obtained in the second approach showed that the net present cost is less than 50 % of that for the first approach. The third approach is found to be of a higher cost.[10] This system under research is for district level implementation where smaller system components will used to reduce cost effect.

Another African based study assessed in the literature survey was the modeling of Wind-diesel-battery hybrid system in north Cameroon by Nfah and Ngundam[11]. The objective of the study was to provide electricity for households and schools in remote areas of Cameroon from Wind-Diesel-Battery hybrid power system. The wind resource used is of the period 1991–1995 and the diurnal pattern is in the range of 3–6 m/s from 9:00 to 15:00 for eight months. In the study it has been found that two wind turbines with power rating of 180 W and 290W were enough for the hybrid system for typical rural households' energy needs in the range 0f 70–300 kWh per year. Another combination consisting of two wind turbines rated as 290W and a 5 kW single phase generator requiring only 106 generator hours per year has been found to supply 2585 kWh per year or 7 kWh per day load to a typical secondary school. [11]

Looking at a bigger picture, issues surrounding the production of energy from renewable energy resources globally, a study done by Iakovos Tzanakis[7] is based on the combined use of solar and wind energy, in the hope to discover and determine to what extent the energy produced is capable of satisfying the energy demands of a building. His analysis took place in two different locations, in Dalmarnock (nearby Glasgow), Scotland and Heraklion, a Greek city on the island of Crete. The buildings used in both cases were a typical three-bedroom domestic building. In addition, the same type of photovoltaics and ducted wind turbines were used for both analyses.

The weather data he used in the two cases were obviously not identical. The weather data for Glasgow was already installed in "Merit", the programme used for the analysis, while for Heraklion the data had to be collected from several research centres in Crete. In addition, the energy demands of the building in Glasgow were already inputted in the programme while for Crete, once again, the demands were collected from local research centres.

The ability of the systems to match consumer demand, with varying amounts of energy storage capacity included, was assessed using the "Merit" software. It was assumed that any energy deficits would be made up by purchase of electricity from the national grid. For each site, two promising system configurations were identified and subjected to an economic analysis, making the appropriate assumptions for levels of subsidy, maintenance costs and interest rates for repayments.[7]

He suggested in his work that none of the renewable energy installations could then not be justified on economic grounds, compared to the alternative of simply purchasing electricity from the grid. Changes in electricity prices, subsidy levels or costs for renewable energy equipment might alter the position in the future. [7]

The study conducted by Ghassan[12] also examines this subject critically. The paper presents the electrical power generation using solar and wind energy for the country of Jordan. It is found that the cost of windmill farm to produce 100-150 MW costs $290 million, while the solar power station to produce 100MW costs $560. The electrical power production costs per kWh are 2 cents for the wind and 7.7 cents for the solar. The feasibility for using wind energy is now, solar energy when price of oil reaches $100 per barrel. The paper also discusses different control methods to link with the national grid.[12]

Another paper that reviewed the current state of the simulation, optimization and control technologies for the stand-alone hybrid solar–wind energy systems with battery storage was carried out by Wei Zhou et al[13]. It was found that continued research and development effort in this area is still needed for improving the systems' performance, establishing techniques for accurately predicting their output and reliably integrating them with other renewable or conventional power generation sources.[13]

The work of Deepti Ranjan et al[14] was also useful to this work. The aim of this study was to introduce the local PV-wind hybrid system working principle by reviewing one case where the system is connected to the grid. He concluded that the construction of a complete hybrid power system may be too expensive and too labour-intensive for many Industrial Technology Departments. However, many of the associated benefits could be obtained from using some components of the system, for example a PV panel, invertors, batteries and a DC motor.[14]

CHAPTER TWO

THEORY

2.0 Introduction

This chapter begins with the sun as a source of energy, the determination of total global irradiance from solar radiation data, with the utilization of empirical formulas derived from different authors. Discussions are made regarding the basic background theory for the determination of the wind energy potential. This includes sources of wind energy, the energy in the wind, and the energy output of a wind turbine, how to measure wind speed and extrapolate to a higher height.

2.1 Basic Theory of Solar Energy

To a good approximation the sun acts as a perfect emitter of black body radiation at a temperature close to 5800k. The resulting (average) energy flux incident on a unit area perpendicular to the beam outside Earth's atmosphere is known as the solar constant of value 1367 Wm^{-2}. When the solar radiation enters the earth's atmosphere, a part of the incident energy is removed through scattering or absorption by air molecules, clouds and particulate matter usually referred to as aerosols. The radiation that is not reflected or scattered and reaches the surface directly in line from the solar disc is called direct or beam radiation whereas the scattered radiation which reaches the ground is called diffuse radiation. Some of the radiation may reach a receiver after reflection from the ground, and is called the albedo. The total radiation consisting of these three components is called global radiation. [15, 16]

The amount of radiation that reaches the ground is, of course, extremely variable. In addition to the regular daily and yearly variation due to the apparent motion of the sun, irregular variations are caused by the climatic conditions (cloud cover), as well as by the general composition of the atmosphere. For this reason, the design of a photovoltaic system relies on the input of measured data close to the site of the installation. [15, 16]

A concept which characterizes the effect of unclear atmosphere on sunlight is the air mass. This is a measure of the relative length of the direct beam path through the atmosphere, and it is dimensionless. On a clear summer day at sea level, the radiation from the sun at zenith corresponds to air mass 1. At other times, the air mass is given by:

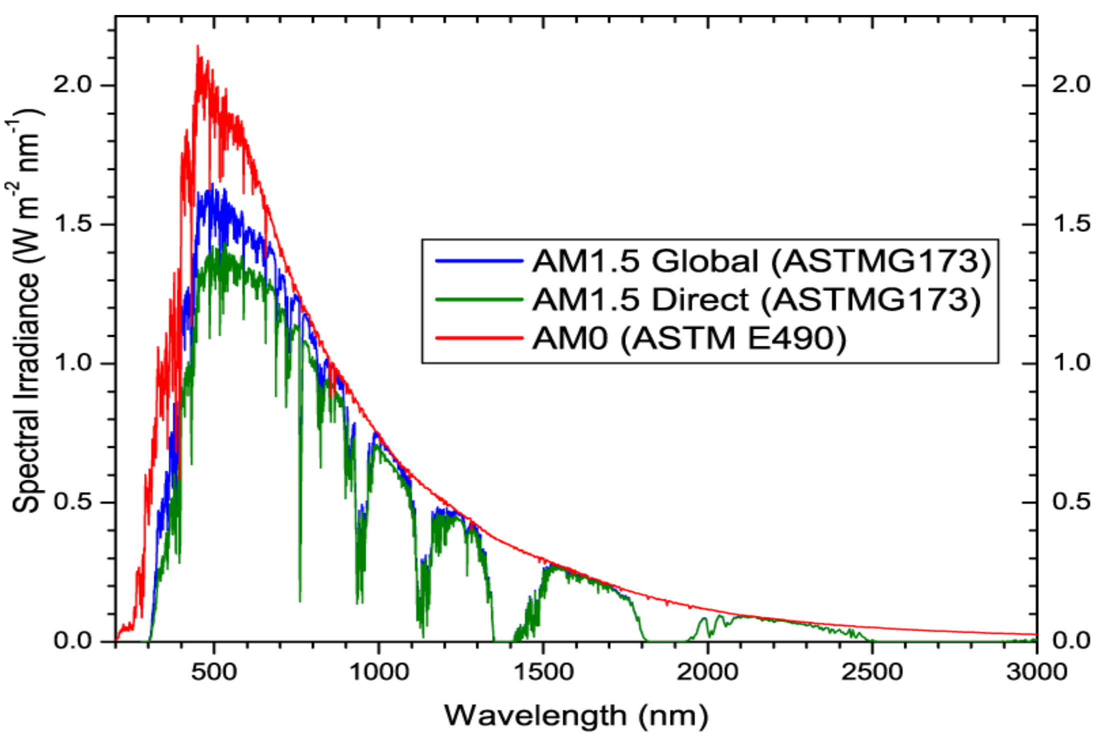
$$AM = \frac{1}{\cos\theta} \qquad (2.1)$$

Where AM is air mass and θ is zenith angle. [17, 18]

The effect of the atmosphere (as expressed by the air mass) on the solar spectrum is shown in Fig. 2.1. The extraterrestrial spectrum, denoted by AM0, is important for satellite applications of solar cells. On a clear day with solar irradiance of 1.0 kWm^{-2} the air mass is typically 1.5. This is the standard used for the calibration of solar cells and modules. Also shown in the figure are the principal absorption bands of the air molecules. [17]

Although the global irradiance can be as high 1 kWm^{-2}, the available irradiance is usually considerably less than this maximum value because of the rotation of the Earth and adverse weather conditions. [18]

Fig. 2.1 The Solar Spectrum



2.2 Radiation on an inclined surface

The solar radiation data, when available, are frequently given in the form of global radiation on a horizontal surface at the site. Since PV panels are usually positioned at an angle to the horizontal plane, the energy input to the system must be calculated from the data. [17]

The calculation proceeds in three steps. In the first step, the data for the site are used to determine the separate diffuse and beam contributions to the global irradiation on the horizontal plane. This is done by using the extraterrestrial daily irradiation H_o as a reference, and calculating the ratio

$$K_T = \frac{G}{H_o} \ldots\ldots\ldots\ldots (2.2)$$

known as the clearness index. K_T indicates the (average) attenuation of solar radiation by the atmosphere at a given site during a given month and G is the global radiation on a horizontal plane. In the evaluation of H_o, the variation of the extraterrestrial irradiance on account of the eccentricity of the Earth's orbit (approximately$\pm$ 3%) is usually also taken into account. [18]

In the second step, the diffuse radiation is obtained using the empirical rule that the diffuse fraction D/G of the global radiation is a universal function of the clearness index K_T and the diffuse radiation on a horizontal D. Since

$$H = G - D \ldots\ldots\ldots\ldots\ldots..(2.3)$$

this procedure determines both the diffuse and beam irradiation on the horizontal plane.

In the third step, the appropriate angular dependences of each component are used to determine the diffuse and beam irradiation on the inclined surface. With allowance for the reflectivity of the surrounding area, the albedo can also be determined. The total daily irradiation on the inclined surface is then obtained by adding the three contributions. [18]

The relation H_o received, over one day, by a unit horizontal area outside the Earth's atmosphere is calculated using the expression

$$H_o = \frac{24}{\pi} S\{1 + 0.33\, cos(2\pi d_n/365)\}(cos\,\theta \cos\delta \sin w_s + w_s \sin\theta \sin\delta) \ldots (2.4)$$

Where d_n is the number of the day in the year, S the solar constant and δ solar declination for the days of the year. The value of d_n is 1 on 1st January and 365 for 31st December for an ordinary year, but 366 for a leap year. The clearness index is calculated for each month of the year using equation (2.2).

Various empirical formulas are available for the calculation of the diffuse radiation. Equation 2.6 is adopted for its simplicity and accuracy

$$D/G = 1 - 1.13K_T \ldots\ldots\ldots (2.5)$$

The beam irradiation is then calculated from equation (2.3). The beam irradiation $H(\beta)$on a south-facing panel inclined at an angle β to the horizontal surface is now given by

$$H(\beta) = H\frac{\cos(\theta-\beta)\cos\delta\sin[w_s(\theta-\beta)] + w_s(\theta-\beta)\sin(\theta-\beta)\sin\delta}{\cos\theta\cos\delta\sin w_s + \mathrm{w_s}\sin\theta\sin\delta} \ldots (2.6)$$

Assuming that the diffuse radiation is distributed isotropically over the sky dome, then the component on the inclined surface is given by

$$D(\beta) = \frac{1}{2}(1 + cos\beta)D \ldots\ldots\ldots (2.7)$$

The radiation reflected from the ground is generally small, and a simple isotropic model is usually sufficient to characterize it. [15] This gives the result

$$R(\beta) = \frac{1}{2}(1 - cos\beta)\rho D \ldots\ldots\ldots (2.8)$$

The albedo radiation takes on special importance for photovoltaic modules (bifacial) which can utilise energy incident both from the front and the rear of the panel. The total global irradiation G(β) on the inclined surface as a sum of all the contributions

$$G(\beta) = H(\beta) + D(\beta) + R(\beta) \ldots\ldots\ldots\ldots. (2.9)$$

2.3 Solar Cells

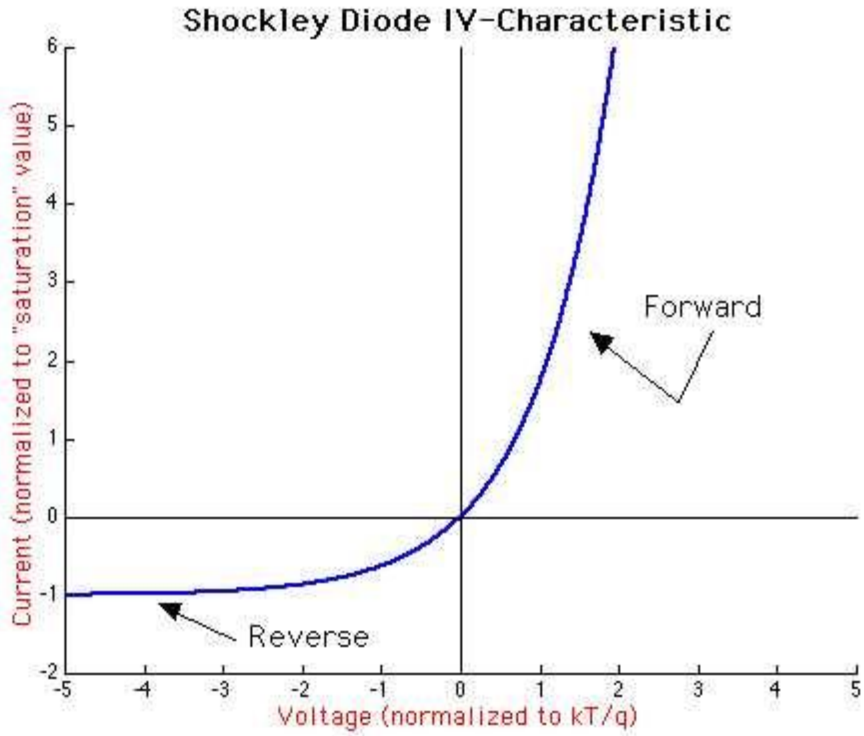
Solar cells represent the fundamental power conversion unit of a photovoltaic system. They are made from semiconductors, and have much in common with other solid-state electronic devices, such as diodes, transistors and integrated circuits. For practical operation, solar cells are usually assembled into modules.[19, 20]

