A COMPARATIVE ASSESSMENT OF SOLAR RESOURCE DATABASES, SIMULATIONS AND GROUND OBSERVATIONS FOR KUMASI.

By

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DECLARATION

I hereby declare that this thesis is the result of my own original research work undertaken under the supervision of the undersigned, that all works consulted have been referenced and that no part of the thesis has been presented for another degree in this University or elsewhere.

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CERTIFICATION

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ABSTRACT

Increasing global energy demand, fossil fuel prices, energy security problems and environmental awareness have motivated countries all over the world to reduce energy consumption, employ energy efficient strategies and exploit renewable energy sources such as wind, solar, biomass and hydropower. With regards to solar energy sources there are a variety of resource databases in the world today and investors in solar energy require accurate solar resources data in their analysis to determine the feasibility of projects.

This thesis undertakes a statistical and financial comparison of a solar PV project on KNUST campus, studying the implications of using various sources of solar data. Data from Ghana Meteorological Agency (GMA), METEONORM database, RETScreen database and SODA-HelioClim-3 database were compared against 8-years ground-measured data from KNUST using MBE, RMSE and MPE. Financial comparison was also carried out to determine how the various data sources affect the 5 MW Solar PV plant using annual incomes, simple payback period, NPV and IRR as indicators.

Results for MBE ranged 0.11 - 0.81 kWh/m^2 and RMSE from 0.42 to 1.06 kWh/m^2. Where as MPE ranged form 2.89 to 20.23%. Financially a PV project that utilizes RETScreen data closely resembles ground-measured data in Simple Payback, NPV & IRR. Also as compared with ground-measured data, it is observed that RETScreen data, METEONORM, GMA data and SODA-HelioClim-3 have showed variations of $51,452.00; $139,789.00; $142,563.00 & $358,849.00 in annual changes in incomes respectively.

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LIST OF ABREVIATIONS

GWh	Gigawatt hour
IRR	Internal Rate of Return
KNUST	Kwame Nkrumah University of Science and Technology.
kWp	Kilowatt peak
kWh	Kilowatt hour
$kWh/m^2/day$	Kilowatt hour per meter squared per day
MBE	Mean Bias Error
MPE	Mean Percentage Error
MWh	Megawatt hour
NPV	Net Present Value
RMSE	Root Mean Square Error
SEAL	Solar Energy Applications Laboratory
SWERA	Solar and Wind Resource Assessment
UNEP	United Nations Environment Programme
US$	United States Dollar

CHAPTER 1 INTRODUCTION

Renewable Energy (RE) offers a promising prospect for meeting the power needs of both developing and developed countries as it is available in all parts of the world. Renewable energy such as solar and wind energy offer an opportunity to provide energy for human development while reducing Green House Gas emissions, curbing climate change and enhancing energy security.

Globally the deployment of renewable energy has risen steadily during 2011 and 2012, supplying an estimated 19% of global final energy consumption in 2011 (REN21, 2013). Total global operating capacity of solar PV also reached a 100 GW milestone in 2012, an increase from 71 GW in 2011. Countries such as Germany, Italy, United States of America, China and Japan showed increases of 32%, 16%, 7.2%, 7% and 6.6% respectively (REN21, 2013). At the subregional level, Cape Verde in 2011, had a total Solar PV systems operating capacity of 7.5 MW. Whereas, Liberia and Mali had 0.89 MW and 0.75 MW respectively (ECREEE, 2012). Ghana recently added a 2 MW solar PV plant in 2013. With more than 28 MW solar photovoltaic projects under construction throughout the ECOWAS sub-region and 189.5 MW of identified and potential PV projects in the region ECOWAS countries are making strides to produce power from solar resources (Kappiah, 2011).

Ghana over the past two decades has experienced a number of power crises due to over reliance on hydroelectric power, unavailability of natural gas and a general lack of investments. It has been estimated that grid electricity demand in Ghana would grow to about 18,000 GWh by 2015 and up to 24,000 GWh by the year 2020. It is the Ghanaian government's policy to attain 5,000 MW of electricity generation capacity by the year 2015 (Energy Commission, 2006, Ministry of Energy, 2010a); targeting at least 10% of the national electricity supply mix coming from renewable energy sources by the year 2020 (Ministry of Energy, 2010b). Renewable energy sources such as solar, wind, mini-hydro, biomass and municipal solid wastes would be considered. To aid in this objective, the parliament of Ghana in 2011 passed the renewable energy bill into law. This law (ACT 832) seeks to provide a framework to support the development and utilization of renewable energy sources and would provide an enabling environment to attract investment into the sector.

To achieve these targets, adequate renewable energy resource assessment needs to be under taken nationwide to determine the potentials for the various renewable energy resources especially solar, wind, micro and small hydropower resources. Various studies by the Energy Commission have been undertaken to help identify and map some of these resources. The outcome of one of these studies was programmed into a toolkit software. Having credible resource assessment data is important to encouraging investment in the Renewable energy sector.

Solar energy technology is expected to play an important role in attaining the 10% renewable energy target by 2020. Solar radiation is highly variable in time and space. The annual sum of incoming solar radiation can change significantly from year to year and the variability patterns are quite different each year (IRENA, 2012). Solar energy is also subject to meteorological fluctuations. A good knowledge of the different meteorological parameters such as temperature, humidity, precipitation and pressure, etc. is essential for any study with regard to the total energy available to be used by the systems (Canada et al., 1997).

The successful design and effective utilization of solar energy systems and devices for human application largely depend on the availability of information on solar radiation characteristic of the location in which the system and devices are to be used or situated (Falayi et al., 2008). Accurate data for projects is preferably measured at the ground level. The best practice would be to use 11-year irradiation data, which represents a typical solar cycle to determine power outputs of a solar energy system. Due to high equipment and installation costs, it is not financially feasible to install solar radiation measuring stations at potential project sites. Although meteorological agencies have been collecting weather data for long periods, they do so for agricultural and other purposes, which are not accurate enough for energy applications. Also, in Africa, long-term solar radiation measurements for energy applications have not been recorded, unlike other parts of the world such as Europe or Northern America. This lack of recorded radiation data makes in necessary to resort to available databases to acquire data for PV projects investment appraisals.

This thesis uses 8-year ground-measured solar irradiation data from Kumasi (latitude 6°42’N and longitude 1°57’W) as reference, to assess data obtained from a number of databases available and mathematical simulations, to access the error variations in the data sets. As well as observe how these could impact on financial metrics and project investment decisions.

1.1 OBJECTIVE

The main objective of this thesis is to compare the different sources and techniques for obtaining solar radiation data and analyzing the effect on financial metrics for solar PV projects. The specific objectives are to:

1. Review of solar irradiation data for energy projects in Ghana.
2. Review databases and empirical models for the estimation of global horizontal solar irradiation.
3. Assess and compare various solar resource databases.
4. Determine the effects of varying solar irradiation database have on PV projects financial metrics and annual incomes.

1.2 SCOPE AND ORGANIZATION OF THESIS

This thesis is organized under five main headings namely, Introduction, Literature Review, Methodology, Results and Discussion, and Conclusions and Recommendations. Chapter One contains the introduction, which is subdivided into background, objectives, methodology, scope and organization of thesis. Chapter Two reviews literature, which includes provide the theoretical foundation on which the thesis is developed and an insight into previous studies relating to the study. Chapter Three captures the methodology, which describes how the thesis was undertaken and the types of analysis performed. Chapter Four presents and discusses the actual results obtained. The final Chapter that is Chapter Five draws conclusions and makes recommendations to improve on solar resource assessment and analysis on KNUST campus.

CHAPTER 2 LITERATURE REVIEW

2.1 SOLAR RADIATION BASICS AND MEASUREMENTS.

To better utilize solar energy, the features of the sunlight and the amount of the solar power on a specific time and place are essential. The Sun is almost 150 million kilometers from the Earth. The energy density per unit time of the sunlight reaching the upper atmosphere of the Earth is about 1,367 W/m^2 referred in this study as $\mathbf{G_{sc}}$, which is known as solar constant.

Solar energy from the sun as measured on the Earth's surface does not remain constant. It varies with time, where it varies with each passing minute and hour. It also varies with seasons, years and even decades. Solar radiation also changes with location. Figure 2.1 below shows the amount of solar radiation reaching the different parts of the earth.

It is perceived by most people that solar radiation comes in a direct beam from the sun. However, as radiation from the sun hits our atmosphere, it is scattered in all directions. Solar radiation as it passes through the atmosphere undergoes several processes including absorption and scattering by various components of the atmosphere. The amount of solar radiation finally reaching the surface of earth depends quite significantly on the concentration of airborne particulate matter, gaseous pollutants and water (vapour, liquid or solid) in the sky.

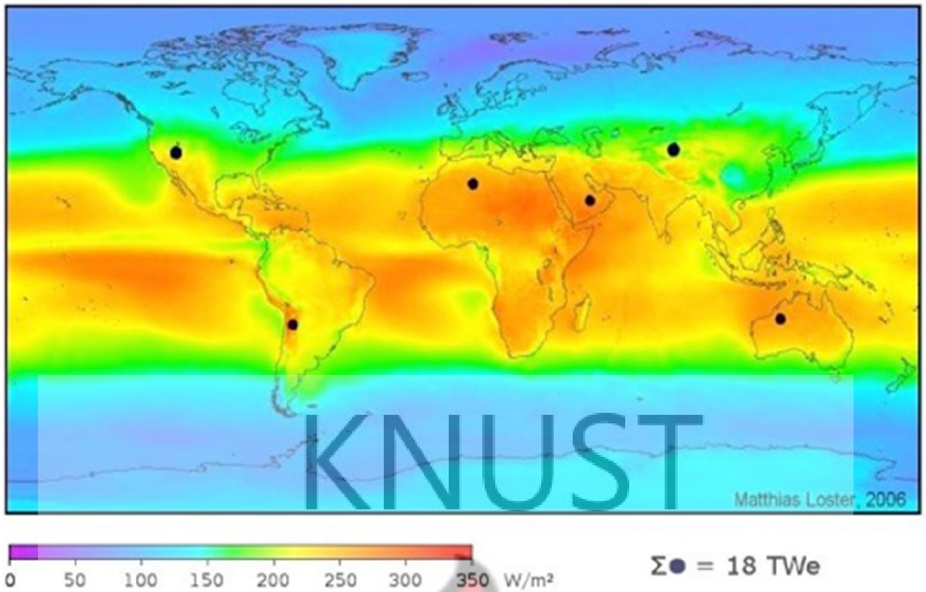

Figure 2.1 Solar Radiation map of the world
Source: (Loster, 2006)

The global solar radiation can be divided into two components: diffuse solar radiation and direct solar radiation. Diffuse radiation is radiation received from the sun after scattering in the atmosphere by atmospheric particles, gases and dispersed water droplets. Whereas direct solar radiation, is radiation that reaches the earth's surface without having been scattered by particulates in the atmosphere. These particles attenuate the solar energy and change the diffuse and direct radiation ratio. The sum of the diffuse and direct solar radiation on a surface is often referred to as global insolation or total solar radiation and the energy flux is measured in W/m^2. In other words, in the earth's atmosphere, solar radiation is received directly (direct radiation) and by diffusion in air, dust, water, etc., contained in the atmosphere (diffuse radiation). The diffuse fraction of radiation under clear-sky conditions can also be calculated theoretically (Duffie and Beekman, 1991)

As shown in Figure 2.2, global radiation is the sum of the reflected radiation, direct radiation and the diffuse solar radiation on any plane. Values of global and diffuse radiations for individual hours are essential for research and engineering applications. The global radiation on a horizontal surface is recorded at a large number of locations in the world and with relative ease, while diffuse radiation and direct solar radiation needed in many solar energy applications, is measured in comparatively few locations.