The solar cell operation is based on the ability of semiconductors to convert sunlight directly into electricity by exploiting the photovoltaic effect. In the conversion process, the incident energy of light creates mobile charged particles in the semiconductor which are then separated by the device structure and produce electrical current. The operation is also much influenced by the formation of a junction. Perhaps the simplest is the p-n junction, an interface between the n and p regions of one semiconductor. When a junction acts as a rectifier or diode, the *I-V* characteristic of a diode is given in mathematical terms as the Shockley equation:

$$I = I_o\left[exp\left(\frac{qv}{KT}\right) - 1\right] \ldots\ldots\ldots. (2.10)$$

Where I is the current, v is the voltage, K is the Boltzmann constant, q is the magnitude of the electron charge, and T is the absolute temperature.[21] The I-V characteristic is shown in Fig. 2

Fig. 2.2 The Shockley Diode IV-Characteristic



2.4 Light Absorption by a Semiconductor

Photovoltaic energy conversion relies on the quantum nature of light whereby we perceive light as a flux of particles-photons-which carry the energy

$$E_{ph}(\lambda) = \frac{hc}{\lambda} \dots\dots\dots\dots..(2.11)$$

Where h is the Planck constant, c is the speed of light, and λ is the wavelength of light. On a clear day, about 4.4 x 1017 photons strike a square centimetre of the Earth's surface every second. Only some of these photons-those with energy in excess of the band-gap-can be converted into electricity by the solar cell. When such a problem enters the semiconductor, it may be absorbed and promote an electron from the valence to the conduction band. Since a hole is left behind in the valence band, the absorption process generates electron-hole pairs. Each semiconductor is therefore restricted to converting only a part of the solar spectrum. [21, 22]

The nature of the absorption of the process also indicates how a part of the incident photon energy is lost in the event. Indeed, it is seen that practically all the generated electron-hole pairs have energy in excess of the band gap. Immediately after their creation, the electron and hole decay to states near the edges of their respective bands. The excess energy is lost as heat and cannot be converted into useful power. This represents one of the fundamental loss mechanisms in a solar cell. [19]

Rough estimates can be made for the magnitude of electrical power that can be produced. When the light-induced electron traffic across the band gap is interpreted as electron current, called the generation current, then a solar cell can indeed transform this fictitious current into real electric current across the device. Neglecting losses, each photon then contributes one electron charge to the generation of current. The electric current is then equal to:

$$I_\iota = qNA \ldots. (2.12)$$

where N is the number of photons in the highlighted area of the spectrum, and A is the surface area of the semiconductor that is exposed to light. [19, 20, 21]

The I-V characteristic contains several important points. One is the short-circuit current I_{sc} which, as we noted, is simply the light-generated current I_ι. The second is the open-circuit voltage V_{oc} obtained by setting I=0:

$$V_{oc} = \frac{kT}{q} In\left(\frac{I_\iota}{I_o} + 1\right) \ldots \ldots \ldots. (2.13)$$

It is worthwhile to examine this equation in more detail. Both I_ι and I_o depend on the structure of the device. However, it is the value of I_o- which can vary by many orders of magnitude, depending on the device geometry and processing- that determines the open circuit voltage in practical devices.[21]

No power is generated under short or open circuit. The maximum power P_{max} produced by the device is reached at a point on the characteristic where the product IV is maximum.

$$P_{max} = V_m I_m = FFV_{oc}I_{sc} \ldots\ldots\ldots\ldots (2.14)$$

where FF is the fill-factor, V_m and I_m are the voltage and current at the maximum power point. The fill-factor of a solar cell is a measure of the quantum efficiency or the photo-electricity conversion efficiency of the solar cell. It can be calculated using the following equation;

$$FF = \frac{I_{MPP}.V_{MPP}}{I_{SC}.V_{OC}} \ldots\ldots\ldots\ldots (2.15)$$

Where IMPP is the maximum power point current, VMPP is the maximum power point Voltage, ISC is the short circuit current and VOC is the open circuit voltage.[23]

The efficiency η of a solar cell is defined as the power P_{max} produced by the cell at the maximum power point under standard test conditions, divided by the power of the radiation incident upon it. [24]

2.5 Wind Resources

The sun heats up air masses in the atmosphere. The spherical shape of the Earth, the Earth's rotation and seasonal and regional fluctuations of the solar irradiance cause spatial air pressure differentials. These are the source of air movements. Irradiation oversupply at the equator is the source for compensating air streams between the equator and the poles. [25]

Besides the spatial compensation streams, less extensive air currents exist due to the influence of local areas of high and low pressure. The Coriolis force diverts the compensating streams between high and low pressure areas. Due to the rotation of the Earth, the air masses in the northern hemisphere are diverted to the right and in the southern hemisphere to the left. Finally, the air masses rotate around the low-pressure areas.

Wind resources are particularly high in coastal areas because wind can move unhindered across the smooth surface of the sea. Furthermore, temperature differences between water and land cause local compensating streams. The sunlight heats the land more quickly than the water during the day. The results are pressure differentials and compensating winds in the direction of the land. These winds can reach up to 50 km inland. During the night the land cools much faster than the sea; this causes compensating winds in the opposite direction. [25]

2.5.1 Geostrophic Winds

The geostrophic winds are largely driven by temperature differences. These winds are found at altitudes above 1000 metres (3300 ft.) above ground level. The geostrophic wind speed may be measured using weather balloons. [25, 26]

2.5.2 Surface Winds

These winds are very much influenced by the ground surface at altitudes up to 100 metres. The wind will be slowed down by the earth's surface roughness and obstacle. Wind directions near the surface will be slightly different from the direction of the geostrophic wind because of the earth's rotation. In dealing with wind energy, we are concerned with surface winds, and how to calculate the usable energy content of it. [25, 26]

2.5.3 Local Winds

Although global winds are important in determining the prevailing winds in a given area, local climatic conditions may wield an influence on the most common wind directions. Local winds are always superimposed upon the larger scale wind system that is their direction is influenced by the sum of global and local effects. These winds are termed as local winds because they occur only in some localities. [25, 26, 27] They include the following:

I. Sea and Land Breezes

These are caused by variation in the temperature on the land and the sea and thus, occur at the coastal areas.

The sun heats landmasses more quickly than the sea in the daytime. The air rises, flows out to the sea, and creates a low pressure at ground level which attracts the cool air from the sea. This is called sea breeze. At nightfall there is often a period of calm when land and sea temperatures are equal.

At night, the wind blows in the opposite direction. The land breeze at night generally has lower wind speeds, because the temperature difference between land and sea is smaller at night. The monsoon known from South-East Asia is in reality a large-scale form of the sea breeze and land breeze, varying in its direction between seasons, because landmasses are heated or cooled more quickly than the sea. [25]

II. Mountainous Wind

Mountainous regions display many interesting weather patterns. One example is the valley wind which originates on south-facing slopes (north-facing in the southern hemisphere). When the slopes and the neighbouring air are heated the density of the air decreases, and the air ascends towards the top following the surface of the slope. At night the wind direction is reversed, and turns into a down slope wind. If the valley floor is sloped, the air may move down or up the valley, as a canyon wind.[25]

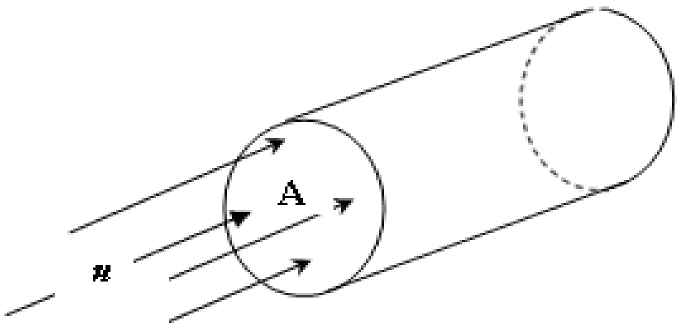
2.6 Wind Power

Unlike fossil fuel, the amount of energy available from wind varies with season and time of the day. The common terminologies used to characterize wind resource are ‘Available Wind Power (AWP)’ and ‘Extractable Wind Power (EWP)’. While available wind power represents the theoretically realizable power, extractable wind power represents the amount of power that can actually be produced by WECS based on the assumed performance characteristics.

2.6.1 Available Wind Power (AWP)

The energy the wind transfers to the rotor of a wind turbine is proportional to the density of the air, the rotor area, and the cube of the wind speed.[25, 26, 27]

Figure 2.3 Air flow through a rotor area, A, at speed u m/s



$$P = \frac{1}{2}\rho A u^3 \text{ ……………………………… (2.16)}$$

Where:

P - Power in the wind (W)

ρ - Density of the air (at normal atmospheric pressure and at 15° Celsius air weighs some 1.225 kilograms per cubic meter)

A - Rotor Area (A typical 1,000 kW wind turbine has a rotor diameter of 54 meters, i.e. a rotor area of some 2,300 square meters) [26].

u - The wind speed (m/s)

It is to be noted that the mean wind speed should not be simply inserted into the equation, as this will give an erroneous result because of the fact that the mean of the cubes of wind velocities will almost always be greater than the cube of the mean wind speed.[27]

The most accurate estimate for wind power density is that given by

$$P/_A = \frac{1}{2}.\frac{1}{n}.\sum_{j=1}^{n}(\rho_j . u_j^3) \text{ ………………………… (2.17)}$$

Where n is the number of wind speed readings and ρ_j and u_j are the j^{th} readings of the air density and wind speed. [27]

For a known pressure and temperature:

$$\rho = \frac{P_r}{RT} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.18)$$

Where P_r is air pressure (Pa) and R is the specific gas constant (287 $JKg^{-1}\ K^{-1}$) and T is air temperature in 0K. [26]

For the available temperature data:

$$\rho = \frac{P_0}{RT} \exp\left(-\frac{gz}{RT}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.19)$$

Where Po is standard sea level atmospheric pressure (101,325 Pa), g is the gravitational constant (9.8 m/s^2); and z is the region's elevation (m). [26]

If pressure and temperature data is not available, the following correlation may be used for estimating the density: [26]

$$P = 1.225 - (1.194 * 10^{-4}) * Z \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.20)$$

2.6.2 Extractable Wind Power (EWP)

Due to the law of conservation of matter (continuity constraint), the extractable power, PE, from the wind stream depends on the AWP and the operation characteristics of the wind energy extraction device. The extractable power output may then be written as:

$$P_E = 0.5\, C_P \rho v^3 A \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (2.21)$$

Where Cp = power coefficient, the power coefficient is a function of wind speed.

The EWP is the mechanical shaft power and not final electrical output power. Thus, Power losses due to mechanical efficiency of gear trains and electrical efficiency of generators are accounted for separately. [26]

An estimation of the EWP, with an assumed average power coefficient is given by the relation,

$$\overline{P_E} = 0.5\, \overline{C_P}\, \rho\, \overline{v^3} A \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (2.22)$$

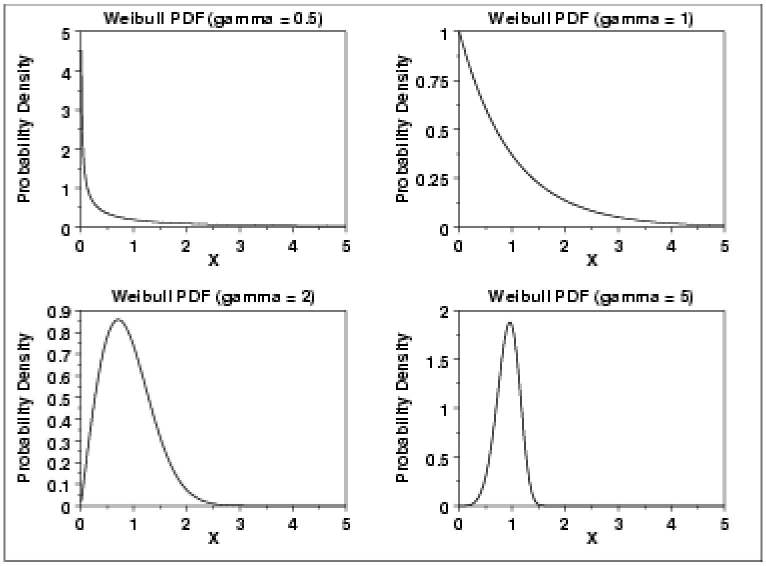
The output characteristics of a particular machine based on a relation for Cp(v) can also be used to evaluate EWP (PE) via the probability density of wind speed p(v), namely,

$$\overline{P_E} = 0.5\rho A \int C_P\,(v) v^3 p(v) dv \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (2.23)$$

Betz estimate the power coefficient of an ideal propeller type wind machine to be 16/27. [16, 17, 19]

2.7 Weibull Statistics

The variation in wind speeds is best described by the Weibull probability distribution function f(v) with two parameters; the shape parameter, k, and the scale parameter, c. If wind speeds are measured over a time, the probability of getting various values of wind speeds is represented by this speed. The following are some plots of the Weibull probability density function.