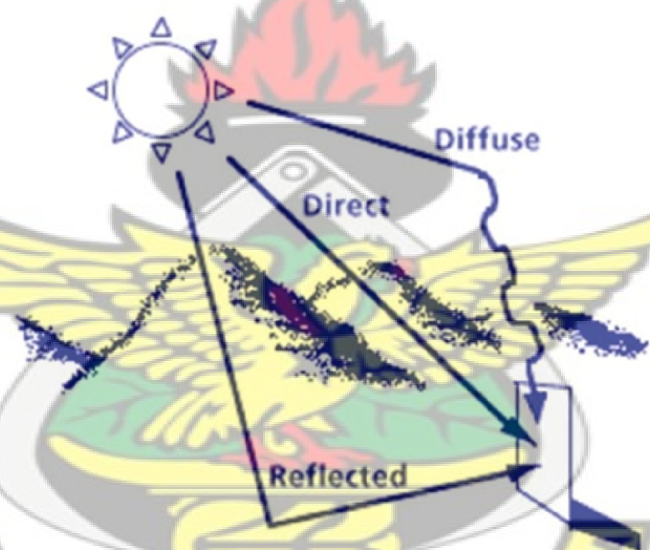

Figure 2.2 Direct, diffuse and reflected radiation.
Source: Inforse (2010)

Measurements of the solar radiation at ground level can be done by a number of different instruments including the pyranometer that measures global radiation and the pyreliometer, which measures direct solar radiation. These instruments measure all the radiation coming from the sun and from atmosphere at a specific location. These instruments are connected to data loggers that record the various solar radiation measurements onto a storage device to be processed at a later date.

These instruments and devices are part of a weather station, which measures a variety of atmospheric conditions.

Such stations are quite expensive to setup and it is not financially feasible to setup solar radiation measuring stations at several sites for data collection purposes only hence causing a lack of ground measured solar radiation data. In the case where ground-measured data is not readily available, two different kinds of models are used to circumvent the lack of ground measurements: models based on 10 to 20 years of ground measurements and interpolation models between stations, and satellite based models that give real time series for specific years (Ineichen, 2011).

2.2 GENERAL CLIMATE OF KUMASI/ GHANA.

Ghana spanning over 230,000 km^2 lies between latitude 4°44'N and 11°11' N and longitudes 3°11'W and 1°11' E. There are two main types of vegetation, namely rainforest in the south below longitude 9°N and Guinea Savanna in the north reaching to latitude 13°N. At the costal plane dry savanna lands can be found. KNUST is located on latitude 6°42'N and longitude 1°57'W and covers a total land area of about 18 km^2. It is located about 12 km to the east of Kumasi (located nearly at the geological center of the rainforest belt), the capital city of the Ashanti region of Ghana (Jackson and Akuffo, 1992).

As with most tropical locations, seasons are effectively determined by the rainfall patterns. Ghana has two major seasons during a typical year, the wet and dry season. There are two rainy seasons, which occur within a year. The major rainy season start in March and build up to a high intensity during June/July. With the minor rainy season being short, stretching over September and October. These two seasons are separated by a short relatively dry and cloudy period in August.

The other months experiencing little or no rainfall and cloud cover. Also, December and January constitute the harmattan period during which dry wind blows southwards across the Sahara desert, carrying dust along with it. The dust raises turbidity of the atmosphere and increase attenuation and dispersion of solar radiation Thus although the cloudiness is minimum during the harmattan and dry season, the insolation is on the low side (Akuffo and Brew-Hammond, 1993).

2.3 DATA SOURCES

This work utilizes data from several sources. Ground measured data from KNUST, Kumasi, data from Ghana Meteorological Agency (GMA), METEONORM software, Clean Energy Project Analysis Software (RETScreen) software, Data from the SODA-HelioClim[1] website.

2.3.1 GROUND-MEASURED DATA

Data for the study was collected from the Solar Energy Application Laboratory (SEAL) at KNUST and the synoptic station in Kumasi of the Ghana Meteorological Agency (GMA) all covering a period of 8 years (1995-2002). At the synoptic station, the data of interest was the sunshine duration.

KNUST measured global solar radiation using Licor radiometers connected to a data logger. These instruments are generally classified as second-class equipment according to the World Meteorological Organization. The instruments are

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[1] HelioClim is a database of solar radiation which is acquired by processing Meteosat images. They can be accessed through the SODA Web service as www.soda-is.com.

estimated to have a 5% margin of error. At the synoptic station, the Campbell – Stokes sunshine recorder was used to measure the duration of bright sunshine called the sunshine hour duration.

2.3.2 EMPIRICAL EQUATIONS UTILISED IN PREDICTING THE AVAILABILITY OF SOLAR RADIATION.

Many researchers have explored various methods to estimate the solar radiation from various factors. Parameters used as inputs for various relationships to accurately attempt to estimate solar radiation include astronomical factors (solar constant, earth-sun distance, solar declination and hour angle); geographical factors (latitude, longitude and altitude); geometrical factors (surface azimuth, surface tilt angle, solar altitude, solar azimuth); physical factors (albedo, scattering of air molecules, water vapor content, scattering of dust and other atmospheric constituents); and meteorological factors (atmospheric pressure, cloudiness, temperature, sunshine duration, air temperature, soil temperature, relative humidity, evaporation, precipitation, number of rainy days etc.).

Parameters that have been most frequently investigated are sunshine; cloud cover; temperature and/or precipitation variables. Although many empirical relationships exist for this conversion, the Angstrom correlation was chosen because it is the simplest and the most widely used for estimating global irradiation. Angstrom (1924) proposed a model to predict monthly mean global solar radiation, the most widely used correlation is a linear relationship between the ratio of mean daily global solar radiation to the corresponding value on a clear sky day and the ratio of mean daily sunshine duration to the maximum possible sunshine duration. The Angstrom correlation was modified by Prescott (1940) and Page (1961). Solar radiation can be easily estimated from sunshine duration; the Angstrom-Prescott models are sunshine-based and have widely applied to estimate global solar radiation

Others have also modified the Angstrom correlation to form new equations based on extraterrestrial radiation on horizontal surface rather than on clear day radiation for particular locations (Marwal et al., 2012, Ahmad and Tiwari, 2010, Duffie and Beekman, 1991).

Sunshine duration data used in this thesis was acquired from the Ghana Meteorological Agency (GMA) for the same 8-year period (1995-2002).

The Angstrom – Page's correlation is written as:

$$H = H_O\left(a + b\frac{S}{S_O}\right) \text{... Equation 2:1}$$

Monthly-daily mean maximum possible sunshine duration is calculated in hours as prescribed by Duffie and Beekman (1991)

$$S_O = \frac{2}{15}Cos^{-1}(-tan\emptyset \,/\, tan\delta) \text{... Equation 2:2}$$

Average extraterrestrial radiation is also calculated as:

$$H_O = \frac{24}{\pi}\, G_O \left(Cos\emptyset Cos\delta Sin\omega_{s_s} + \frac{\pi\omega_s}{180} Sin\emptyset Sin\delta\right) \text{... Equation 2:3}$$

$$G_O = Gsc\left[1 + 0.033Cos\frac{360n}{365}\right] \text{... Equation 2:4}$$

$$\delta = 23.45sin\left[\frac{360(284+n)}{365}\right] \text{... Equation 2:5}$$

$$\omega_s = Cos^{-1}\left(\frac{-\tan\emptyset}{\tan\delta}\right) \text{... Equation 2:6}$$

Extensive research has been carried out on Angstrom – Page's correlation to establish suitable regression coefficients for Ghana. Akuffo et al. (2003) used values of 0.25 and 0.45, for the regression constants a and b respectively. This was chosen as a result of previous works done by Jackson and Akuffo (1992) where they determined the coefficients for Kumasi to be 0.25 and 0.45.

Where,

H= Monthly average daily global irradiation

H_o= Average extraterrestrial radiation

Gsc= Solar Constant

S= Monthly-average daily hours of sunshine

S_o= Monthly-average of the maximum possible daily hours of sunshine

a, b= Regression coefficient

δ= Solar Declination angle (degree)

$\emptyset$= Latitude of the area

ω_s= Sunset hour angle

n= Day number (where n=1 on 1st January & 365 on 31st December)

G_O= Extraterrestrial radiation on the nth day

2.3.3 OTHER RADIATION DATABASES

2.3.3.1 RETScreen

The RETScreen Clean Energy Project Analysis Software is a decision support tool developed with the contribution of numerous experts from governments, industries, and academia. RETScreen is an Excel-based clean energy project analysis software provided free-of-charge, helps decision makers determine the technical and financial viability of potential renewable energy, energy efficiency and cogeneration projects. It also can be used worldwide to evaluate the energy production and savings, costs, emission reductions, and risk for various types of Renewable Energy and Energy-efficient Technologies. The CanmetENERGY research centre of Natural Resources Canada, a department of the Government of Canada, developed RETScreen. Its database contains 6,700 ground-station locations plus NASA satellite data covering the entire surface of the planet where ground measuring stations are not located (Natural Resources Canada RETScreen Website).