The probability distribution of the wind speeds during any time interval is given by the following equation:

$$f(v) = \frac{k}{c'}(\frac{v}{c'})^{k-1}\exp\left[-\left(\frac{v}{c'}\right)^{k}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (2.24)$$

Where:

v = the wind speed,

k = a constant known as shape factor, as the value of k increases the curve will have a sharper peak

c' = a scale parameter in m/s; the larger the scale parameter, the more spread out the distribution.[27]

By definition of the probability function, the probability that the wind speed will be between zero and infinity during that period is unity, i.e.: [27]

$$\int_0^\infty h.dv = 1 \ldots\ldots\ldots\ldots\ldots (2.25)$$

2.8 Rayleigh and Normal Distributions

Rayleigh distribution is a special case of the Weibull distribution in which k =2. The function is:

$$f(v) = \frac{\pi v}{2\bar{v}^2} exp\left[-\frac{\pi}{4}\left(\frac{v}{\bar{v}}\right)^2\right] \ldots\ldots\ldots\ldots\ldots (2.26)$$

with the cumulative function:

$$F(v) = 1 - exp\left[-\frac{\pi}{4}\left(\frac{v}{\bar{v}}\right)^2\right] \ldots\ldots\ldots\ldots\ldots\ldots (2.27)$$

It may be noted that the variance is only a function of the mean wind speed. This means that important statistical parameter is completely described in terms of a second quantity, the mean wind speed. Since the mean wind speed is always computed at any measurement site, all the statistics of the Rayleigh density function used to describe that site are immediately available without massive amount of additional computation. The Rayleigh is also noted to yield acceptable results in most cases. The natural variability in the wind from year to year tends to limit the need for greater sophistication of the Weibull density function.[27]

2.9 Wind-Speed Variation with Height

Knowledge of wind speed at heights 20-120m above ground is very desirable in any decision about location and type of wind turbine to be installed. Many times, these data are not available and more estimates must be made from wind speeds measured at about 10m. This requires an equation that predicts the wind speed at one height in terms of the measured speed at another lower height. [25]

One possible form for the variation of wind speed V with height h is

$$V_h = \frac{U_f}{K}\left[log_e \frac{h}{z_o} - \xi\left(\frac{h}{L}\right)\right] \dots\dots\dots\dots (2.28)$$

Here U_f is the friction velocity, z_0 is the surface roughness length, K is Von Karman's constant (normally assumed to be 0.4) [26]. L is a scale factor called the Monin Obukov length. The function ξ (h/L) is determined by the net solar radiation at the site. This equation applies to short-term (e.g., 1 minute) average wind speeds, but not to monthly or yearly averages.[26]

This is quite satisfactory for detailed studies on certain critical sites, but is too difficult to use for general engineering studies. This has led to many simpler expressions which will yield satisfactory results even if they are not theoretically exact.

2.9.1 The Power Law

For estimation of the distribution of the mean wind speed with height a simple power, law can be used to provide a reasonable fit to the data, and is given by:

$$\frac{V_{(h)}}{V_{(h_o)}} = \left(\frac{h}{h_o}\right)^{\alpha} \dots\dots\dots\dots\dots\dots. (2.29)$$

where α depends on the surface roughness.

In the above equation h_o is usually taken as the height of measurement, approximately 10 m, h, is the height at which a wind-speed estimate V is desired. The parameter α is determined empirically. The equation can be made to fit observed wind data reasonably well over the range 10 to perhaps 100 to 150 m if there are no sharp boundaries in the flow. [16, 17]

The exponent α varies with height, time of day, season of the year, nature of the terrain, wind speeds and temperature. [25, 27] A number of models have been proposed for the variation of α with the above variables. One of these models is a linear logarithmic plot. It shows one plot for a day and another plot for night, each varying with wind speed according to equation

$$\alpha = a - b * (log_e V_{h_o}) \dots \dots \dots \dots \dots \dots (2.30)$$

The coefficients a and b are determined by a linear regression program. Typical values of a and b are 0.11 and 0.061 in daytime and 0.38 and 0.209 at night. [25, 26, 27]

The average value of α has also been determined by many measurements around the world to be about one-seventh (1/7). [25] This average value could be used only if site specific data are not available, because of the wide range of values that α can assume.

Justus and Mikhail have also suggested the following relationship for estimating α:

$$\alpha = \frac{0.37 - 0.0881 log_e V_{ho}}{1.0 - 0.0881 log_e V_{ho}} \dots .. (\ \alpha \ absolute\ value\ is\ taken) \dots \dots (2.31)$$

The expression is valid for surface roughness values in the range 0.05m to 0.5m. [26]

2.9.2 The Log Law

A logarithmic law can represent the variation of wind speed with height. The law for neutrally stable conditions is given by:

$$\frac{V_z}{V_r} = \frac{In\left(\frac{Z}{Z_o}\right)}{In\left(\frac{Z_r}{Z_o}\right)} \dots \dots \dots \dots \dots \dots \dots \dots (2.32)$$

where V_z is the velocity at height Z, with a roughness height Z_o and Z_r is the reference height constant. [27]

2.10 Types of Wind Turbine

There are two fundamentally different types of wind turbine. The first is the horizontal axis wind turbine (HAWT) which has the axis of rotation of its rotor parallel to the wind stream; the second is the vertical axis wind turbine (VAWT), which has the axis of rotation of its rotor perpendicular to the wind stream. HAWT has long been used for small-scale applications, such as water pumping and non-utility electricity generation, as well as large-scale power production.[25]

The VAWT may prove to be cost effective in some applications, but it is limited because, unlike the HAWT, it cannot take advantage of the higher wind velocity and lower turbulence at higher elevations. The vast majority of wind turbines in use today are horizontal axis machines.[26] Horizontal axis wind machines are classified as classic windmills, slow turbines and fast wind turbines. Slow wind turbines are multi-bladed. The blades which vary in number from 12 to 24 cover the whole surface of the wheel. They are well adapted to low wind velocities, start freely with wind speed from 2 to 3m/s.[25, 26] Thus, the slow windmills are suitable for areas of moderate wind. They have high starting torque, useful for moderate wind velocity, especially for water pumping and battery charging. The only disadvantage of these machines is that it is not easy to erect turbine of diameter between 9-10m due to the weight of the machine. [27]

CHAPTER THREE

METHODOLOGY AND DATA COLLECTION

3.0 Introduction

This chapter discusses the methodological choices made by the researcher. Specifically, discussion of research strategy, research methods, data collection method, methodology of the study, Ghana Meteorological Agency and the equipment used for data collection for the analysis of the data collected over the past one year for the five selected sites across the country.

3.1 Data Source

One year relevant data on wind speed and direction, solar radiation, air temperature, precipitation, pressure, dew point and relative humidity from Tamale, Accra, Takoradi, Sunyani and Kumasi in the country were measured at the specific sites in time series format and transmitted through their network system to the Ghana Meteorological Agency Headquarters, Accra.

An industrial attachment was sought for the researcher at the Ghana Meteorological Agency, Head quarters Accra and occasionally with the assistance of the Agency visited the four other sites across the country to enable the researcher to familiarize himself with the situation on the ground and to ascertain the status of the measuring instruments so that the veracity of the data acquired could be checked and to find if there was any margin of error to be calculated before the analysis.

The data was collected from May 2011 to April 2012 consistently at every one hour interval for 24 hours per day at the Ghana Meteorological Agency stations under study in table 3.1. The raw data was then downloaded onto a pen drive and sent to University of Ghana Legon, Physics Department for further analysis.

Table 3.1: Location of sites used in the study

Site	**Latitude**	**Longitude**	**Elevation(m)**
Accra	$05^0 39'$ N	$00^0 09'$ W	77.0
Kumasi	$06^0 43'$ N	$01^0 36'$ W	286.3
Takoradi	$04^0 53'$ N	$01^0 46'$ W	4.6
Sunyani	$07^0 20'$ N	$02^0 20'$ W	308.8
Tamale	$09^0 33'$ N	$00^0 51'$ W	183.3

3.2 Ghana Meteorological Agency

The Ghana Meteorological Agency (Gmet) is the major source of wind, solar radiation and related data in the country. The Gmet collect these data for a number of reasons including Aviation purposes, weather forecasting and climatic conditions. The Gmet does not involve itself in projects but it is there to purely collect data and use it for the above stated functions. The Gmet has a network of 21 synoptic stations, 54 agro-meteorological station, 75 climatological stations, 463 rainfall stations and 5 experimental stations throughout the country. [16] This indicates that the Gmet has comprehensively covered the country. Gmet has now installed Automatic Weather Station equipments at 7 synoptic stations across the country at a height of

10.0 m above ground level of which five of the sites are mentioned above and a newly commissioned surveillance radar equipment at the head office in Accra taking recordings in a radius of 300 km. These new facilities and their height of installation make it possible for recordings to be used for energy analysis and prediction.

3.3 Determination of the Various Parameters

The various parameters are wind speed and direction, air temperature, solar irradiance, pressure, dew point, relative humidity and precipitation. The height of the equipment was 10 metres above ground level and surface roughness between 0.00001 m to 3.0 m. The equipment used for measuring the above mentioned parameters was the Automatic Weather Station which has been configured to measure, record and transmit all the parameters from the sites to the headquarters simultaneously.

3.4 The Energy X Software

The major problem faced with when one undertakes the harnessing of renewable energy resources for rural electrification is the difficulty in selecting a suitable technology for the target area. Technical feasibility and economic performance are often the two major criteria used in the evaluation process and selection process. In order to evaluate and identify the proper power system technology for the area application, simulation software called “Energy X” was developed for this purpose. “Energy X” was developed by Dr. Michael Addae-Kagyah at the Department of Physics, University of Ghana, Legon.

The software is a sizing, simulation and economic analysis tool for both renewable energy and conventional energy technology applications. Renewable technologies considered here consist of PV-Wind Hybrid System, Stand-alone PV Station and Solar Home System. Conventional technology consists of Stand-alone Diesel Generator Station and Grid Extension. Economic result output by the software shows net present value, life cycle costs and levelized costs of each system which the user can use to compare with other systems or technologist. This software serves as a useful tool for energy planners and system designers when selecting the most appropriate options that offer the most optimal technical and economic benefits for the project area.

The software offers a graphic user interface that is simple and easy to understand. All system components are stored in different libraries to minimize input time by the user. The models of PV modules, wind turbine from the manufacturers and other meteorological data will personally be included in the database of the software. Integrated help files together with step by step instructions given during the execution of the program ensures that the software is a self-learning and user-friendly application tool.

The software provides tools for analyzing a wide range of energy supply systems which are already present in its software libraries. The software comprises many modules and associated sub-modules. One of such modules is the renewable energy system, called PRO VITUS. All of these modules can simulate both technical and economic performances. PRO VITUS is the module used for the entire analysis done in this work.

3.5 Wind Power Determination

Recording of wind speeds at heights of 20-120 m above ground would have been very desirable in any decision about the location and type of wind turbine to be installed. But our recordings are only available at 10.0m height; however estimates have been made from wind speeds measured at about 10.0m. This is done with the Power Law equation that can estimate the wind speed at one height in terms of the measured speed at another lower height and is given by:

$$\frac{u_{(h)}}{u_{(h_o)}} = \left(\frac{h}{h_o}\right)^{\alpha} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.1)}$$

where α depends on the surface roughness.

In the above equation h_o is the height of measurement, approximately 10.0 m, h, is the height at which a wind-speed estimate u is desired, approximately 100.0 m. The parameter α is determined empirically and varies with height, time of day, season of the year, nature of the terrain, wind speeds and temperature. The average value of α has also been determined by many measurements around the world to be about one-seventh (1/7). The value of α for this work is 0.143 and the surface roughness value of 2.5 m since all the chosen sites are in the midst of cities.

The extractable power from the wind stream depends on the available wind power given by;

$$P = \frac{1}{2}\rho A u^3 \quad \ldots\ldots\ldots\ldots\ldots \text{(3.2)}$$

and the operation characteristics of the wind energy extraction device. The extractable power output is given by:

$$P_E = 0.5\ C_P \rho u_{(h)}{}^3 A \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

Where Cp is power coefficient, the power coefficient is a function of wind speed

$u_{(h)}$ is the estimated wind speed at a height (100.0 m).

An estimation of the extracted wind power which is the mechanical shaft power and not the final electrical output power. Power losses due to mechanical efficiency of gear trains and electrical efficiency of generators is accounted for by the relation:

$$\overline{P_E} = 0.5\ \overline{C_P}\ \rho\ \overline{u_{(h)}{}^3} A \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3.3)$$

The measured mean wind speed has inherent variability and hence best described by various statistical distributions to reveal the monthly, annual mean and maximum wind speeds.