The RETScreen Climate Database includes meteorological data and climate data from ground monitoring stations and/or from NASA's global satellite/analysis data. If climate data is not available from a specific ground monitoring station, data is then provided from NASA's satellite/analysis data. NASA satellite data within the RETScreen Climate Database contains a full dataset and maps available from NASA and covers the entire surface of the planet, and is also available at the NASA Surface meteorology and Solar Energy Data Set website[2]. The source of the data (i.e. "Ground" or "NASA") is indicated next to the data in the climate database dialogue box as shown in Figure 2.3 below. The figure also shows a computer screen grab indicating data for KNUST, Kumasi which was collected

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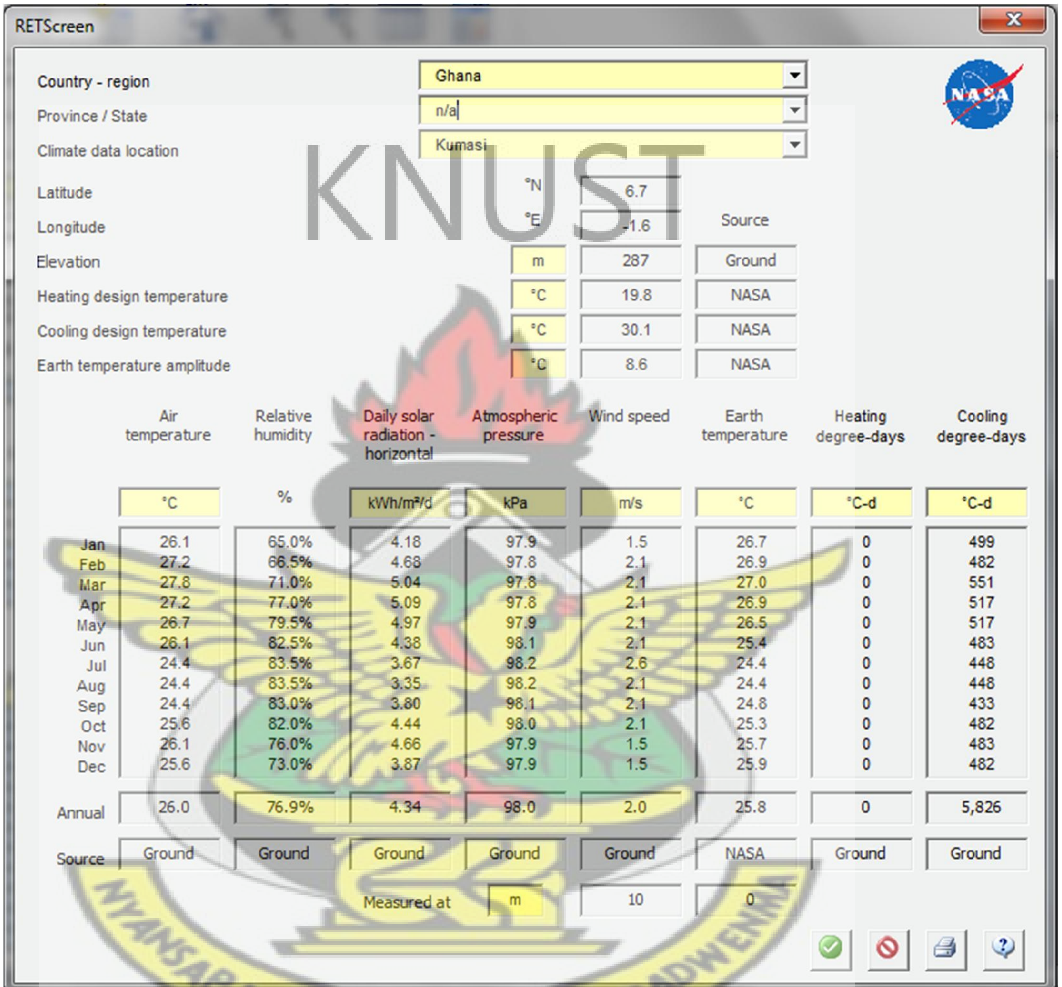
[2] http://eosweb.larc.nasa.gov/sse/RETScreen. (Assessed on 12th January 2013)

from a ground-measuring stations. Figure 2.4 shows a climate database map used by RETScreen. The red dots represent ground monitoring station data locations and the blue dots represent the NASA global satellite/analysis data locations all over the world. RETScreen is available freely on the RETScreen Website.



	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
Jan	26.1	65.0%	4.18	97.9	1.5	26.7	0	499
Feb	27.2	66.5%	4.68	97.8	2.1	26.9	0	482
Mar	27.8	71.0%	5.04	97.8	2.1	27.0	0	551
Apr	27.2	77.0%	5.09	97.8	2.1	26.9	0	517
May	26.7	79.5%	4.97	97.9	2.1	26.5	0	517
Jun	26.1	82.5%	4.38	98.1	2.1	25.4	0	483
Jul	24.4	83.5%	3.67	98.2	2.6	24.4	0	448
Aug	24.4	83.5%	3.35	98.2	2.1	24.4	0	448
Sep	24.4	83.0%	3.80	98.1	2.1	24.8	0	433
Oct	25.6	82.0%	4.44	98.0	2.1	25.3	0	482
Nov	26.1	76.0%	4.66	97.9	1.5	25.7	0	483
Dec	25.6	73.0%	3.87	97.9	1.5	25.9	0	482
Annual	26.0	76.9%	4.34	98.0	2.0	25.8	0	5,826
Source	Ground	Ground	Ground	Ground	Ground	NASA	Ground	Ground

Figure 2.3 Screen capture from RETScreen software, showing data from Kumasi as being collected from a ground-measuring stations.

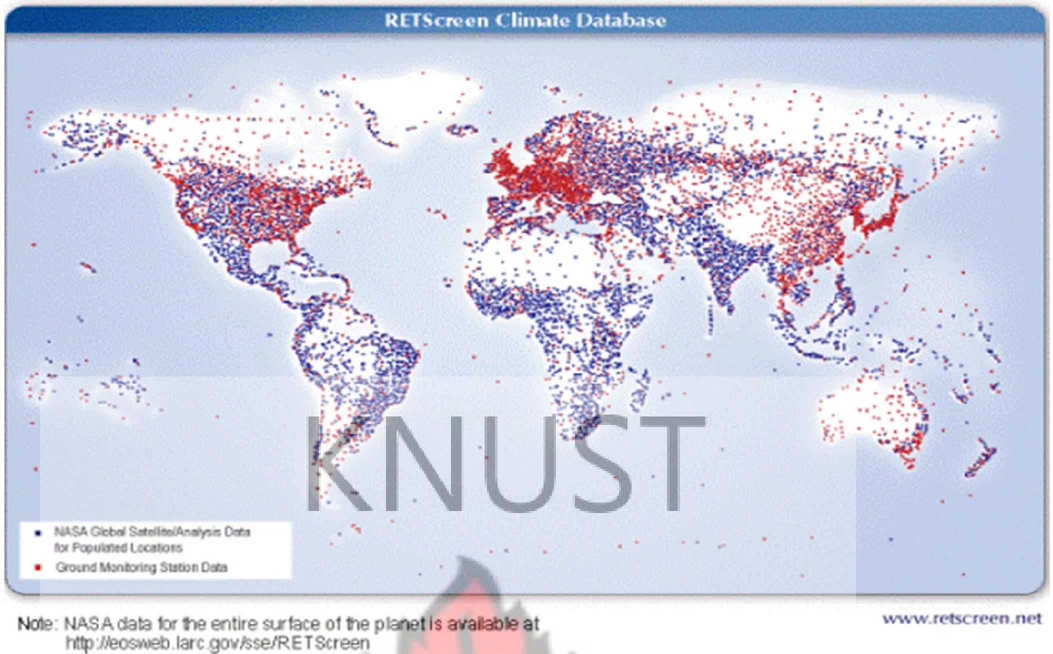


Figure 2.4 RETScreen Climate Database showing locations with ground measure data and satellite data

2.3.3.2 METEONORM

METEONORM is a computer software, which contains a vast meteorological database and interpolation algorithms to produce comprehensive climatological data for various locations. METEONORM contains a database with climate data from 8,300 stations around the world. This includes global radiation, temperature, humidity, precipitation, days with precipitation, wind speed and direction and sunshine duration. Data is stochastically generated from typical years from interpolated long term monthly means. As such, the results do not represent a real historic year but a hypothetical year, which statistically represents a typical year at the selected location, in the case of this thesis - Kumasi. (Remund et al., 2012). Meteorological data including solar resource data is usually used in the locality of a weather station. Elsewhere the data has to be interpolated between different stations.

The sophisticated interpolation algorithms METEONORM possesses create values of solar radiation, temperature and other parameters at any site in the world. In addition to interpolating data and managing sites, METEONORM can also calculate hourly values of all parameters. The resulting time series corresponds to 'typical years' and are used for system design.

The program produces about 36 different predefined export formats and can be imported into various software of choice. All export formats are available for hourly as well as monthly values. Parameters and desired units can be exported in a user-defined format. METEONORM is developed by METEOTEST, in Switzerland (Remund et al., 2012).

2.3.3.3 Solar Radiation Data (SODA): Solar Energy Services for Professionals

The third database used in this work is the Solar Radiation Data (SODA): Solar Energy Services for Professionals website[3]. The SODA website provides a variety of services available to both free and paid users. According to SODA, a service can be a database or an algorithm that performs on data to create new information, or an application that provides information that can be directly used by professionals. Daily irradiation values are available over Europe, Africa and Atlantic Ocean, from 1985 onwards.

[3] http://www.soda-is.com/ (Assessed on 12th January 2013)

The database used was from the free services section and the data was given from HelioClim-3 hourly irradiation dataset on a horizontal plane, which forms part of the HelioClim Surface Solar Radiation (SSR) databases. Data can be acquired from the following website[4]

The HelioClim surface solar radiation (SSR) databases are based on surface solar radiation estimation from Meteosat Second Generation (MSG) satellite images. This satellite-based method used to estimate the irradiation is called HelioSat-2 method and was proposed and developed by the Center for Energy and Processes (MINES ParisTech / ARMINES) It provides an alternative to interpolation methods used by other databases which are based on meteorological ground stations. It enables a better spatial and temporal coverage of data.

Radiation data is obtained from satellite images through the HelioSat-2 method. The method indicates that the whiter the pixel on the satellite image, the cloudier it is. In order to deduce the radiation value at ground level, the method also calculates the proportion of cloud contained in each MSG pixel compared to the same pixel value in clear sky conditions. This database covers Europe, Africa, the Mediterranean Basin, the Atlantic Ocean and part of the Indian Ocean with a spatial resolution of approximately 5 km and a temporal resolution up to 15 (HelioClim Overview, 2006).

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[4] http://www.soda-is.com/eng/services/services_radiation_free_eng.php (Assessed on 12th January 2013)

2.4 STATISTICAL COMPARISON.

Statistical comparisons are done using the Mean Bias Error (MBE), Root Mean Square Error (RMSE) and Mean Percentage Error (MPE). These statistics metrics were obtained from previous studies performed in this field (Almorox et al., 2005, Falayi and Rabiu, 2012, Marwal et al., 2012, Vecan, 2011).

2.4.1 MEAN BIAS ERROR (MBE) AND ROOT MEAN SQUARE ERROR (RMSE)

The MBE provides information on the long-term performance of the correlations by allowing a term-by-term comparison of the actual deviation between calculated and measured values. A positive MBE represents an over estimation whereas a negative MBE shows an under estimation. A low value of MBE is desired for a good correlation (ideal value is 0) Che et al. (2007).

The RMSE provides information on the short-term performance of the correlations by allowing a term-by-term comparison of the deviation between the calculated and measured values.

The RMSE is a frequently used measure of the differences between values predicted by a model or an estimator and the values actually observed from the values being modeled or estimated. RMSE is a good measure of precision. The RMSE indicates the level of scatter that a model produces, thus providing a term-by-term comparison. It also provides information on the short-term performance of the correlations of the actual deviation between the estimated and measured values. The value of RMSE is always positive. Almorox et al. (2005), Che et al. (2007) have recommended that a zero value for MBE & RMSE is ideal and the lower the RMSE the more accurate is the estimate. The values of the MBE represent the systematic error or overall bias, while the RMSE represent non-systematic error.

MBE and RMSE are determined as

$$MBE = \frac{1}{n}\left[\sum\left(G_{pred} - G_{obs}\right)\right] \text{ … Equation 2:7}$$

$$RMSE = \left\{\frac{1}{n}\left[\sum\left(G_{pred} - G_{obs}\right)^2\right]\right\}^{\frac{1}{2}} \text{ …. Equation 2:8}$$

2.4.2 MEAN PERCENTAGE ERROR (MPE)

The Mean Percentage Error (MPE) gives long term performance of the examined regression equations, a positive MPE values provides an indication of some amount of overestimation in the calculated values, while the negatives value indicates underestimation. A low value of MPE is desirable as proposed by Akpabio and Etuk (2002). MPE is an overall measure of forecast bias, computed from the actual differences between a series of forecasts and actual data point observed; each difference is expressed as a percentage of each observed data point, then summed and averaged (Almorox, 2011).

MPE is determined as

$$MPE = \left[\sum\left(\frac{G_{pred} - G_{obs}}{G_{obs}} \times 100\right)\right]/n \text{ … Equation 2:9}$$

Where,

G_{obs} = observed ground measured value of monthly global radiation on a horizontal surface while

G_{pred} = computed value monthly global radiation on the same surface

n = number observations.

2.5 COMPARATIVE STUDIES ON SOLAR ENERGY

Pierre Ineichen (2011) in his work on "Global irradiation; Average and typical year and year to year annual variability." The study utilized 10 to 30 years of ground-measured data acquired at 27 different sites worldwide to analyze the inter-annual variability (Percentage errors) of the solar irradiation and to compare it to averaged and interpolated data, software generated typical years and satellite derived data.

The main results are that the majority of the tested state of the art products (including METEONORM, PV GIS, RETScreen, SODA-HelioClim-3 databank, NASA SSE, Solar GIS) gave yearly values within the natural inter-annual variability of the solar radiations.

His work also drew the following conclusions:

- Even though Satellite derived data present some bias, the derived data inter-annual variation follows satisfactorily with ground measurements variation.
- For the various locations for the 1999-2006 period of comparison RETScreen, METEONORM, showed mean bias deviation -2%, -4% respectively.
- The sites with potential snow cover show an important overestimation by HelioClim data and an underestimation by SolarGIS data.

Vignola et al. (2007), after analyzing satellite derived beam and global solar radiation data determined that the Mean Bias error (MBE) is less than 5% while

Root Mean Square error was about 21% for global irradiance, indicating their high error margins observed with satellite data.

Remund and Müller (2011) estimated a 2 – 10 % error margin when they compared ground-measured data to that of METEONORM's database. Direct Normal Irradiation and Global Irradiation on and inclined surface all recorded uncertainties of 3.5 - 20% and 3 – 12% respectively. Accra's uncertainty was determined and it recorded an error of about 4.8%.

In Nigeria, Kolebaje and Mustapha (2012) concluded after their study of five models based on various variants of the Angstrom-Page equation. It was noticed that the Angstrom-Page equation based on sunshine hours in the dry season at Port Harcourt resulted in the best results as compared to the second and third order Angstrom-Page equations, although the models used showed underestimation of resulting data.

Almorox (2011) researched into the relationship between daily global solar radiation and some geographical and meteorological factors. In his study fifteen empirical global radiation models based on meteorological variables were generated and validated using daily data in 2003–2008 at the Aranjuez station (Madrid, Spain). He wanted to compare, calibrate and validate existing solar radiation models to predict solar global radiation from available meteorological data and develop a model based on meteorological variables without sunshine hours. Validation criteria included coefficient of determination, root mean square error, mean bias error, mean absolute bias error, mean percentage error, and mean absolute percentage error. The best result was derived from the model proposed, which uses extraterrestrial solar radiation, saturation vapor pressures, transformed rainfall data and daily minimum relative humidity as predictors. The model was considered the best relation for estimating the global solar radiation intensity for the Aranjuez area with an acceptable error.

Finally, Cros et al. (2004) compared irradiation data available in HelioClim database and those measured by ground stations in Europe available on the SODA-HelioClim website. The root mean square error (RMSE) increases as the irradiation increases and is less than 850 Wh/m^2, and a relative error of about 20%, which was deemed a satisfactory result. Espinar et al. (2009) also recorded similar RMSE and relative errors when they benchmarked 29 ground stations against the HelioClim-3 database.

2.6 SOLAR RADIATION DATA FOR SOLAR ENERGY PROJECTS IN GHANA.

Solar Energy projects in Ghana obtain their data from various sources, depending on the financial resources available to the project. In relation to solar energy, the Ghana Meteorological Agency (GMA) collects sunshine duration in hours for most regions in Ghana. This data is made available to the public at a fee. Sunshine duration data is collected at all 22 synoptic stations of GMA in Ghana. Their locations are as follows: Abetifi; Accra; Ada; Akatsi; Akim Oda; Akuse; Axim; Bekwai; Bole; Ho; Koforidua; Krachi; Kumasi; Navrongo; Saltpond; Sunyani; Takoradi; Tamale; Tema; Wa; Wenchi; Yendi. These stations were equipped with a Campbell-Stokes recorder, which measures the sunshine duration of all days throughout the year.

Other projects in Ghana acquire solar data for its analysis from GMA, RETScreen, or other online paid databases. The 2MW grid-connected solar farm constructed at Navrongo in the Upper East Region by VRA acquired data that is available on NASA's website. VRA also intends to investigate the potential of constructing a Solar Thermal Power plant, as part of if investigations the company has purchased detailed solar maps for Ghana from GeoModel Solar. VRA also intends to acquire an Automatic Weather Station to collect ground-measured data on GHI, DHI and DNI data to research into the feasibility of the project. As relying solely on these maps doesn't necessarily provide accurate date. The Navrongo solar farm forms part of a 10 MW project, the rest of which are to be sited at Kaleo (4 MW), Lawra (2 MW) and Jirapa (2 MW), all in the Upper West Region.

Signik Energy, a Canadian company also wishes to construct a 50 MW Solar PV farm in Bole Bamboi. Data used in this project was acquired from the Ghana Meteorological Agency, GMA. The Company has completed its feasibility study and plans are well under way.

2.7 FINANCIAL ANALYSIS.

The financial Analysis carried out in the study was to determine how various financial indicators vary depending on the solar data sources. It was carried out with the help of RETScreen software. The software has the capability of simulating some financial indicators such net present value and simple payback period over the life of the project. RETScreen also has the capability of estimating the greenhouse gas saving potential of renewable energy projects over their entire operational life.

The analysis considers the total investment cost as well as the operation and maintenance cost of the system and matches these against the revenue generated from the sale of electricity to the utility grid. The main financial indicators used for this analysis are Simple Payback Period; Net Present Value (NPV) and Internal Rate of Return (IRR).

2.7.1 SIMPLE PAYBACK PERIOD

Simple payback period is the time in which the initial cash outflow of an investment into a project is expected to be recovered from the cash inflows generated by the project (Jan, 2011a). The payback period of a given investment or project is an important determinant of whether to undertake the project, since longer payback periods are typically not desirable. The use of the Payback Period as a Capital Budgeting decision rule specifies that all independent projects with a Payback Period less than a specified number of years should be accepted. It intuitively measures how long the project takes to "pay for itself." All else being equal, shorter payback periods less than the target period are preferable to longer payback periods.

The formula to calculate payback period of a project depends on whether the cash flow per period from the project is even or uneven. In case the cash flow per period are even, the formula to calculate payback period is:

$$\text{Payback Period} = \frac{\text{Initial Investment}}{\text{Cash Inflow per Period}}$$

When cash inflows are uneven, we need to calculate the cumulative net cash flow for each period and then use the following formula for payback period:

$$\text{Payback Period} = \text{A} + \frac{\text{B}}{\text{C}}$$

In the above formula,

A= Last period with a negative cumulative cash flow;

B= Absolute value of cumulative cash flow at the end of the period A;

C= Actual Cash Flow during the period after A (Jan, 2011a).

Limitations: The payback period is considered a method of analysis with serious limitations and qualifications for its use. It does not account for the time value of money, risk, financing or other important considerations, such as the opportunity cost. Whilst the time value of money can be rectified by applying a weighted average cost of capital discount, as in the uneven calculations above. Due to these reasons payback period should not be used in isolation. Alternative measures of "return" preferred by economists are net present value and internal rate of return.

2.7.2 NET PRESENT VALUE (NPV)

Net Present Value (NPV) of the project, is the value of all future cash flows, discounted at the discount rate, in today's currency. Under the NPV method, the present value of all cash inflows is compared against the present value of all cash outflows associated with an investment project. The difference between the present values of these cash flows, determines whether or not the project is generally a financially acceptable investment (Jan, 2011b). NPV is also used in capital budgeting to analyze the profitability of an investment or project. NPV analysis is sensitive to the reliability of future cash inflows that an investment or project will yield. NPV is an indicator of how much value is added to an investment under the specified conditions of discount rate, d, and the economic life time of the investment, T; positive NPV indicates the economic viability of an investment. Positive NPV values are an indicator of a potentially feasible project. However, if NPV is negative, the project should probably be rejected because cash flows will also be negative. The greater the value of the NPV, the more profitable the investment will be.

Formula:

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t}$$

Where,
Ct = Net cash flow (revenue + savings – expenses)

r = Discount rate

t = Period

T = Total number of periods

Limitations of NPV: The NPV calculation is very sensitive to the discount rate: a small change in the discount rates causes a large change in the NPV. As the estimate of the appropriate discount rate is uncertain, this makes NPV numbers very uncertain NPV is related to the internal rate of return (IRR). NPV is thus calculated at a time 0 corresponding to the junction of the end of year 0 and the beginning of year 1.

2.7.3 INTERNAL RATE OF RETURN (IRR)

The Internal Rate of Return (IRR) is the discount rate at which the Net Present Value (NPV) of a project equals zero. The IRR decision rule specifies that all independent projects with an IRR greater than the cost of capital should be accepted. When choosing among mutually exclusive projects, the project with the highest IRR should be selected as long as the IRR is greater than the cost of capital (Mathis, 2001).

To help calculate IRR, the following equation is used:

$$NPV = 0 = \sum_{t=1}^{T} \frac{CF_t}{(1 + IRR)^t}$$

Where,
CF_t = the cash flow at time t.
t = Period

T = Total number of periods

The determination of the IRR for a project, generally, involves trial and error or a numerical technique. Fortunately, financial calculators greatly simplify this process.

CHAPTER 3 METHODOLOGY

Literature was sought in order to get acquainted with the relevant works done in the field of solar resources assessment. The areas of interest included measurements of solar energy, solar resource data analysis, and applicable equations for the estimation of solar radiation. Sources of information included the KNUST library, published articles in relevant areas, Internet, Ghana Energy Commission, Ghana Meteorological Agency (GMA).