3.6 Solar Power Determination

Solar radiation at normal incidence received at the surface of the earth is subject to variations due to changes of the extraterrestrial radiation. The calculation of the possible extraterrestrial radiation is necessary to obtain the ratio of radiation level under the atmosphere. This is then used for the calculation of daily solar radiation to deduce the integrated daily extraterrestrial radiation on a horizontal surface (H_o) over the period from sunrise to sunset. The monthly mean daily extraterrestrial radiation, ($\overline{H_o}$), is an absolutely useful quantity.

$$\overline{H_o} = \frac{24 * 3600 * G_{sc}}{\pi}\left\{1 + 0.033 * \cos\left(\frac{360 n_d}{365}\right)\right\} * \left(cos\phi cos\delta sin w_s + \frac{\pi w_s}{180} sin\phi sin\delta\right) \qquad (3.4)$$

Where:

n_d = the day number,

$G\ SC$ = 1367 Wm^{-2}, the solar constant,

ϕ = the latitude of the location,

δ = the declination angle

w_s = is the sunset hour angle

φ = Latitude of location, Degrees

$\overline{H}$= Monthly mean daily total radiation on horizontal surface, MJm^{-2}.day

$\overline{H_o}$ = Monthly mean daily extraterrestrial radiation on horizontal surface, MJm^{-2}.day

The total solar power produced by a panel is given by the Shockley equation:

$$P = P_R F_D \left[\frac{R}{R_{STC}}\right] [1 + \alpha(T_m - T_{STC})] \ldots\ldots\ldots\ldots\ldots (3.5)$$

Where

P is the solar power

F_D is the derating factor of the solar panel

R is the solar radiation measured

P_R is the rated power of the panel

R_{STC} is the solar radiation at STC

T_{STC} is the temperature of the solar panel at standard temperature conditions

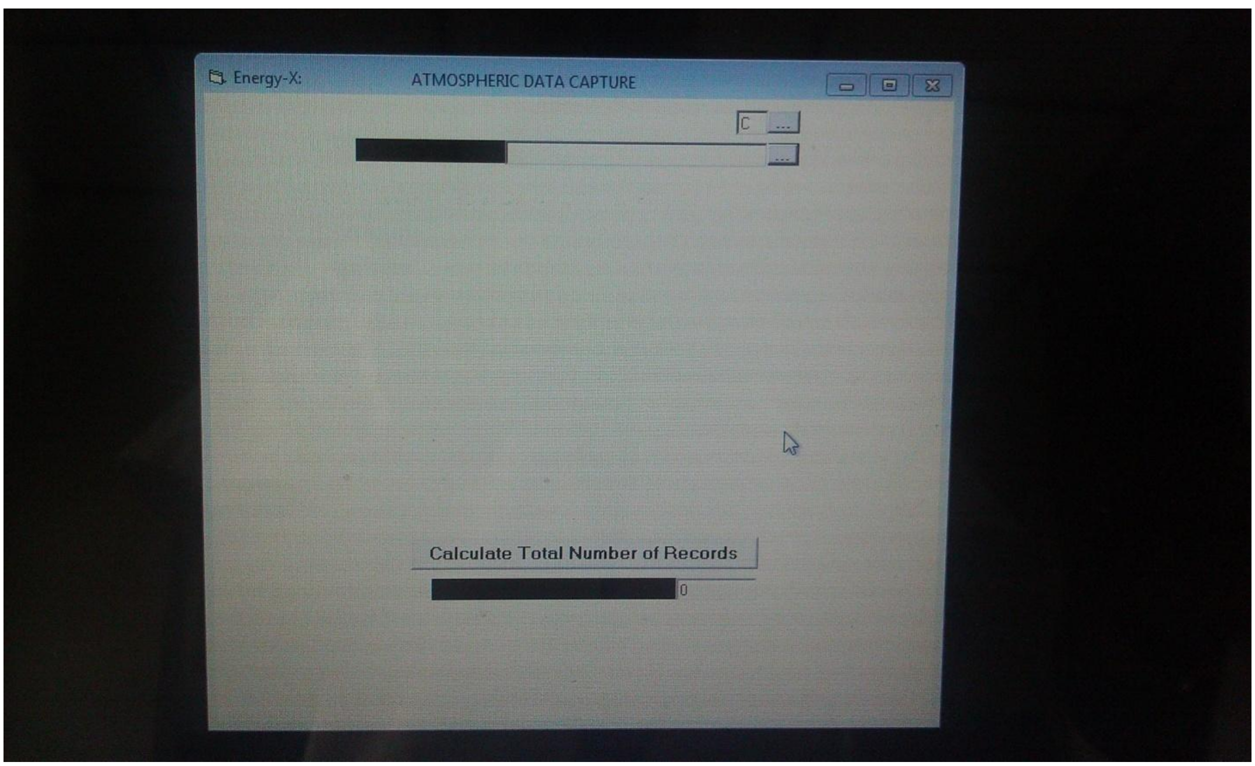
T_m is the measured temperature.

3.7 The PRO VITUS Model

This section describes the systematic framework of the approach taken, the analysis conducted and the choices made. It describes the process from the selection of relevant meteorological data to the PRO VITUS model and the relation to various other factors. The following paragraphs show the path followed from the initial assessment of the data to the selection of the solar module and wind turbine input parameters.

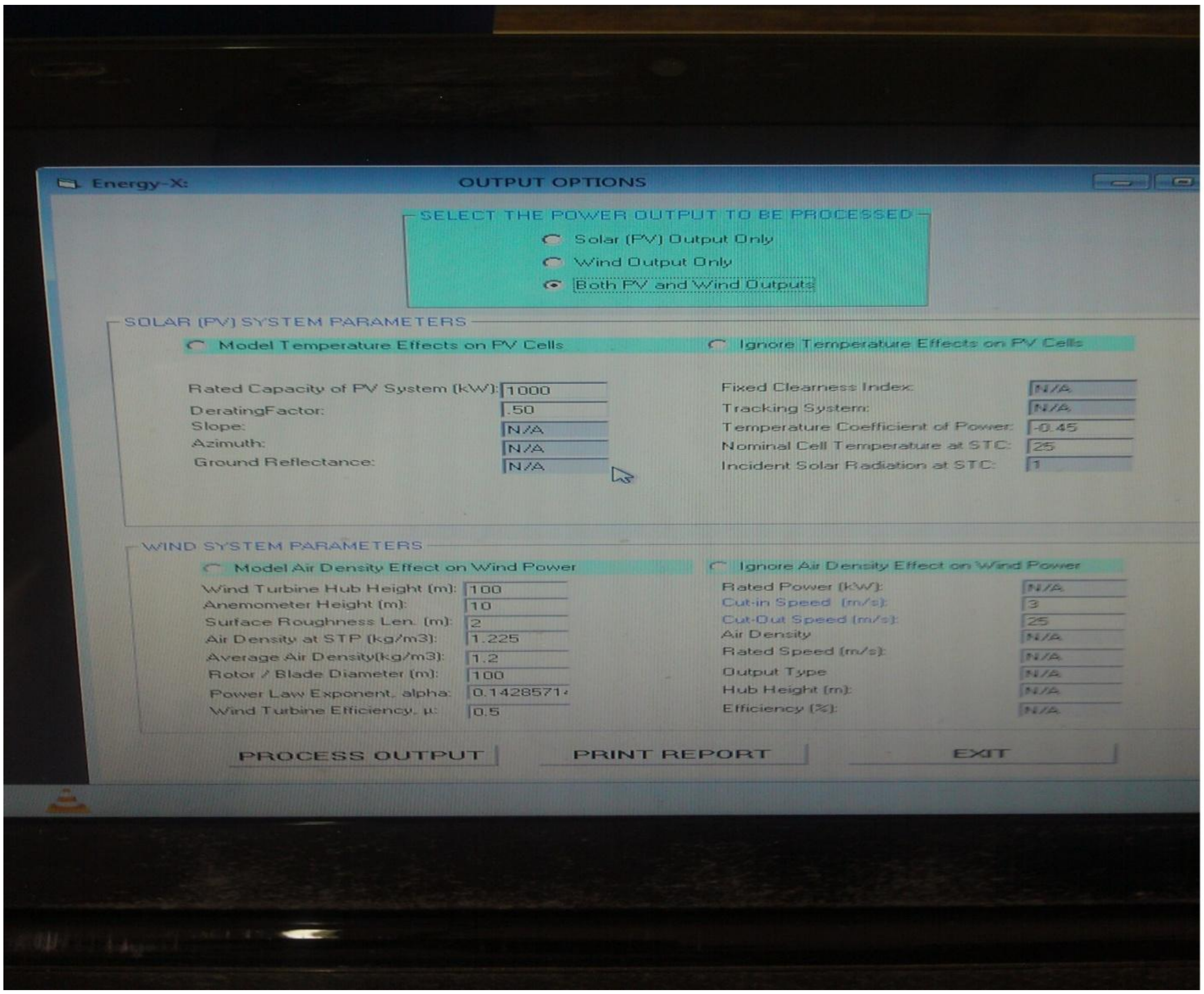
The software provides an input interface where the relevant data for analysis can be chosen from any of the computer files and is captured one site at a time with its total tally generated.

Fig. 3.1 Data capturing interface



Then the interface of the software changes to the output options where the power output to be processed can be selected. One can then go on to do a solar (PV) output only, wind output only or both PV and wind outputs, depending on the nature of project one is carrying out.

Fig. 3.2 Output options interface

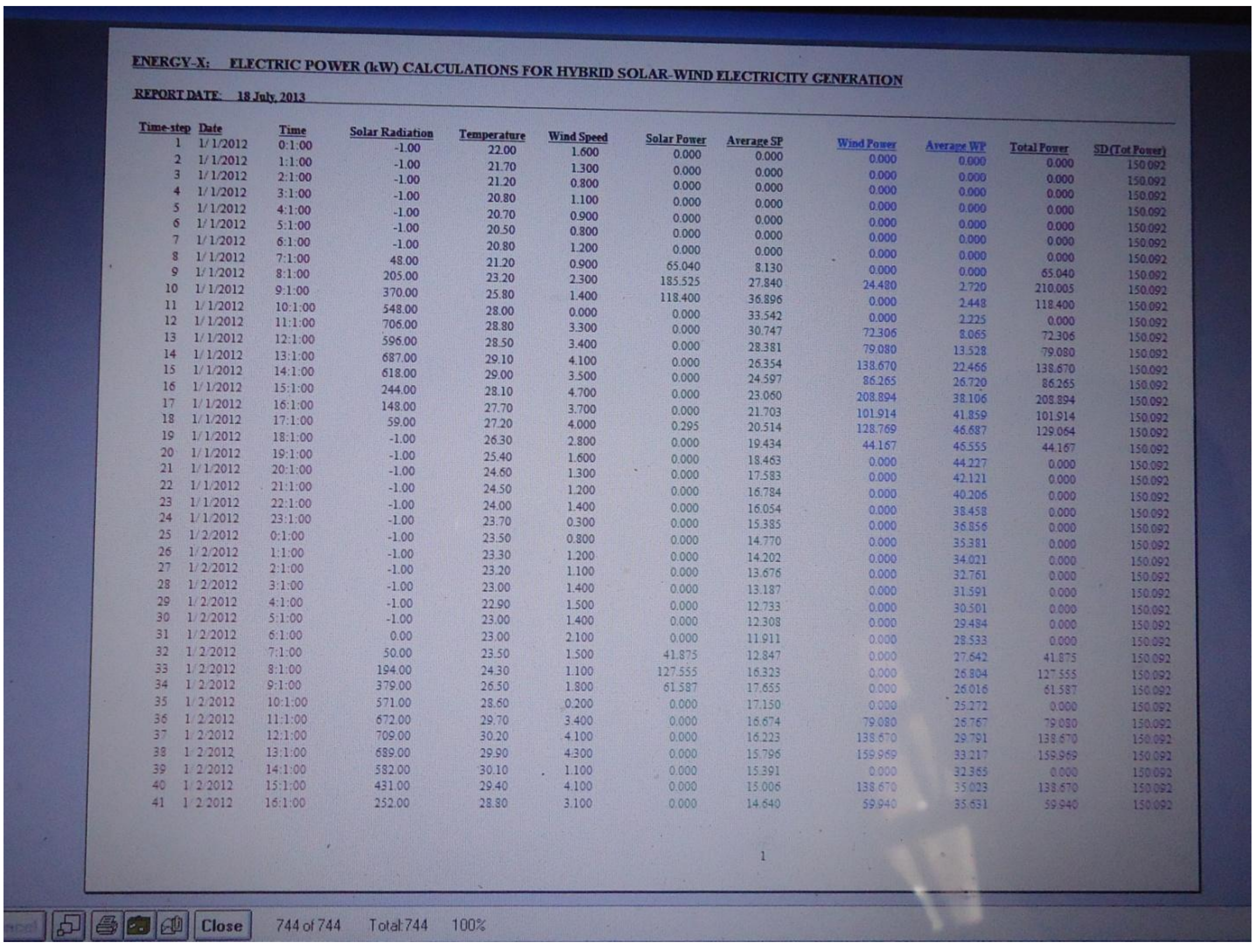


When the choice of both PV and wind outputs is selected, the system parameters of the solar and wind are manually entered at the appropriate spaces provided on the screen.

The 'PROCESS OUTPUT' button is clicked after the above steps have been followed through. At this stage the algorithms for determining both the solar and wind power as described in section 3.4 and 3.5 above are executed simultaneously. An appropriate signal is given after a successful or unsuccessful execution of the process.

The print report button launches the results of the executed task and gives options for storage format. The results can then be analysed with other statistical or analytical tools for further information.

Fig. 3.3 Results display interface



ENERGY-X: ELECTRIC POWER (kW) CALCULATIONS FOR HYBRID SOLAR-WIND ELECTRICITY GENERATION

REPORT DATE: 18 July, 2013

Time-step	Date	Time	Solar Radiation	Temperature	Wind Speed	Solar Power	Average SP	Wind Power	Average WP	Total Power	SD(Tot Power)
1	1/1/2012	0:1:00	-1.00	22.00	1.600	0.000	0.000	0.000	0.000	0.000	150.092
2	1/1/2012	1:1:00	-1.00	21.70	1.300	0.000	0.000	0.000	0.000	0.000	150.092
3	1/1/2012	2:1:00	-1.00	21.20	0.800	0.000	0.000	0.000	0.000	0.000	150.092
4	1/1/2012	3:1:00	-1.00	20.80	1.100	0.000	0.000	0.000	0.000	0.000	150.092
5	1/1/2012	4:1:00	-1.00	20.70	0.900	0.000	0.000	0.000	0.000	0.000	150.092
6	1/1/2012	5:1:00	-1.00	20.50	0.800	0.000	0.000	0.000	0.000	0.000	150.092
7	1/1/2012	6:1:00	-1.00	20.80	1.200	0.000	0.000	0.000	0.000	0.000	150.092
8	1/1/2012	7:1:00	48.00	21.20	0.900	65.040	8.130	0.000	0.000	65.040	150.092
9	1/1/2012	8:1:00	205.00	23.20	2.300	185.525	27.840	24.480	2.720	210.005	150.092
10	1/1/2012	9:1:00	370.00	25.80	1.400	118.400	36.896	0.000	2.448	118.400	150.092
11	1/1/2012	10:1:00	548.00	28.00	0.000	0.000	33.542	0.000	2.225	0.000	150.092
12	1/1/2012	11:1:00	706.00	28.80	3.300	0.000	30.747	72.306	8.065	72.306	150.092
13	1/1/2012	12:1:00	596.00	28.50	3.400	0.000	28.381	79.080	13.528	79.080	150.092
14	1/1/2012	13:1:00	687.00	29.10	4.100	0.000	26.354	138.670	22.466	138.670	150.092
15	1/1/2012	14:1:00	618.00	29.00	3.500	0.000	24.597	86.265	26.720	86.265	150.092
16	1/1/2012	15:1:00	244.00	28.10	4.700	0.000	23.060	208.894	38.106	208.894	150.092
17	1/1/2012	16:1:00	148.00	27.70	3.700	0.000	21.703	101.914	41.859	101.914	150.092
18	1/1/2012	17:1:00	59.00	27.20	4.000	0.295	20.514	128.769	46.687	129.064	150.092
19	1/1/2012	18:1:00	-1.00	26.30	2.800	0.000	19.434	44.167	45.555	44.167	150.092
20	1/1/2012	19:1:00	-1.00	25.40	1.600	0.000	18.463	0.000	44.227	0.000	150.092
21	1/1/2012	20:1:00	-1.00	24.60	1.300	0.000	17.583	0.000	42.121	0.000	150.092
22	1/1/2012	21:1:00	-1.00	24.50	1.200	0.000	16.784	0.000	40.206	0.000	150.092
23	1/1/2012	22:1:00	-1.00	24.00	1.400	0.000	16.054	0.000	38.458	0.000	150.092
24	1/1/2012	23:1:00	-1.00	23.70	0.300	0.000	15.385	0.000	36.856	0.000	150.092
25	1/2/2012	0:1:00	-1.00	23.50	0.800	0.000	14.770	0.000	35.381	0.000	150.092
26	1/2/2012	1:1:00	-1.00	23.30	1.200	0.000	14.202	0.000	34.021	0.000	150.092
27	1/2/2012	2:1:00	-1.00	23.20	1.100	0.000	13.676	0.000	32.761	0.000	150.092
28	1/2/2012	3:1:00	-1.00	23.00	1.400	0.000	13.187	0.000	31.591	0.000	150.092
29	1/2/2012	4:1:00	-1.00	22.90	1.500	0.000	12.733	0.000	30.501	0.000	150.092
30	1/2/2012	5:1:00	-1.00	23.00	1.400	0.000	12.308	0.000	29.484	0.000	150.092
31	1/2/2012	6:1:00	0.00	23.00	2.100	0.000	11.911	0.000	28.533	0.000	150.092
32	1/2/2012	7:1:00	50.00	23.50	1.500	41.875	12.847	0.000	27.642	41.875	150.092
33	1/2/2012	8:1:00	194.00	24.30	1.100	127.555	16.323	0.000	26.804	127.555	150.092
34	1/2/2012	9:1:00	379.00	26.50	1.800	61.587	17.655	0.000	26.016	61.587	150.092
35	1/2/2012	10:1:00	571.00	28.60	0.200	0.000	17.150	0.000	25.272	0.000	150.092
36	1/2/2012	11:1:00	672.00	29.70	3.400	0.000	16.674	79.080	26.767	79.080	150.092
37	1/2/2012	12:1:00	709.00	30.20	4.100	0.000	16.223	138.670	29.791	138.670	150.092
38	1/2/2012	13:1:00	689.00	29.90	4.300	0.000	15.796	159.969	33.217	159.969	150.092
39	1/2/2012	14:1:00	582.00	30.10	1.100	0.000	15.391	0.000	32.365	0.000	150.092
40	1/2/2012	15:1:00	431.00	29.40	4.100	0.000	15.006	138.670	35.023	138.670	150.092
41	1/2/2012	16:1:00	252.00	28.80	3.100	0.000	14.640	59.940	35.631	59.940	150.092

1

3.8 Brief Description of the Solar Panel and Wind Turbine

The solar panel used is a Sharp Nd-240QcJ 240 WATT multi-purpose module of cross-sectional area 994 x 1640mm, thickness 46 mm which has a 25-year limited warranty on power output. It incorporates an advanced surface texturing process to increase light absorption and improve efficiency. Common applications include commercial and residential grid-tied roof systems as well as ground mounted arrays which offer high power output per square foot of solar array.[28] The table below shows the system input parameters that will be fed into the model for processing. The quoted Rated Capacity of PV system in the table is achieved by multiplying with a factor F_m, to make equal to a 10,000 m^2 area module. F_m is the multiplication factor that will multiply with the quoted rated capacity of the PV system to give us a rated capacity for an area of 10,000 m^2 since an installation covering the area of a typical football field is being considered.

$$F_m = \frac{10,000}{\text{area of solar panel under consideration}} \quad \ldots\ldots\ldots (3.6)$$

Table 3.2: System input parameters for Sharp Nd-240QcJ 240 WATT panel

Rated Capacity of PV system	1,331.16 kW
Derating Factor	0.75
Nominal Cell Temperature @ STC	25 ^oC
Incident Solar Radiation @ STC	1 kWm^{-2}

The chosen wind turbine was a Siemens SWT-2.3-113 which is suitable for low to moderate wind speed conditions.

Fig 3.4: Photo of Siemens SWT-2.3-113 wind turbines in operation[29]

It has a revolutionary direct drive generator and an optimized Quantum Blade paired to extract as much energy as possible from the wind. Its rotor had three blades, a horizontal axis, an upright position with a diameter of 113 m and a swept area of 10,000 m^2. Its grid terminals (LV) characteristics were; Nominal power: 2,300 kW, Voltage: 690 V, Frequency: 50 Hz or 60 Hz. The Cut-in wind speed is 3 ms^{-1} with a Nominal power at 12–13 ms^{-1} and Cut-out wind speed of 25 ms^{-1}. [29] The table below shows the system input parameters that will be fed into the model for processing.

Table 3.3: System input parameters for Siemens SWT-2.3-113 Wind Turbine

Wind Turbine Hub Height	100.0 m
Anemometer Height	10.0 m
Surface Roughness	2.5
Air Density at STP	1.225 kgm^{-3}
Average Air Density	1.225 kgm^{-3}
Rotor Blade Diameter	113 m
Power Law Exponent α	0.1428571428

CHAPTER FOUR

RESULTS AND DISCUSSION

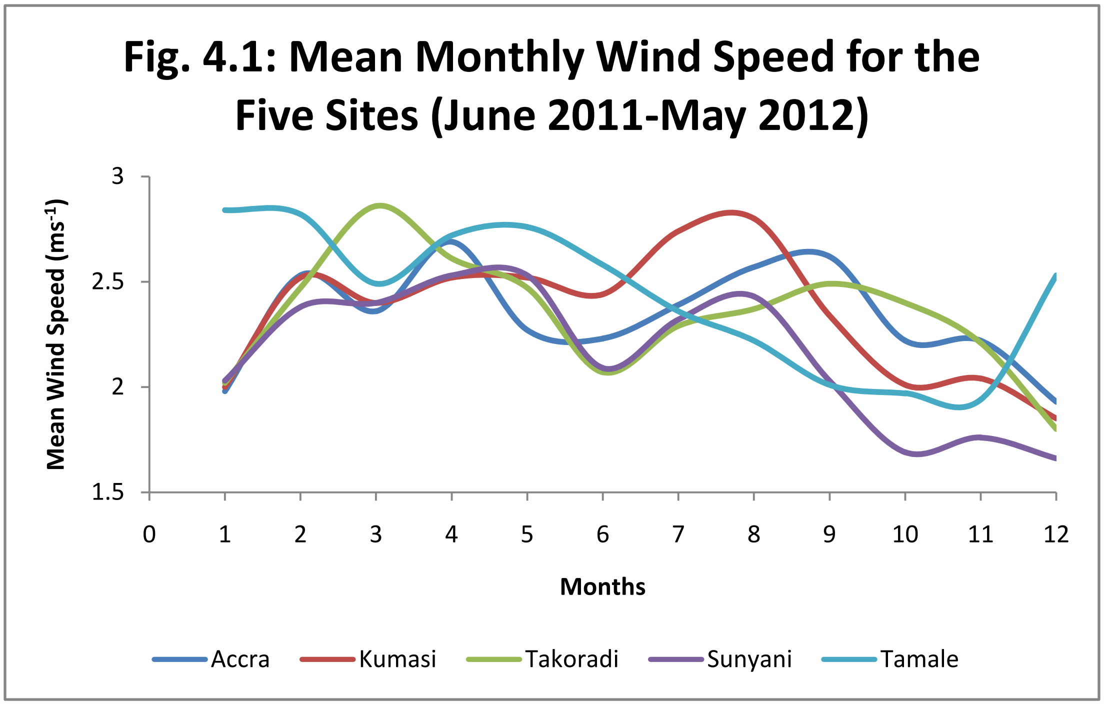
4.0 INTRODUCTION

In this chapter, the dependence of the output performance of a PV-Wind hybrid power generation system on selected meteorological data is presented. The data for various locations have been processed, analyzed and discussed using different scenarios. The key results of the data processing and analysis are presented in the following paragraphs.

4.1 Monthly Mean Wind Speed

The monthly mean wind speeds for the year measured at 10.0m above ground level are illustrated in Fig. (4.1). The trends of the monthly means for the different sites of Kumasi, Sunyani and Accra are similar but slightly different from the trends exhibited by Takoradi and Tamale. The wind speeds of Accra, Kumasi, Takoradi and Sunyani start with very low values in January and suddenly rise during the second month of the year.

It can be seen that the overall monthly average wind speed for all the sites lie in the range of 1.66 ms^{-1} — 2.86 ms^{-1}. The highest monthly average wind speed was recorded in February at Tamale and the lowest recorded in December at Sunyani. This range of mean wind speeds do not meet the *cut-in* wind speed of the wind turbine used for this design. Hence the need to use the power law discussed earlier in chapter two to determine the speeds at 100.0m above ground level for the analysis. Also to cater for the long diameter of the wind turbine blade which is more than 10m, measurements at 100.0m are necessary.



4.2 Mean Wind Speed

Table 4.1 and table 4.2 shows the mean and maximum wind speeds for each of the five sites respectively at 10.0m above ground level for the year. The maximum mean wind speed occurred at Tamale 2.47 ms^{-1}, followed by Kumasi 2.39 ms^{-1}, Accra and Takoradi both having 2.38 ms^{-1} and Sunyani having the lowest value of 2.18 ms^{-1}. The maximum annual wind speed of 2.86 ms^{-1} occurred in Takoradi probably due to the winds which are mostly sea and land breeze, followed by Tamale 2.84 ms^{-1}, Kumasi 2.80 ms^{-1}, Accra 2.62 m^{-1} and Sunyani having the lowest value of 2.53 ms^{-1}during the period of 1st June, 2011 to 31st May, 2012.

Table 4.1: Monthly Mean Wind Speeds

SITE	**Mean Wind Speed (ms^{-1})**
Accra	2.38
Kumasi	2.39
Takoradi	2.38
Sunyani	2.18
Tamale	2.47

Table 4.2 Maximum Wind Speed for each Site

SITE	**Maximum Wind Speed (ms^{-1})**
Accra	2.62
Kumasi	2.80
Takoradi	2.86
Sunyani	2.53
Tamale	2.84

4.3 Monthly Mean Solar Radiation

The monthly average solar radiation for each of the sites is shown in Fig. (4.2). It can be noticed that the five sites follow a common pattern. Tamale shows a better radiation pattern with relatively higher recorded values than the rest of the sites, making it the most suitable site for solar power generation. The Kumasi site, as revealed in the figure, has the lowest radiation values but they are high enough for power production. These lowest radiation values recorded by the Kumasi site may be due to its location in the deciduous forest vegetation zone in the country.

The five sites recorded relatively higher radiation values from the months of February to May but dipped in the months of June to September. The values rose again through to the end of the year. This situation can be accounted for by the climatic conditions prevailing at those periods of the year where there exist thicker clouds during May, June, July, August and September but clearer clouds thereafter.

It can be seen that the overall monthly average solar radiation for all the sites lie in the range of 113.24 Wm^{-2} — 236.58 Wm^{-2}. The highest monthly solar radiation was recorded in November in Takoradi and the lowest recorded in August in Kumasi.