Ground measured data was collected from the Solar Energy Applications Laboratory, of the Mechanical Engineering Department, KNUST for the period 1995-2002. Measurements of global radiation data were done using a Licor (LI-200) pyranometer and a Licor data logger. Through these instruments most of the available data on solar radiation are obtained. A pyranometer produces voltages from the thermopile detectors that are a function of the incident radiation. Radiation data usually must be integrated over some period of time, such as an hour or a day. Data was measured at an interval of 10 minutes and accumulated every hour and recorded on the data logger. Table 3.1 below presents the specifications of the Licor pyranometer used to gather the data,

Table 3.1: Specifications of Licor pyranometer

Spectral range	315-2800nm
Sensitivity	7.00 u/Wm^2
Impedance	72 ohms
Response time	15s
ISO-9060 Class	Secondary Standard

(Source: Calibration certificate)

Data required for the analysis was needed to be monthly-daily averages. Radiation data collected from the ground measuring station was outputted as hourly measurement for a 24-hour day period for the entire 8 years. These daily values were processed by accumulating the hourly solar radiation values (between 7am and 6pm for each day) to get daily radiation values. The daily values for each month were further also accumulated and then averaged to get monthly average daily radiation values in kWh/m^2/day for each month within the 8-year period. Data from GMA was collected from the GMA synoptic Weather station at the Kumasi Airport.

Data collected from the other databases (METEONORM and SODA) also underwent similar processing to the monthly daily average irradiation values in kWh/m^2/day. The data provided by both databases is a hypothetical year, which statistically represents a data in a typical year.

Sunshine duration data collected and used in this thesis was acquired from the Ghana Meteorological Agency (GMA) for the same 8-year period and was processed through the Angstrom – Page's correlation as indicated in Equation 2:1 to Equation 2:6. This processing resulted in monthly-daily average global irradiation (*H*) for each month within the 8-year period.

The Angstrom – Page's correlation is written as:

$$H = H_O\left(a + b\,\frac{S}{S_o}\right) \text{ ... Equation 2:1}$$

$$S_O = \frac{2}{15}Cos^{-1}(-t\,an\emptyset\,/\,t\,an\delta) \text{ ... Equation 2:2}$$

$$H_O = \frac{24}{\pi} G_O \left(Cos\emptyset Cos\delta Sin\omega_{s_s} + \frac{\pi\omega_s}{180} Sin\emptyset Sin\delta \right) \text{... Equation 2:3}$$

$$G_O = Gsc\left[1 + 0.033Cos\frac{360n}{365}\right] \text{... Equation 2:4}$$

$$\delta = 23.45sin\left[\frac{360(284+n)}{365}\right] \text{... Equation 2:5}$$

$$\omega_s = Cos^{-1}\left(\frac{-\tan\emptyset}{\tan\delta}\right) \text{... Equation 2:6}$$

by Jackson and Akuffo (1992) where they determined the coefficients for Kumasi to be 0.25 and 0.45.

Where,

H= Monthly average daily global irradiation

H_o= Average extraterrestrial radiation

Gsc= Solar Constant

S= Monthly-average daily hours of sunshine

S_o= Monthly-average of the maximum possible daily hours of sunshine

a, b= Regression coefficient

δ= Solar Declination angle (degree)

$\emptyset$= Latitude of the area

ω_s= Sunset hour angle

n= Day number (where n=1 on 1st January & 365 on 31st December)

G_O= Extraterrestrial radiation on the nth day

RETScreen's data was already processed and outputted as monthly average daily global irradiation. This poses some limitation, as daily statistical comparisons cannot be possible.

The statistical comparisons of these monthly average daily global irradiation values were run in Microsoft Excel using the following statistical metrics: Mean Bias Error (MBE), Root Mean Square Error (RMSE) & Mean Percentage Error (MPE).

$$MBE = \frac{1}{n}\left[\sum\left(G_{pred} - G_{obs}\right)\right] \text{ … Equation 2:7}$$

$$RMSE = \left\{\frac{1}{n}\left[\sum\left(G_{pred} - G_{obs}\right)^2\right]\right\}^{\frac{1}{2}} \text{ …. Equation 2:8}$$

$$MPE = \left[\sum\left(\frac{G_{pred} - G_{obs}}{G_{obs}} \times 100\right)\right]/n \text{ … Equation 2:9}$$

RETScreen was used to analyze a 5 MW grid-connected solar PV system using data from the various databases to ascertain how different solar data sources have an effect on the financial viability of a solar PV project. Indicators used using Simple Payback period, Net Present Value and Internal Rate of Return, special care was also given to the annual incomes and how they were affected. Parameters to be used as inputs in the analysis were determined and run for ground-measured data. After which the parameters were kept constant and solar radiation data was altered within RETScreen to further check for variations to the financials of the project. The flowchart below provides a summary of the methodology employed in this research

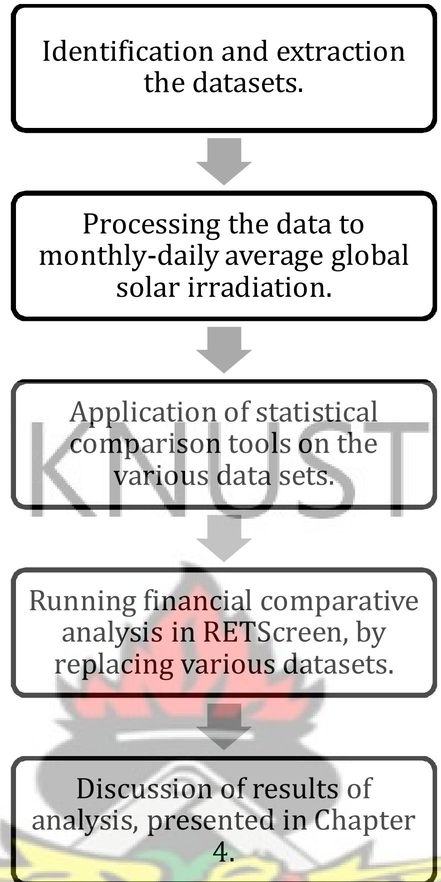

Figure 3.1: Flow chart showing a summary of the methodology

CHAPTER 4 RESULTS & DISCUSSIONS

4.1 SOLAR RESOURCE COMPARISON

The equations mentioned in Chapter 2 were calculated in order to estimate the monthly-daily average global irradiation. Starting from Equation 2:5 on page 12, solar declination angle (δ) values were calculated and results varied between -23.44° and 23.44°. In order to estimate S_o values Equation 2:2 was used.

Table 4.1 shows the monthly average of the maximum possible daily hours of sunshine in hours and average extraterrestrial irradiation calculated for the 8-yr period in kWh/m^2. H_o resulted in values between 9.08 (kWh/m^2) and 10.45 (kWh/m^2). Table 4.2 below shows the monthly-daily average sunshine hours (S) for Kumasi, Ghana from GMA.

Table 4.1 Monthly-average of the maximum possible daily hours of sunshine and Average extraterrestrial irradiation for 1995 - 2002

MONTH	S_o (h)	H_o (kWh/m^2)
JAN	11.66	9.30
FEB	11.79	9.87
MAR	11.96	10.35
APR	12.15	10.45
MAY	12.31	10.20
JUN	12.38	9.98
JUL	12.35	10.05
AUG	12.21	10.28
SEP	12.03	10.32
OCT	11.84	9.96
NOV	11.69	9.39
DEC	11.62	9.08

Table 4.2 Monthly average sunshine duration (*S*) for Kumasi in hours

MONTH	1995	1996	1997	1998	1999	2000	2001	2002
JAN	7.8	5.2	5.7	6.0	6.7	5.8	6.9	5.5
FEB	8.1	6.9	6.3	7.0	6.9	7.7	7.3	7.4
MAR	6.6	5.7	5.3	6.1	7.1	6.1	7.0	7.0
APR	6.7	5.9	6.6	6.8	7.2	7.1	7.1	6.8
MAY	7.0	6.3	6.4	6.7	6.6	6.7	6.7	7.0
JUN	4.8	4.2	3.7	5.0	5.8	4.6	5.0	5.6
JUL	4.0	4.2	3.9	3.1	3.5	3.9	4.1	3.8
AUG	2.8	3.0	2.6	2.4	2.7	3.1	2.3	3.0
SEP	3.6	2.6	3.5	3.1	2.7	2.9	3.1	3.6
OCT	5.2	4.8	5.7	4.7	4.4	5.2	6.0	6.4
NOV	6.8	7.1	6.8	6.6	6.8	7.0	6.9	7.0
DEC	6.7	4.6	6.1	5.8	6.4	5.7	6.2	6.6

For each year, the monthly-daily average global solar irradiation was calculated using Equation 2:1 and the results are presented in Table 4.3. The maximum value of the monthly-daily average global irradiation (*H*) for the average of 8-years was calculated to be 5.261 kWh/m^2 recorded in April. The minimum value of H was 3.634 kWh/m^2 observed during August.

For each year, the monthly average daily global solar irradiation was calculated for data collected from SEAL, KNUST and the results are displayed in Table 4.4. The maximum value of the monthly-average daily global irradiation for the average of 8-years was calculated to be 5.212 kWh/m^2 observed in May. The minimum monthly-average daily global irradiation was 3.316 kWh/m^2 also observed during August.

Table 4.3 Calculated monthly-daily average global irradiation using Angstrom-Page correlation (kWh/m^2/day)

MONTH	1995	1996	1997	1998	1999	2000	2001	2002	MONTHLY8-YEAR AVERAGE
JAN	5.124	4.191	4.371	4.478	4.730	4.407	4.801	4.299	4.550
FEB	5.735	5.066	4.840	5.103	5.066	5.367	5.216	5.254	5.206
MAR	5.378	4.809	4.653	4.965	5.354	4.965	5.315	5.315	5.094
APR	5.423	4.895	5.166	5.243	5.398	5.359	5.359	5.243	5.261
MAY	5.369	4.900	4.937	5.049	5.012	5.049	5.049	5.161	5.066
JUN	4.437	4.019	3.838	4.309	4.599	4.164	4.309	4.527	4.275
JUL	4.175	4.049	3.939	3.646	3.793	3.939	4.012	3.903	3.932
AUG	3.840	3.707	3.555	3.480	3.593	3.745	3.442	3.707	3.634
SEP	4.185	3.585	3.933	3.778	3.624	3.701	3.778	3.971	3.819
OCT	4.669	4.306	4.647	4.268	4.155	4.458	4.760	4.912	4.522
NOV	5.000	4.915	4.806	4.734	4.806	4.879	4.842	4.879	4.858
DEC	4.805	3.887	4.414	4.308	4.519	4.273	4.449	4.590	4.406
ANNUAL MEAN	4.845	4.361	4.425	4.447	4.554	4.525	4.611	4.647	

Table 4.4 Ground-measured monthly-daily average global solar irradiation for 8-year period (kWh/m2/day)