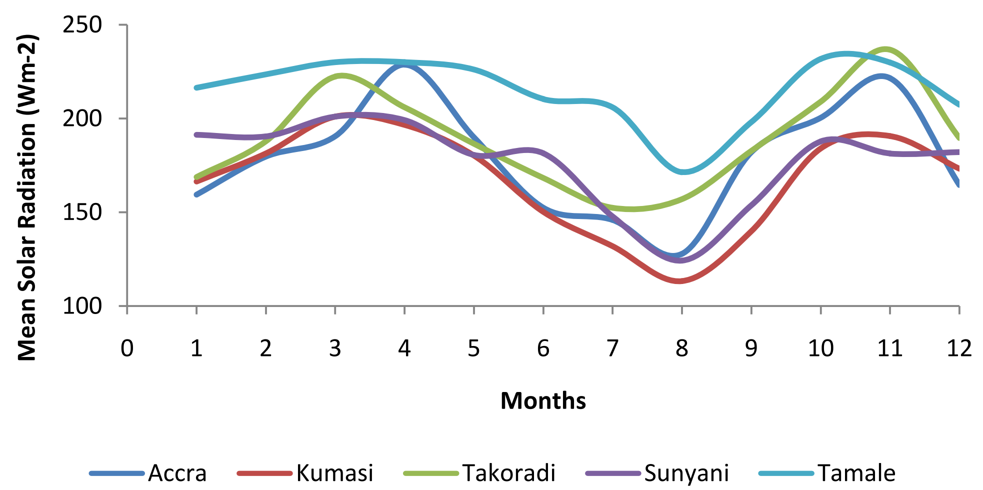


Fig. 4.2 Monthly Mean Solar Radiation for the Five Sites(June 2011-May 2012)

4.4 Mean Solar Radiation

Table 4.3 and table 4.4 shows the mean and maximum solar radiation flux for each of the sites respectively for the year. The maximum annual solar radiation of 236.58 Wm^{-2} occurred in Takoradi, followed by Tamale 231.63 Wm^{-2}, Accra 228.71 Wm^{-2}, Sunyani 200.99 Wm^{-2} and Kumasi having the lowest value of 187.69 Wm^{-2}. The highest mean solar radiation occurred at Takoradi 236.58 Wm^{-2} with Kumasi and Sunyani having the lowest value of 200.99 Wm^{-2}.

Table 4.3: Mean Solar Radiation (Wm^{-2})

SITE	**Solar Radiation (Wm^{-2})**
Accra	183.20
Kumasi	171.53
Takoradi	191.55
Sunyani	179.66
Tamale	217.88

Table 4.4 Maximum Mean Solar Radiation

SITE	**Solar Radiation(Wm^{-2})**
Accra	228.71
Kumasi	200.99
Takoradi	236.58
Sunyani	200.99
Tamale	231.63

4.5 Output of the Pro Vitus Model

After running the model, the following vital statistics on hourly power (kW) for the mean and standard deviations of the solar power, wind power and total power were generated for the five sites for the whole year;

Table 4.5: Vital Statistics on Hourly Power (kW) for each site per m^2

Parameters/Kw	**Accra**	**Kumasi**	**Takoradi**	**Sunyani**	**Tamale**
Mean (Solar Power)	197.51	166.73	197.2	196.82	228.74
Mean (Wind Power)	72.72	65.23	101.92	62.66	104.46
Mean (Total Power)	248.08	230.02	274.51	226.91	294.97
Standard Deviation (Solar Power)	266.95	261.02	282.31	268.63	302.81
Standard Deviation(Wind Power)	132.41	133.83	182.69	126.79	216.63
Standard Deviation (Total Power)	329.11	297.74	394.77	306.43	398.62

One would expect the standard deviation to be less than the mean but the figures indicate the reverse because there are wide fluctuations in the atmospheric parameters.

The following graphs below describe the mean monthly wind, solar and hybrid total power generated from the sites with the above input system parameters.

Figure 4.3 below describes the mean monthly solar power generation capacity for the five sites. The tamale site shows a relatively consistent generation capacity with a least capacity of 206.03 kW and a maximum of 231.71 kW of power in November. The excellent characteristic of this site is due to its location in the Guinea Savanna where the solar radiation exposure is greater. The features of the other four sites are very good and have similar patterns. The generation capacities of all the sites see a reduction in the months of May through to August and November when the rains are heavy during the year causing a reduction in the solar radiation exposure.

The overall monthly average solar power for all the sites lies in the range of 82.92 kW — 229.89 kW. The lowest mean monthly solar power generation capacity was recorded in August in both Kumasi and Sunyani which are both located in deciduous zones and a month with the heaviest rainfall during the year, hence the low value. The highest value was however recorded in November in Takoradi.

The figure 4.4 below describes the monthly mean power generated from wind of the five sites across the country. In the month of March, the Takoradi site recorded the highest value of 106.37 kW and Sunyani recorded the least value, 18.81 kW, in the month of November. The generation capacities of the various sites are fairly good and can be very useful for several applications.

The available total power that can be generated from both the solar and wind resources nationwide is shown in figure 5.5 below. The Sunyani site records both the maximum monthly mean power of 391.12 kW in November and the minimum of 134.85 kW in the month of August. The total mean power generation per month for the hybrid system looks very encouraging. Comparatively, Tamale and Takoradi sites are more suited for the hybrid system although the other three sites are also well in place for the system.

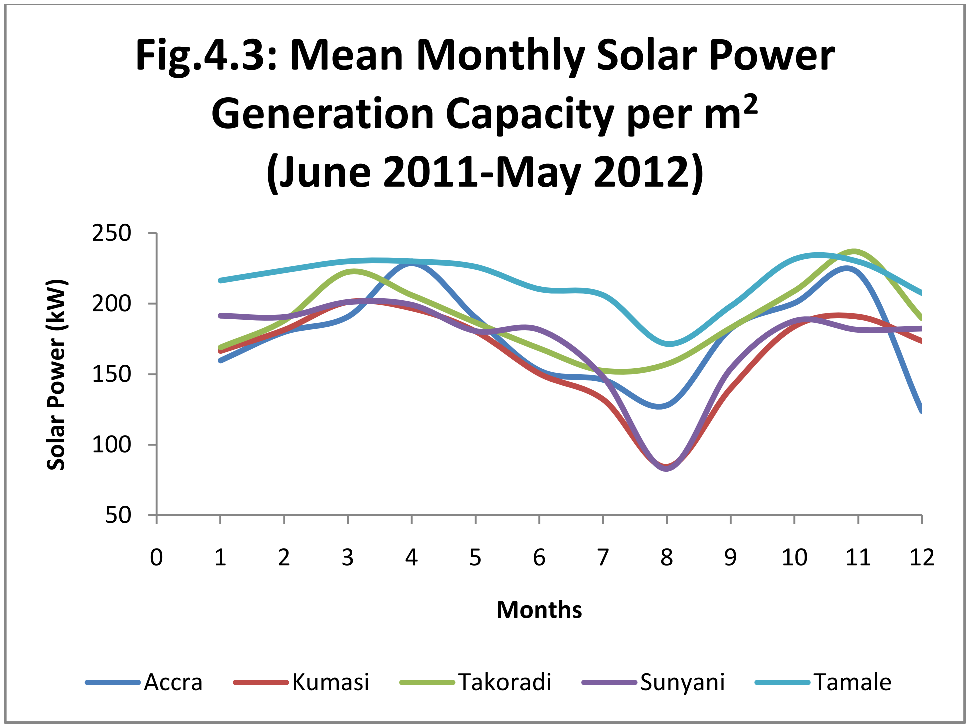


Fig.4.3: Mean Monthly Solar Power Generation Capacity per m2 (June 2011-May 2012)
Solar Power (kW)
250
200
150
100
50
0 1 2 3 4 5 6 7 8 9 10 11 12
Months
Accra
Kumasi
Takoradi
Sunyani
Tamale

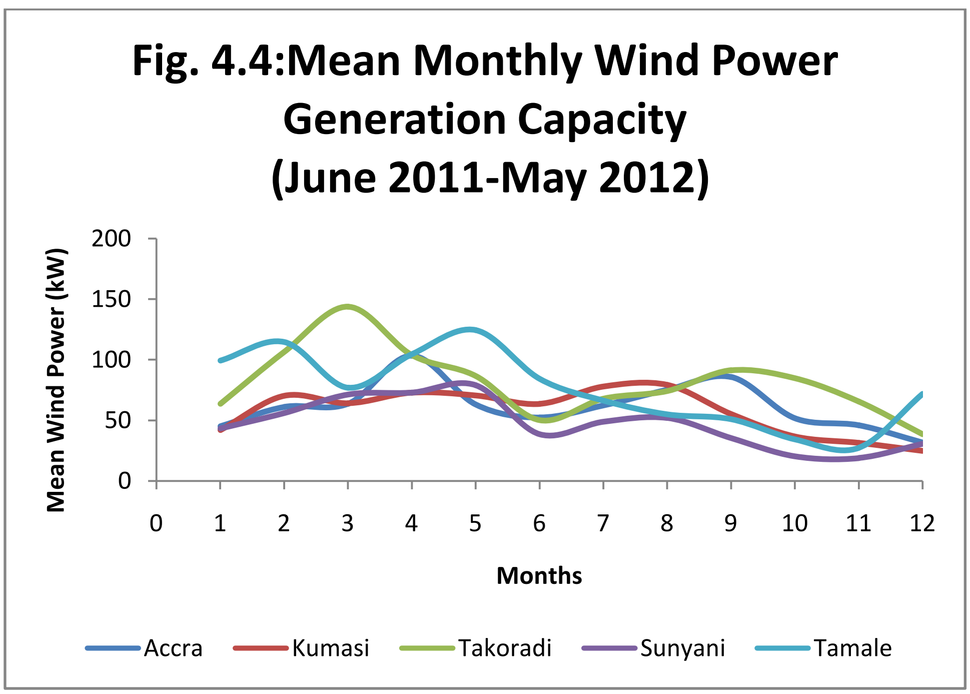
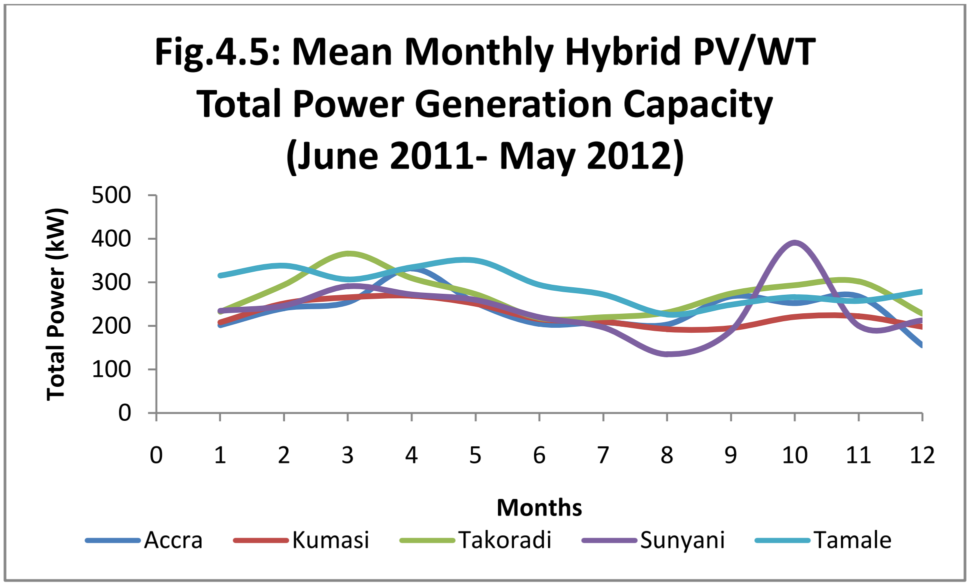


Fig. 4.4:Mean Monthly Wind Power Generation Capacity (June 2011-May 2012)
Mean Wind Power (kW)
200
150
100
50
0
0 1 2 3 4 5 6 7 8 9 10 11 12
Months
Accra
Kumasi
Takoradi
Sunyani
Tamale



4.6 Extrapolation of the Statistics

Assuming a location with similar conditions exist as the chosen sites in each district of the ten regions, then taking a land area of 10,000 m^2 to develop the hybrid system across the country in each of the 216 Metropolitan, Municipal and District assemblies will generate about 9.35 x 10^2 MW of total power annually from the hybrid system with the utilization of just 9.18 % of the total land area of Ghana. This 10,000 m^2 is equivalent to a football field area which is suitable and readily available in every District Assembly for the setting up of the complete hybrid system. Solar power is sparsely distributed hence will require a large area of land for the system yield adequate power. Below is a table showing the energy break down on regional basis with their corresponding extrapolated estimates. The power that can be generated annually from only solar resource across the 216 districts from this extrapolation is 3.40 x 10 MW. The wind resources can yield 1.04 x 10 MW from the estimation.