MONTH	1995	1996	1997	1998	1999	2000	2001	2002	8-YEAR AVERAGE
JAN	3.534	3.565	3.767	3.768	3.767	3.775	3.79	3.906	3.734
FEB	4.727	3.515	3.422		4.727	4.923	4.52	3.905	4.248
MAR	4.151	2.728	4.622	5.335	4.151	5.028	5.197	5.114	4.541
APR	3.445	4.94	4.895	3.445	4.826	5.406	5.36	5.198	4.689
MAY	5.335	5.139	4.897	5.335	5.333	5.151	5.335	5.169	5.212
JUN	4.943	4.043	4.272	4.95	4.94	4.178	5.361	4.401	4.636
JUL	3.905	3.934	2.981	3.936	3.905	3.59	3.759	3.61	3.703
AUG	3.635	3.232	3.635	3.323	3.637	3.243	2.773	3.047	3.316
SEP	3.445	3.358	3.712	4.926	3.444	3.294	3.358	3.633	3.646
OCT	5.287	4.212	3.801	4.022	4.151	4.196	4.615	4.856	4.393
NOV	4.563	4.939	4.94	4.824	4.826	4.581	4.654	4.832	4.770
DEC	5.287	3.285	3.285	4.03	4.027	3.436	3.64	3.969	3.870
Annual Mean	3.534	3.565	3.767	3.768	3.767	3.775	3.79	3.906	

Table 4.5 Monthly average daily global irradiation for all databases

MONTH	Ground-Measurement	GMA Data	METEONORM	RETScreen	SODA-HelioClim-3
JAN	3.734	4.550	4.296	4.180	5.715
FEB	4.248	5.206	4.831	4.680	5.629
MAR	4.541	5.094	5.308	5.040	5.838
APR	4.689	5.261	5.424	5.090	5.717
MAY	5.212	5.066	5.264	4.970	5.348
JUN	4.636	4.275	4.655	4.380	3.902
JUL	3.703	3.932	3.870	3.670	4.042
AUG	3.316	3.634	3.515	3.350	4.192
SEP	3.646	3.819	3.924	3.800	4.171
OCT	4.393	4.522	4.610	4.440	5.445
NOV	4.770	4.858	4.995	4.660	5.301
DEC	3.870	4.406	4.039	3.870	5.193

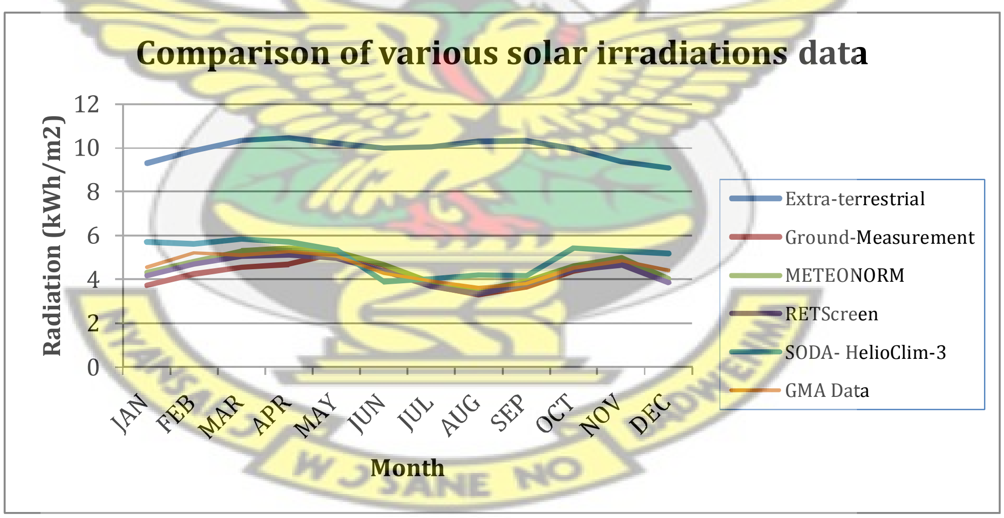

Figure 4.1 Comparison of various solar radiation datasets

Figure 4.1 shows a graphical comparison of the various data used in the thesis, including mean monthly daily extraterrestrial irradiation (*Ho*), calculated monthly daily average global solar irradiation (*H*) and actual ground measured data from KNUST, data from METEONORM, RETScreen and SODA-HelioClim-3. It is observed that there is a reduction in extraterrestrial irradiation that hits the earth surface from outside the earth's atmosphere. Factors including clouds; ozone and other gaseous concentrations, particulate matter, distance between the atmosphere and the ground. The graph shows results that are close to each other. To analyze the comparison in detail, statistical Equation 2:7 to Equation 2:9 were used to calculated values of MBE, RMSE and MPE of the selected data were shown in Table 4.6 below. Ground measured data was used as the reference in this analysis.

Table 4.6 Comparison of various statistical methods for global irradiation data

Data	MBE (kWh/m^2)	RMSE (kWh/m^2)	MPE (%)
RETScreen	0.11	0.42	2.89
METEONORM	0.33	0.42	7.91
GMA Data	0.32	0.49	8.11
SODA-HelioClim-3	0.81	1.06	20.23

From Table 4.6, it is observed that the best results for MBE = 0.11 kWh/m^2, RMSE = 0.42 kWh/m^2 and MPE = 2.89% were obtained from RETScreen data. MPE values calculated showed a general overestimation throughout the entire database of which RETScreen data recorded the lowest error. It is observed that METEONORM and Empirical Data closely resemble each other. With regards to this study, poorest results was observed from SODA-HelioClim-3 database with MBE = 0.81 kWh/m^2, RMSE = 1.06 kWh/m^2 and MPE = 20.17%. This shows that of the data compared with the ground-measured data, RETScreen is more reliable and can be used for most solar energy applications. SoDa-HelioClim-3 free database had the highest error margins in this analysis. From the MPE results as compared with ground-measured data, there is a general over estimation in the irradiation data sources under comparison for Kumasi.

The findings in this thesis however goes in line with the findings of Remund and Müller (2011) where they recorded MPEs of between 2-10% for worldwide data, after researching into the uncertainties of METEONORM. Also findings of this thesis are strongly in-line with the works of Espinar et al. (2009) and Cros et al. (2004) where they recorded relative errors of about 20% after benchmarking 29 ground stations against the HelioClim-3 database

4.2 FINANCIAL ASSESMENT

In order to ascertain how different solar data sources have an effect on the financial viability of a solar PV project using Simple Payback Period, Net Present Value and Internal Rate of Return, parameters such as total investment cost, operation and maintenance (O & M) costs, Feed-in-Tariff are important and need to be identified. Other parameters such as Project Life, Inflation Rate, Discount Rate, Grant/Capital Subsidy also need to be determined.

The total investment cost of a solar PV system encompasses the following costs: modules, inverter, mounting structures, accessories and installation. For the purpose of this study, the cost of the solar system was taken from a recent installation of a 20 kWp PV system commission at the College of Engineering.

Table 4.7 Cost break-down for grid-connected Solar PV systems per watt

Component	Cost ($/W)
Module	2.36
Inverter	0.51
Mounting Structures	0.42
Accessories	0.24
Installation	0.92
Total	4.45

The investment of US$ 22,250,000 would be needed to construct a 5 MW Grid-connected PV system. Such Grid-connected solar PV systems are considered globally to require very low level of maintenance during their operational life compared to other electricity generation systems. For the purpose of this study, the fixed operation and maintenance (O & M) costs for the systems was set at 5% of the capital cost as specified by the Public Utility and Regulation Commission

(PURC) draft feed-in-tariff policy and guidelines. Also Variable O & M costs were determined for the project on an annual bases as 0.23% of the cost of electricity (PURC, 2011). For the purpose of this thesis we shall assume no grant/ capital subsidy. All parameters used are displayed in Table 4.8. Table 4.9 displays the results of the analysis performed using RETScreen. It shows how the various databases result in different financial indicators.

Table 4.8 Parameter used to run analysis in RETScreen

Parameter	Description
Solar PV system cost	US$4.45/Wp
Fixed Operating and Maintenance Cost	5% of capital cost
Variable Operating and Maintenance Cost	0.23% of cost of electricity
Project Life	25years
Inflation Rate	10%
Discount Rate	12.5%
Grant/Capital Subsidy	0
GHG Credit	US$0/tonne
Electricity Export Rate (feed-in tariffs)	US$0.3/kWh
Debt Ratio	70%
Debt Interest rate	12%
Debt Term	10years

Table 4.9 Results of Financial Analysis

	Ground Measured	RETScreen	METEONORM	Empirical	SODA-HelioClim-3
Capacity Factor (%)	13.9	14.3	14.9	15	16.6
Variable O&M Cost ($)	4,196.00	4,314.00	4,517.00	4,524.00	5,021.00
Electricity Export Income ($)	1,824,334.00	1,875,786.00	1,964,123.00	1,966,897.00	2,183,183.00
Electricity Exported to Grid (MWh)	6081	6253	6547	6556	7277
Total Annual Cost ($)	2,898,921.00	2,899,040.00	2,899,243.00	2,899,249.00	2,899,747.00
Total Annual Income ($)	1,824,334.00	1,875,786.00	1,964,123.00	1,966,897.00	2,183,183.00
IRR - Equity (%)	2.9	3.3	4	4	5.6
IRR - Assets (%)	-1.4	-1.2	-0.7	-0.7	0.3
Simple Payback (Year)	12.8	12.5	11.9	11.9	10.7
Equity Payback (Year)	19.9	19.3	18.4	18.4	16.6
NPV	-9,288,811	-8,901,098	-8,235,430	-8,214,528	-6,584,705

Table 4.9 show the results of the financial analysis, it indicates a 5 MW project using the varied range of radiation data sources has a total annual cost ranging from $2,898,921.00 to $2,899,747.00. This variation in annual cost if due to variable operation and maintenance costs. It also shows the electricity exported to the grid increased sturdily with increase solar irradiation. The data has been graphically represented in Figure 4.2 to Figure 4.5 below.

Figure 4.2 below shows how the simple payback periods of the various databases vary against each other. A Project using ground measured data would take 12.8 years to payback its initial investments cost, using RETScreen data it would require 12.5 years, METEONORM 11.9 years, a difference of 0.9 years. While SODA-HelioClim-3 data source based project would require a period of 10.7 years, a difference of 2.1 years.

Figure 4.3 also shows the Internal Rate of Return on Equity of the various databases used. Ground measured data had the least IRR of 2.9%, with RETScreen having 3.3% and SODA-HelioClim-3 having the highest of 5.6%. For the NPV from Table 4.9 above Ground measured data has the largest negative value, as opposed to SODA-HelioClim-3 with the least large negative value.

In most projects a lesser payback period, a higher IRR and a positive NPV Value would be preferable such as in the case of SODA-HelioClim-3 results, however, using these would pose a strong misrepresentation from what is actually happening on the ground. Using Ground-measured data as a point of reference, RETScreen results closely resemble the financial makeup of the project. Using the simple payback period financial metric and considering SODA-HelioClim-3 Data, an investor would expect that if he would receive a return on his financial investment in 10.7 years. However in an actual situation it would take him 2.1 more years to receive the return on his investment.