Table 4.6 Extrapolated Estimates of Power Distribution

Region	**Land Area (km^{-2})**	**No. of Districts**	**Mean Total Wind Power/ District x 10^2**	**Mean Total Solar Power/ Dis't(MW)**	**Mean Total Power Output (MW)/Dis't**	**Regional Outlook x 10^2 (MW)**
Gt. Accra	225.00	16.00	1,131,693.00	3.00	4.00	0.70
Ashanti	24,389.00	30.00	1,023,269.00	3.00	4.00	1.21
Western	23,921.00	22.00	1,451,041.00	3.90	5.90	1.06
Central	9,826.00	20.00	1,451,041.00	3.90	5.90	0.96
Eastern	19,323.00	26.00	1,131,693.00	3.00	4.00	1.13
Volta	20,334.00	25.00	82,250.20	3.00	3.20	0.81
Br. Ahafo	39,557.00	27.00	82,250.20	3.00	3.20	0.88
Northern	70,384.00	26.00	1,348,151.00	4.00	5.00	1.35
U. East	8,842.00	13.00	1,348,151.00	4.00	5.00	0.67
U. West	18,478.00	11.00	1,348,151.00	4.00	5.00	0.57
Total	**235,279.00**	**216.00**	**1,040,000.00**	**34.80**	**44.20**	**9.34**

Rural electrification raises a number of issues for the Ghanaian government, in terms of low population densities and their remote locations, connecting them to the national grid can be costly and often impractical. This system does not require long grids for interconnection since they are local based hence will come with low transmission losses. Ghana lost 522 GWh, representing 4.3% of net generated energy in 2012, due to transmission. The nature of the system is to supply the immediate locality and then feed the national grid with the surplus, if any. The decentralized nature of the system which does not require long transmission lines will help reduce transmission losses.

In 2005, a report published by the Resource Center for Energy, Economics and Regulation[4] which is based at the Institute of Statistical, Social and Economic Research, University of Ghana, Legon revealed that the annual per-capita electricity consumption of the average Ghanaian is about 358 kilowatt hours. Rudimentary mathematics and unit conversions suggest that the average Ghanaian consumes only 99.44 watts of electricity per day. Just 0.66 watts shy of the power required to turn on a 100 watt light bulb. [4]

Several decades later in the Twenty-first Century, Ghana still relies heavily on hydroelectric power. This constitutes an imposing 54.41 percent of total installed capacity. Thermal power sources roughly account for the rest. Ghana's energy challenge is manifested in her expanding economy and growing population. Ghana's population was 18.9 million in 2000 and is about 25 million according to the Ghana Statistical Survey Population and Housing Census conducted in 2010. The population is expected to increase to 29 million in 2015, which is the target year for the Millennium Development Goals. Table 4.6, 4.7 and 4.8 below provides various national energy statistics.

Table 4.7 Installed Electricity Generation Capacities (End of May, 2013) [8]

Plant	**Fuel Type**	**Install Capacity (MW)**	**Share (%)**
Hydro Generation			
Akosombo	Water	1,020	
Kpong	Water	160	
Bui	Water	133	
Sub-Total		***1,313***	***54.41***
Thermal Generation			
Takoradi Power Company (TAPCO)	LCO/Natural Gas	330	
Takoradi International Company (TICO)	LCO/Natural Gas	220	
Sunon Asogli Power (Ghana) Limited (SAPP)	Natural Gas	200	
Cenit Energy Ltd (CEL)	LCO/Natural Gas	110	
Tema Thermal 1 Power Plant (TT1PP)	LCO/Natural Gas	110	
Mines Reserve Plant (MRP)	Diesel	80	
Tema Thermal 2 Power Plant (TT2PP)	Natural Gas	50	
Sub-Total		***1,100***	***45.59***
Total		**2,413**	**100**

Table 4.8: Energy Indicators (2012) [8]

Energy Indicator	**Unit**	**2012**
Total Energy Consumed	KTOE	8,162.60
Total Electricity Generated	GWh	12,024.00
Total Electricity Consumed	GWh	9,258.00
Population	Million	25.90
GDP (Constant 2000 US$)	million US$	10,847.90
Energy Intensity	KTOE/US$ 1,000 of GDP	0.75
Total Electricity Generated/capita	kWh/capita	464.20
Total Electricity Consumed/capita	kWh/capita	357.50
Total Electricity Consumed/GDP	kWh/US$1,000 of GDP	853.40

Source: GDP data from World Bank National Account NB: Total Electricity Consumed include commercial losses

Table 4.9 Electricity Generation by Plant (GWh) [8]

Plant	**2012**	**Share (%)**
Hydro Generation		
Akosombo	6,950	
Kpong	1,121	
Bui	NA	
Sub-Total	***8,071***	***67.12***
Thermal Generation		
Takoradi Power Company (TAPCO)	1,061	
Takoradi International Company (TICO)	1,168	
Sunon Asogli Power (Ghana) Limited (SAPP)	848	
Cenit Energy Ltd (CEL)	94	
Tema Thermal 1 Power Plant (TT1PP)	622	
Mines Reserve Plant (MRP)	20	
Tema Thermal 2 Power Plant (TT2PP)	141	
Sub-Total	***3,954***	***32.88***
Total	**12,025**	**100**

The construction of more hydropower stations with their attendant problems, such as the disruption of the natural environment and in some cases causing of severe flooding, is not the way to go. Even if the resources are available to embark on such projects, the rivers with the capacity to generate power are few with a total output of less than 1,000 MW. Ghana can lose up to half of the power coming from hydropower in the event of severe drought. This PV/WT hybrid system can help reduce drastically the effects and dependence on hydropower.

Most forms of advanced machinery, tools and entire industries rely on electric power. Electricity's extraordinary versatility as a means of providing energy means it can be put to an almost limitless set of uses; from transport to lighting, communications to computing. Electrical power is undoubtedly the backbone of modern industrial society, and it is expected to remain so for the foreseeable future.

4.7 Economic Impact of the Surplus Power

In recognition of the need to spur economic growth and reduce poverty, the government, through the Ministry of Energy in January 2009, set objectives of increasing power generation capacity from 1,810 megawatts (MW) to 5,000 MW by 2015, and also make electricity accessible to every part of the country by 2020. [2] In order to meet these goals, the Ministry set to work enhancing the generation, transmission and distribution of electricity throughout the country. As of December 2010, Ghana's generation capacity as recorded by the Energy commission was 1865 Megawatts. Even this significant step up is not enough to cater for the country's vast energy needs. Currently, the Volta Aluminum Company Limited lies woefully under-powered with just one pot-line operating. Major steel mills in Tema also operate at drastically low power levels. It is an established fact that Ghana's industries need far more power than we currently have planned for. And not only is this power needed in quantum, but in constant regularity. An exceedingly vital piece of the power puzzle is not only the ability to generate power but to transport and distribute it efficiently. [6]

While the use of electricity for domestic purposes (e.g., lighting, radio, television, ironing) will normally lead to improvement only in the lives of consuming individuals, productive use of electricity by industries (all other things being equal), should lead to general macroeconomic improvement and a rise in the standard of living of the populace. The major consideration for Ghana is the ability of the country to match the rate of electricity demand with adequate supply, as well as the proportion of energy produced for productive use. It is estimated that about 50 percent of electricity produced in Ghana is consumed for non industrial applications domestic. If this proportionate use can be altered in favour of industrial and/or productive use, then Ghana stands to gain. The table below shows the electricity consumption by customer class.

Table 4.10: Electricity Consumption by Customer Class (GWh) [8]

Customer Class	**2012**	**Share (%)**
Residential	2,931	34.28
Non-Residential	1,153	13.48
Industrial	4,153	48.56
Street Lighting	315	3.68
Total	**8,552**	**100**

A real example of this scenario is the situation with the Volta Aluminum Company (VALCO). VALCO needs 375 MW of electricity to run all its pot lines. Each pot line is capable of producing 40,000 metric tons of aluminum metal. Together, all five pot lines can produce about

200,000 metric tons of aluminum per annum. With aluminum currently selling for about $2,300 a ton on the world market, VALCO can potentially generate over $460 million a year in revenues for the Ghanaian economy almost at par with revenues from all Oil. [6] It is easy, therefore, to see the immediate financial gains Ghana can enjoy from a fully powered VALCO. Currently VALCO receives 75 MW of electricity, which is good to power only one pot line. Apart from the obvious immense financial gains that a fully powered VALCO can generate for the country, there are also numerous knock on benefits to the Ghanaian economy to be derived from a robust VALCO. For instance, the company single handedly has the potential to directly and indirectly create jobs for over 15,000 Ghanaians in the aluminum subsector, as well as another 55,000 additional employment opportunities in other related industries downstream. [6]

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The objective of determining the potential of hybrid solar and wind resources for generating electricity power for Ghana has been accomplished. This approach can assist us to cut down on increasing cost of electric power, environmental pollution, and transmission losses and provide clean power to our rural folks to better their standard of living.

From the analysis carried out in chapter four, the power needs of the nation can be met vis-a-vis the energy deficit the country is currently facing. The surplus power can be exported for foreign exchange.

Ghana has enormous potential to generate electricity from both solar and wind resources across the country if the hybrid system is adopted. Depending on the PV/WT technologies adopted in the set up, the country may achieve higher estimates or lower values of power as stated in this work. This work puts the potential of solar power at 340.2 kW per m^2. As technology and research into renewable energy improves, it is expected that the efficiencies of the various system components will improve. This will result in cheaper pricing of the technologies and encourage mass production of system components. At the long run solar and wind power will become very cheap and competitive for energy investors to venture into.

5.2 Recommendation

The following are some of the recommendations reached after carrying out the project:

- Further studies are recommended to be carried out on the same subject matter with different models and renewable energy technologies since only one pair of a solar panel and a wind turbine were used for this analysis.
- Since the weather of a particular site can change at any time and may differ from one place to the other, direct measurements of an interested site should be carried out and analysed before embarking on set up of plants.
- Assistance should be given to Gmet to purchase another weather radar surveillance equipment to enable them to extend their measurements to areas that are outside the 300 km radius of the first one installed at the headquarter in Accra. This will end up covering the entire nation hence putting the agency in a better position to provide timely data for energy and other purposes.

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Appendix A

Excerpts of the measured data

<u>Kumasi site</u>

Date & Time	DP (°C)	PA (hPa)	PR (mm)	RH (%)	SR	TA (°C)	WD (°)	WS (m/s)
2011-05-28 17:02:00	23.5	978.3	0.0	88	-1.0	25.7	165	3.0
2011-05-28 18:02:00	21.1	979.1	0.0	90	-1.0	22.9	158	2.3
2011-05-28 19:02:00	21.4	979.8	0.0	94	-1.0	22.5	138	1.7
2011-05-28 20:02:00	21.7	980.9	0.0	94	-1.0	22.8	111	0.8
2011-05-28 21:02:00	22.0	981.4	0.0	95	-1.0	22.9	76	2.8
2011-05-28 22:02:00	21.8	981.2	0.0	95	-1.0	22.6	231	1.6
2011-05-28 23:02:00	21.8	980.7	0.0	96	-1.0	22.6	270	1.8
2011-05-29 00:02:00	22.0	980.1	0.0	96	-1.0	22.7	241	1.7
2011-05-29 01:02:00	22.2	979.3	0.0	97	-1.0	22.7	287	2.2
2011-05-29 02:02:00	22.1	978.6	0.0	96	-1.0	22.7	151	1.7
2011-05-29 03:02:00	22.2	978.7	0.0	96	-1.0	22.9	183	2.7
2011-05-29 04:02:00	22.2	979.3	0.0	96	-1.0	22.8	263	1.7
2011-05-29 05:02:00	22.3	979.7	0.0	97	0.0	22.7	217	1.3
2011-05-29 06:02:00	22.4	980.3	0.0	97	5.0	22.9	185	2.1

2011-05-29 07:02:00 22.5 980.7 0.0 96 79.0 23.2 288 0.9

2011-05-29 08:02:00 22.6 981.0 0.0 89 353.0 24.6 249 4.9

2011-05-29 09:02:00 23.0 982.0 0.0 84 512.0 25.8 242 2.3

Accra site

Date & Time

DP

(°C)

PA

(hPa)

PR

(mm)

RH

(%)

SR

TA

(°C)

WD

(°)

WS

(m/s)

2011-12-01 00:00:00 23.4 1003.2 0.0 94 -1.0 24.5 286 0.4

2011-12-01 01:00:00 23.1 1002.8 0.0 95 -1.0 23.9 360 0.6

2011-12-01 02:00:00 23.1 1002.2 0.0 95 -1.0 24.0 291 1.4

2011-12-01 03:00:00 23.2 1001.8 0.0 94 -1.0 24.2 295 0.9

2011-12-01 04:00:00 23.3 1002.0 0.0 94 -1.0 24.2 302 1.1

2011-12-01 05:00:00 23.2 1002.1 0.0 94 -1.0 24.1 295 1.5

2011-12-01 06:00:00 23.2 1002.6 0.0 95 4.0 24.0 293 1.7

2011-12-01 07:00:00 24.0 1003.2 0.0 91 137.0 25.7 270 0.8

2011-12-01 08:00:00 24.0 1003.6 0.0 80 352.0 27.7 263 1.8

2011-12-01 09:00:00 23.6 1004.0 0.0 72 484.0 29.1 244 0.4

2011-12-01 10:00:00 22.9 1003.6 0.0 65 612.0 30.2 124 1.0

2011-12-01 11:00:00 22.8 1002.8 0.0 62 203.0 31.0 194 1.7

2011-12-01 12:00:00 22.5 1002.0 0.0 59 851.0 31.4 157 4.2

2011-12-01 13:00:00 22.5 1001.5 0.0 59 800.0 31.5 134 3.9

2011-12-01 14:00:00 22.0 1000.8 0.0 60 673.0 30.8 190 3.9

2011-12-01 15:00:00 22.7 1000.6 0.0 62 488.0 30.8 173 2.6

2011-12-01 16:00:00 22.4 1000.7 0.0 64 268.0 30.0 154 3.1

2011-12-01 17:00:00 22.0 1001.2 0.0 66 70.0 29.1 133 1.6

2011-12-01 18:00:00 22.7 1001.8 0.0 72 -1.0 28.2 160 1.5

Sample data recordings for Takoradi site

Time

DP

(°C)