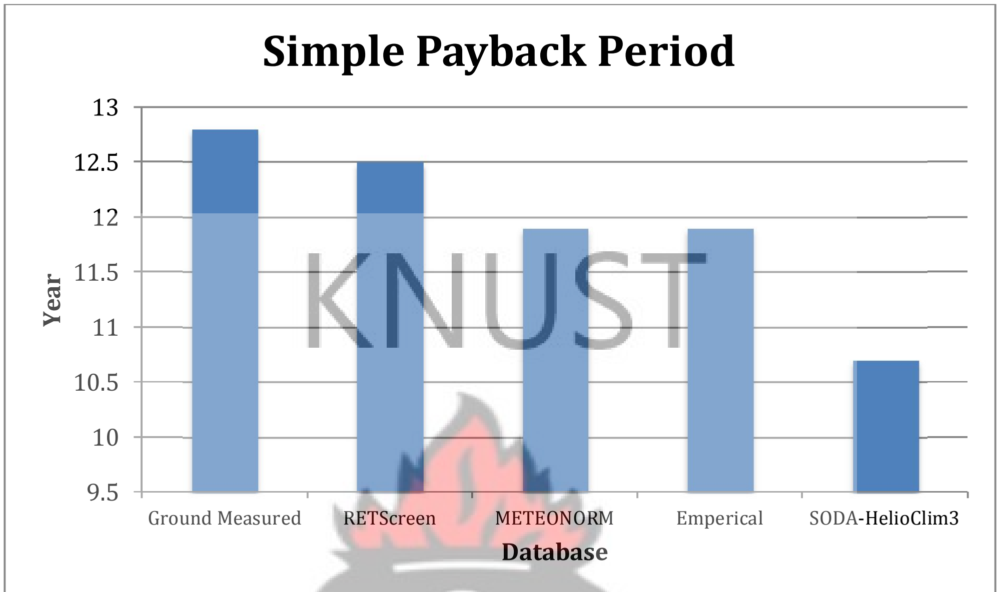

Figure 4.2: Simple Payback Period for all the databases used.

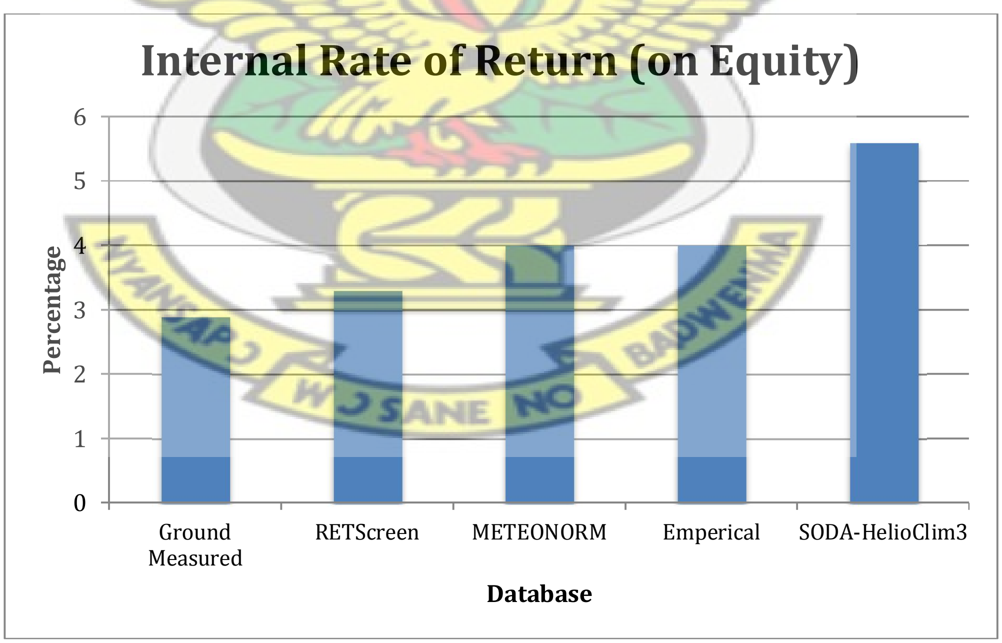

Figure 4.3: Internal Rate of Return on Equity of various databases

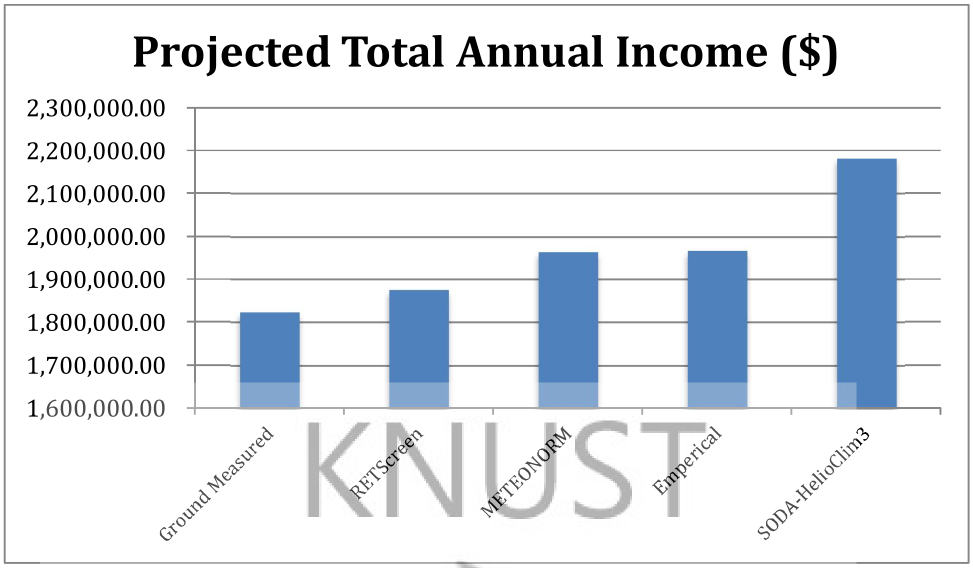

Figure 4.4 Projected Total Annual income for various databases

Figure 4.4 above indicates the projected total annual income generated by the 5 MW project annually over the project's lifetime. Also the annual income ranges from $1,824,334.00 to $2,183,183.00, with the SODA- HelioClim-3 data source having the largest income.

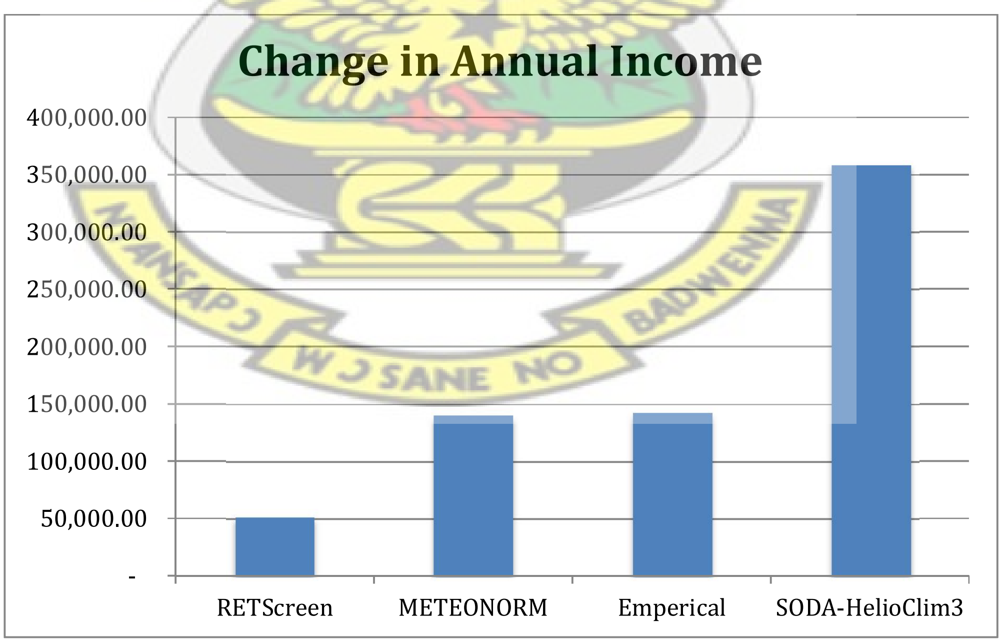

Figure 4.5: Change in annual income using ground-measured data as a point of reference

Figure 4.5 shows the change in annual income that is perceived from using the various databases. This graph was derived from subtracting the ground-measured data annual income from that of the various databases. It is observed that RETScreen data, METEONORM, Empirical data and SODA-HelioClim-3 have changes of $51,452.00; $139,789.00; $142,563.00 & $358,849.00 respectively. Which represents the following percentage changes of 2.8%; 7.7%; 7.8% & 19.7% respectively, which will be wide variations in annual incomes using various databases as opposed to ground measured data.

CHAPTER 5 CONCLUSIONS & RECOMMENDATIONS

5.1 CONCLUSIONS

Solar energy technologies offer a clean, renewable energy source, and are essential components of a sustainable energy future. In the design and evaluation of solar energy systems, information on solar irradiation and its components at a given location is needed. In this regard, reliable solar radiation data and databases are of huge importance.

From this study it is found that data provided by RETScreen is statistically more reliable as compared to the solar resource data gatherered from other databases used throughout this study. This is due to fact that RETScreen has a significant ground-data component, which makes its output quite close to the reference ground-measured data. Additionally, it is observed that there are general over estimations in the radiation data sources under comparison for Kumasi.

It can also be concluded that substituting data from various databases for the same location in RETScreen data yields quite interesting results in relation to financial parameters. Substitutions could result in variations of more than \$50,000 as projected annual income from projects. As compared with ground-measured data, it is observed that RETScreen data, METEONORM, Empirical data and SODA-HelioClim-3 have changes \$51,452.00; \$139,789.00; \$142,563.00 & \$358,849.00 in projected annual changes in incomes respectively. Hence special care must also be taken in the selection choice of radiation data. Investors also need to be aware of the variation in annual incomes that is brought on different databases. And should strive to use databases close to ground-measured data in the financial analysis.

5.2 RECOMMENDATIONS

The recommendations from this study are that;

1. It is recommended that more research be done on the various Renewable energy databases to expand on the key finding of this thesis.
    a. For instance, how various solar PV technologies will compare financially with each other.
    b. How other different meteorological parameters such as temperature, humidity, precipitation and pressure affect solar irradiation.
2. Financiers who would like to invest in solar energy projects should spend some resources and time in acquiring accurate solar radiation data, to ensure the valid and curate of the financial projections of projects.