PA

(hPa)

PR

(mm)

RH

(%)

SR

TA

(°C)

WD

(°)

WS

(m/s)

2011-12-01 00:01:00 23.7 1010.0 0.0 87 -1.0 26.0 166 0.8

2011-12-01 01:01:00 23.1 1009.6 0.0 91 -1.0 24.7 336 0.8

2011-12-01 02:01:00 22.9 1009.0 0.0 94 -1.0 23.8 330 0.9

2011-12-01 03:01:00 22.9 1008.8 0.0 95 -1.0 23.8 344 0.9

2011-12-01 04:01:00 22.8 1008.9 0.0 93 -1.0 23.9 360 1.1

2011-12-01 05:01:00 22.5 1009.1 0.0 94 -1.0 23.5 360 0.8

2011-12-01 06:01:00 22.8 1009.6 0.0 94 1.0 23.7 355 1.2

2011-12-01 07:01:00 23.5 1010.0 0.0 91 126.0 25.1 283 0.7

2011-12-01 08:01:00 24.6 1010.6 0.0 82 327.0 28.0 106 0.6

2011-12-01 09:01:00 24.2 1010.6 0.0 73 568.0 29.5 167 3.3

2011-12-01 10:01:00 23.4 1010.4 0.0 67 753.0 30.4 168 0.9

2011-12-01 11:01:00 23.7 1010.0 0.0 69 882.0 30.2 240 0.9

2011-12-01 12:01:00 24.6 1009.3 0.0 69 864.0 31.1 184 0.6

2011-12-01 13:01:00 24.4 1008.6 0.0 72 827.0 30.1 124 1.3

2011-12-01 14:01:00 24.3 1008.0 0.0 70 712.0 30.4 147 1.1

2011-12-01 15:01:00 23.7 1007.7 0.0 68 533.0 30.2 176 2.0

Some annual recordings for Tamale site

Date & Time

DP

(°C)

PA

(hPa)

PR

(mm)

RH

(%)

SR

TA

(°C)

WD

(°)

WS

(m/s)

2011-12-01 00:04:00 2.5 991.7 0.0 25 -1.0 24.0 70 2.3

2011-12-01 01:04:00 1.8 991.2 0.0 23 -1.0 24.2 74 2.5

2011-12-01 02:04:00 2.4 990.8 0.0 29 -1.0 21.4 4 1.4

2011-12-01 03:04:00 4.4 990.6 0.0 37 -1.0 19.4 82 0.7

2011-12-01 04:04:00 4.4 990.6 0.0 38 -1.0 19.1 46 1.2

2011-12-01 05:04:00 1.7 990.7 0.0 29 -1.0 20.5 65 2.5

2011-12-01 06:04:00 2.7 991.1 0.0 37 0.0 17.5 80 1.6

2011-12-01 07:04:00 4.2 991.8 0.0 34 132.0 20.7 96 1.0

2011-12-01 08:04:00 2.8 992.2 0.0 24 364.0 25.1 80 5.6

2011-12-01 09:04:00 2.8 992.5 0.0 18 583.0 29.4 82 3.8

2011-12-01 10:04:00 2.6 992.3 0.0 16 737.0 31.8 73 5.6

2011-12-01 11:04:00 2.3 991.4 0.0 13 815.0 34.2 74 6.5

2011-12-01 12:04:00 2.2 990.5 0.0 13 821.0 35.1 84 4.0

Some annual recordings for Sunyani site

Date & Time	DP (°C)	PA (hPa)	PR (mm)	RH (%)	SR	TA (°C)	WD (°)	WS (m/s)
2011-12-01 00:02:00	22.5	978.7	0.0	90	-1.0	24.2	204	2.6
2011-12-01 01:02:00	22.1	978.2	0.0	91	-1.0	23.6	237	1.5
2011-12-01 02:02:00	22.0	977.8	0.0	93	-1.0	23.2	238	1.2
2011-12-01 03:02:00	22.0	977.5	0.0	94	-1.0	23.1	228	1.0
2011-12-01 04:02:00	21.7	977.5	0.0	95	-1.0	22.5	148	0.5
2011-12-01 05:02:00	21.6	977.7	0.0	95	-1.0	22.5	99	1.3
2011-12-01 06:02:00	21.8	978.1	0.0	95	1.0	22.5	128	1.9
2011-12-01 07:02:00	22.3	978.8	0.0	95	46.0	23.1	155	1.9
2011-12-01 08:02:00	21.8	979.5	0.0	86	161.0	24.3	36	1.3
2011-12-01 09:02:00	22.1	979.5	0.0	75	624.0	26.9	59	1.7
2011-12-01 10:02:00	21.4	978.9	0.0	69	755.0	27.6	6	0.6
2011-12-01 11:02:00	21.0	978.4	0.0	59	894.0	29.8	103	3.5
2011-12-01 12:02:00	19.8	977.6	0.0	52	945.0	30.9	103	4.0

Appendix B

Excerpts of the processed data by PRO VITUS model

1 Kumasi

Time-step	Date	Time	Solar Radiation	Temperature	Wind Speed	Solar Power	Wind Power	Total Power
1.00	6/ 1/2011	0:2:00	-1.00	24.20	3.10	0.00	68.88	68.88
2.00	6/ 1/2011	1:2:00	0.00	24.10	2.90	0.00	56.39	56.39
3.00	6/ 1/2011	2:2:00	-1.00	24.00	2.50	0.00	36.13	36.13
4.00	6/ 1/2011	3:2:00	-1.00	23.50	2.20	0.00	24.62	24.62
5.00	6/ 1/2011	4:2:00	-1.00	23.20	2.20	0.00	24.62	24.62
6.00	6/ 1/2011	5:2:00	-1.00	23.20	1.90	0.00	0.00	0.00
7.00	6/ 1/2011	6:2:00	7.00	23.50	1.30	6.99	0.00	6.99
8.00	6/ 1/2011	7:2:00	97.00	24.30	1.00	96.84	0.00	96.84
9.00	6/ 1/2011	8:2:00	406.00	25.70	2.60	405.34	40.64	445.98
10.00	6/ 1/2011	9:2:00	356.00	26.30	0.90	355.42	0.00	355.42
11.00	6/ 1/2011	10:2:00	874.00	27.90	2.60	872.58	40.64	913.22
12.00	6/ 1/2011	11:2:00	491.00	28.90	4.80	490.20	255.71	745.91
13.00	6/ 1/2011	12:2:00	765.00	29.80	2.60	763.75	40.64	804.39
14.00	6/ 1/2011	14:2:00	910.00	31.10	4.00	908.52	147.98	1,056.50
15.00	6/ 1/2011	15:2:00	641.00	31.30	3.10	639.96	68.88	708.84

2 Legon

Time-step	Date	Time	Solar Radiation	Temperature	Wind Speed	Solar Power	Wind Power	Total Power
1.00	6/ 1/2011	0:0:00	-1.00	24.50	0.90	0.00	0.00	0.00
2.00	6/ 1/2011	1:0:00	-1.00	24.20	1.10	0.00	0.00	0.00
3.00	6/ 1/2011	2:0:00	-1.00	24.20	1.50	0.00	0.00	0.00
4.00	6/ 1/2011	3:0:00	-1.00	24.20	2.20	0.00	24.62	24.62
5.00	6/ 1/2011	4:0:00	-1.00	24.20	1.80	0.00	0.00	0.00
6.00	6/ 1/2011	5:0:00	-1.00	24.20	1.30	0.00	0.00	0.00
7.00	6/ 1/2011	6:0:00	14.00	24.00	2.00	13.98	0.00	13.98
8.00	6/ 1/2011	7:0:00	162.00	25.10	1.90	161.74	0.00	161.74
9.00	6/	8:0:00	398.00	27.10	0.90	397.35	0.00	397.35

	1/2011							
10.00	6/ 1/2011	9:0:00	689.00	28.30	4.10	687.88	159.36	847.24
11.00	6/ 1/2011	10:0:00	206.00	29.30	1.20	205.66	0.00	205.66
12.00	6/ 1/2011	11:0:00	275.00	30.40	3.10	274.55	68.88	343.44
13.00	6/ 1/2011	12:0:00	351.00	30.10	3.80	350.43	126.88	477.30
14.00	6/ 1/2011	13:0:00	268.00	26.60	6.30	267.56	578.17	845.73
15.00	6/ 1/2011	14:0:00	131.00	26.40	4.90	130.79	272.03	402.82

3 Sunyani

Time-step	Date	Time	Solar Radiation	Temperature	Wind Speed	Solar Power	Wind Power	Total Power
1.00	6/ 1/2011	0:3:00	-1.00	23.90	2.80	0.00	50.76	50.76
2.00	6/ 1/2011	1:3:00	-1.00	23.50	1.40	0.00	0.00	0.00
3.00	6/ 1/2011	2:3:00	-1.00	23.40	1.40	0.00	0.00	0.00
4.00	6/ 1/2011	3:3:00	-1.00	23.30	1.90	0.00	0.00	0.00
5.00	6/ 1/2011	4:3:00	-1.00	23.00	2.00	0.00	0.00	0.00
6.00	6/ 1/2011	5:3:00	-1.00	23.00	1.10	0.00	0.00	0.00
7.00	6/ 1/2011	6:3:00	10.00	22.80	2.50	9.98	36.13	46.11
8.00	6/ 1/2011	7:3:00	118.00	23.50	1.60	117.81	0.00	117.81
9.00	6/ 1/2011	8:3:00	330.00	25.10	2.80	329.46	50.76	380.22
10.00	6/ 1/2011	9:3:00	442.00	25.30	2.10	441.28	0.00	441.28
11.00	6/ 1/2011	10:3:00	337.00	27.00	4.40	336.45	196.97	533.42
12.00	6/ 1/2011	11:3:00	940.00	28.60	3.40	938.47	90.88	1,029.35
13.00	6/ 1/2011	12:3:00	1,012.00	29.50	2.40	1,010.35	31.96	1,042.31
14.00	6/ 1/2011	13:3:00	452.00	30.00	3.00	451.26	62.43	513.69
15.00	6/ 1/2011	14:3:00	290.00	30.80	0.40	289.53	0.00	289.53

4 Takoradi

Time-step	Date	Time	Solar Radiation	Temperature	Wind Speed	Solar Power	Wind Power	Total Power
1.00	6/ 1/2011	0:1:00	-1.00	25.30	0.50	0.00	0.00	0.00
2.00	6/ 1/2011	1:1:00	-1.00	24.80	0.90	0.00	0.00	0.00
3.00	6/ 1/2011	2:1:00	-1.00	25.10	0.40	0.00	0.00	0.00
4.00	6/ 1/2011	3:1:00	-1.00	24.70	0.80	0.00	0.00	0.00
5.00	6/ 1/2011	4:1:00	-1.00	24.20	1.10	0.00	0.00	0.00

6.00	6/ 1/2011	5:1:00	-1.00	24.20	1.40	0.00	0.00	0.00
7.00	6/ 1/2011	6:1:00	5.00	23.80	0.40	4.99	0.00	4.99
8.00	6/ 1/2011	7:1:00	84.00	25.20	1.20	83.86	0.00	83.86
9.00	6/ 1/2011	8:1:00	187.00	27.20	0.70	186.70	0.00	186.70
10.00	6/ 1/2011	9:1:00	662.00	29.00	0.80	660.92	0.00	660.92
11.00	6/ 1/2011	10:1:00	758.00	29.60	3.40	756.76	90.88	847.64
12.00	6/ 1/2011	11:1:00	869.00	29.70	1.70	867.58	0.00	867.58
13.00	6/ 1/2011	12:1:00	915.00	30.10	3.50	913.51	99.14	1,012.65
14.00	6/ 1/2011	13:1:00	450.00	30.30	2.20	449.27	24.62	473.89
15.00	6/ 1/2011	14:1:00	230.00	27.60	2.70	229.63	45.51	275.14

5 Tamale

Time-step	Date	Time	Solar Radiation	Temperature	Wind Speed	Solar Power	Wind Power	Total Power
1.00	6/ 1/2011	0:4:00	-1.00	26.80	2.00	0.00	0.00	0.00
2.00	6/ 1/2011	1:4:00	-1.00	26.50	1.50	0.00	0.00	0.00
3.00	6/ 1/2011	2:4:00	-1.00	26.10	2.30	0.00	28.13	28.13
4.00	6/ 1/2011	3:4:00	-1.00	25.90	2.30	0.00	28.13	28.13
5.00	6/ 1/2011	4:4:00	-1.00	25.70	2.30	0.00	28.13	28.13
6.00	6/ 1/2011	5:4:00	-1.00	25.50	2.60	0.00	40.64	40.64
7.00	6/ 1/2011	6:4:00	36.00	25.30	1.90	35.94	0.00	35.94
8.00	6/ 1/2011	7:4:00	216.00	26.30	3.10	215.65	68.88	284.53
9.00	6/ 1/2011	8:4:00	458.00	27.60	4.00	457.25	147.98	605.24
10.00	6/ 1/2011	9:4:00	688.00	29.30	3.80	686.88	126.88	813.76
11.00	6/ 1/2011	10:4:00	868.00	30.30	3.00	866.59	62.43	929.02
12.00	6/ 1/2011	11:4:00	373.00	31.10	2.30	372.39	28.13	400.52
13.00	6/ 1/2011	12:4:00	367.00	31.00	2.20	366.40	24.62	391.02
14.00	6/ 1/2011	13:4:00	345.00	32.40	2.00	344.44	0.00	344.44
15.00	6/ 1/2011	14:4:00	321.00	32.90	1.90	320.48	0.00	320.48