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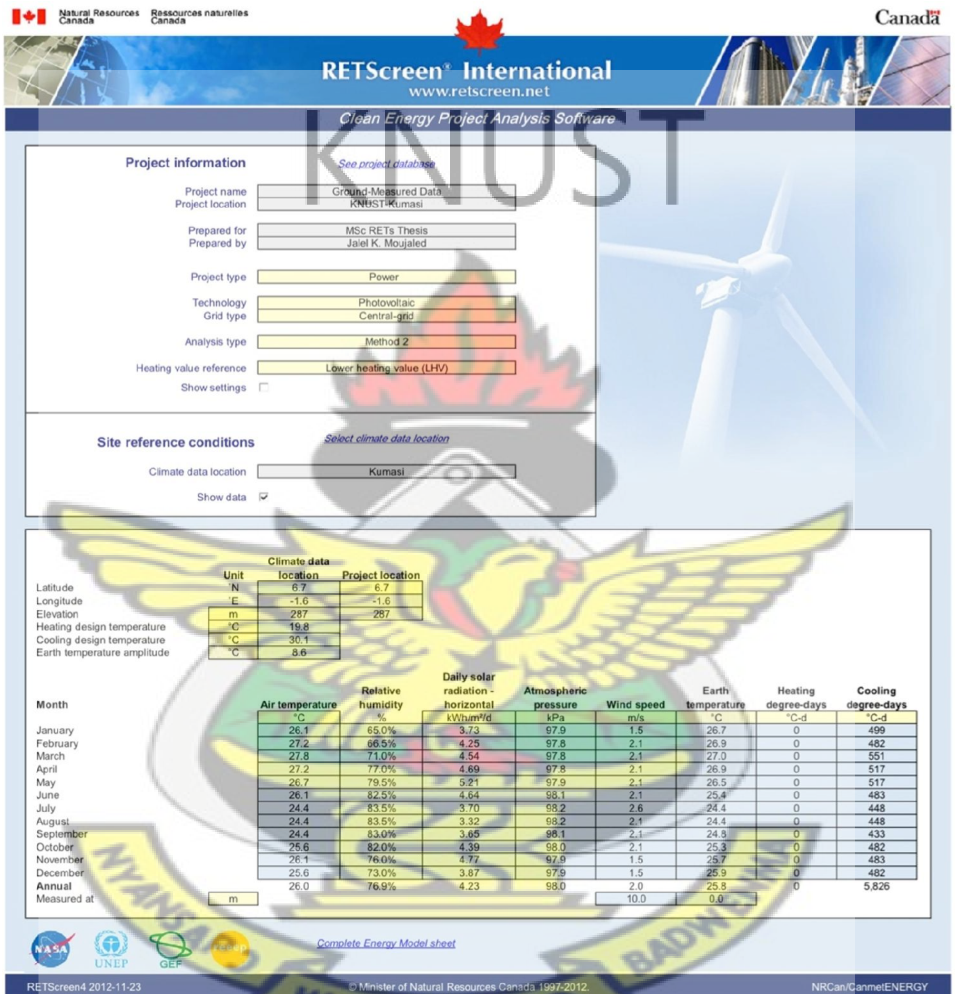
APPENDIX

APPENDIX A: RETSCREEN FINANCIAL VIABILITY PRINTOUTS.

Introductory page of RETScreen for Ground-measured data


Natural Resources Canada / Ressources naturelles Canada — Canada

RETScreen® International
www.retscreen.net
Clean Energy Project Analysis Software

Project information — See project database

Project name	Ground-Measured Data
Project location	KNUST-Kumasi
Prepared for	MSc RETs Thesis
Prepared by	Jalel K. Moujaled
Project type	Power
Technology	Photovoltaic
Grid type	Central-grid
Analysis type	Method 2
Heating value reference	Lower heating value (LHV)
Show settings	☐

Site reference conditions — Select climate data location

Climate data location	Kumasi
Show data	☑

	Unit	Climate data location	Project location
Latitude	°N	6.7	6.7
Longitude	°E	-1.6	-1.6
Elevation	m	287	287
Heating design temperature	°C	19.8	
Cooling design temperature	°C	30.1	
Earth temperature amplitude	°C	8.6	

Month	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	26.1	65.0%	3.73	97.9	1.5	26.7	0	499
February	27.2	66.5%	4.25	97.8	2.1	26.9	0	482
March	27.8	71.0%	4.54	97.8	2.1	27.0	0	551
April	27.2	77.0%	4.69	97.8	2.1	26.9	0	517
May	26.7	79.5%	5.21	97.9	2.1	26.5	0	517
June	26.1	82.5%	4.64	98.1	2.1	25.4	0	483
July	24.4	83.5%	3.70	98.2	2.6	24.4	0	448
August	24.4	83.5%	3.32	98.2	2.1	24.4	0	448
September	24.4	83.0%	3.65	98.1	2.1	24.8	0	433
October	25.6	82.0%	4.39	98.0	2.1	25.3	0	482
November	26.1	76.0%	4.77	97.9	1.5	25.7	0	483
December	25.6	73.0%	3.87	97.9	1.5	25.9	0	482
Annual	26.0	76.9%	4.23	98.0	2.0	25.8	0	5,826
Measured at (m)					10.0	0.0		

Complete Energy Model sheet

RETScreen4 2012-11-23 © Minister of Natural Resources Canada 1997-2012. NRCan/CanmetENERGY

Ground-Measured Data
KNUST-Kumasi

6/18/2013
RETScreen4-1

Energy Model page of RETScreen for Ground-measured data

RETScreen Energy Model - Power project ☐ Show alternative units

Proposed case power system

Technology		Photovoltaic
Analysis type		○ Method 1 ◉ Method 2

Resource assessment

Solar tracking mode		Fixed
Slope	°	15.0
Azimuth	°	0.0

☑ Show data

Month	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d	Electricity export rate $/MWh	Electricity exported to grid MWh
January	3.73	3.96	300.0	488.0
February	4.25	4.40	300.0	485.6
March	4.54	4.55	300.0	553.6
April	4.69	4.52	300.0	533.4
May	5.21	4.82	300.0	584.9
June	4.64	4.24	300.0	502.2
July	3.70	3.47	300.0	431.7
August	3.32	3.19	300.0	399.4
September	3.65	3.60	300.0	434.4
October	4.39	4.50	300.0	553.5
November	4.77	5.11	300.0	602.0
December	3.87	4.16	300.0	512.5
Annual	**4.23**	**4.21**	**300.00**	**6,081.1**

Annual solar radiation - horizontal	MWh/m²	1.54	
Annual solar radiation - tilted	MWh/m²	1.53	
Photovoltaic			
Type		poly-Si	
Power capacity	kW	5,000.64	See product database
Manufacturer		BP Solar	
Model		poly-Si - DC Power Wall	20836 unit(s)
Efficiency	%	11.3%	
Nominal operating cell temperature	°C	45	
Temperature coefficient	% / °C	0.40%	
Solar collector area	m²	44,097	
Miscellaneous losses	%	5.0%	
Inverter			
Efficiency	%	95.0%	
Capacity	kW	1000.0	
Miscellaneous losses	%	5.0%	
Summary			
Capacity factor	%	13.9%	
Electricity exported to grid	MWh	6,081.1	

Ground-Measured Data 6/18/2013
KNUST-Kumasi RETScreen4-1

Cost Analysis page of RETScreen for Ground-measured data

RETScreen Cost Analysis - Power project

Settings			
○ Method 1	◉ Notes/Range		
◉ Method 2	○ Second currency	Notes/Range	None
	○ Cost allocation		

Initial costs (credits)	Unit	Quantity	Unit cost	Amount	Relative costs
Feasibility study					
Site investigation	p-d			$ -	
Resource assessment	project			$ -	
Environmental assessment	p-d			$ -	
Preliminary design	p-d			$ -	
Detailed cost estimate	p-d			$ -	
GHG baseline study & MP	project			$ -	
Report preparation	p-d			$ -	
Project management	p-d			$ -	
Travel & accommodation	p-trip			$ -	
User-defined	cost			$ -	
				$ -	
Subtotal:				$ -	0.0%
Development					
Contract negotiations	p-d			$ -	
Permits & approvals	p-d			$ -	
Site survey & land rights	p-d			$ -	
GHG validation & registration	project			$ -	
Project financing	p-d			$ -	
Legal & accounting	p-d			$ -	
Project management	p-d			$ -	
Travel & accommodation	p-trip			$ -	
User-defined	cost			$ -	
				$ -	
Subtotal:				$ -	0.0%
Engineering					
Site & building design	p-d			$ -	
Mechanical design	p-d			$ -	
Electrical design	p-d			$ -	
Civil design	p-d			$ -	
Tenders & contracting	p-d			$ -	
Construction supervision	p-d			$ -	
User-defined	cost			$ -	
				$ -	
Subtotal:				$ -	0.0%
Power system					
Photovoltaic	kW	5,000.64	$ 4,450	$ 22,252,848	
Road construction	km			$ -	
Transmission line	km			$ -	
Substation	project			$ -	
Energy efficiency measures	project			$ -	
User-defined	cost			$ -	
				$ -	
Subtotal:				$ 22,252,848	95.2%
Balance of system & miscellaneous					
Specific project costs		Fuel handling system			
Delivery equipment	project			$ -	
Preparation equipment	project			$ -	
Storage equipment	project			$ -	
Distribution equipment	project			$ -	
Building & yard construction	m²			$ -	
Spare parts	%			$ -	
Transportation	project			$ -	
Training & commissioning	p-d			$ -	
Fixed O&M Costs	cost	1	$ 1,112,642	$ 1,112,642	
Contingencies	%		$ 23,365,490	$ -	
Interest during construction			$ 23,365,490	$ -	
Subtotal:		Enter number of months		$ 1,112,642	4.8%
Total initial costs				$ 23,365,490	100.0%

Annual costs (credits)	Unit	Quantity	Unit cost	Amount
O&M				
Land lease & resource rental	project			$ -
Property taxes	project			$ -
Insurance premium	project			$ -
Parts & labour	project			$ -
GHG monitoring & verification	project			$ -
Community benefits	project			$ -
General & administrative	%		$ -	$ -
Variable O&M Costs	cost	1	$ 4,196	$ 4,196
Contingencies	%		$ 4,196	$ -
Subtotal:				$ 4,196

Periodic costs (credits)	Unit	Year	Unit cost	Amount
User-defined	cost			$ -
				$ -
End of project life	cost			$ -

Ground-Measured Data
KNUST-Kumasi

6/18/2013
RETScreen4-1

Financial Analysis page of RETScreen for Ground-measured data

RETScreen Financial Analysis - Power project

Financial parameters		
General		
Fuel cost escalation rate	%	0.0%
Inflation rate	%	10.0%
Discount rate	%	12.5%
Project life	yr	25
Finance		
Incentives and grants	$	
Debt ratio	%	70.0%
Debt	$	16,355,843
Equity	$	7,009,647
Debt interest rate	%	12.00%
Debt term	yr	10
Debt payments	$/yr	2,894,725
Income tax analysis		☐

Annual income		
Electricity export income		
Electricity exported to grid	MWh	6,081
Electricity export rate	$/MWh	300.00
Electricity export income	$	1,824,334
Electricity export escalation rate	%	
GHG reduction income		☐
Customer premium income (rebate)		☐
Other income (cost)		☐
Clean Energy (CE) production income		☐

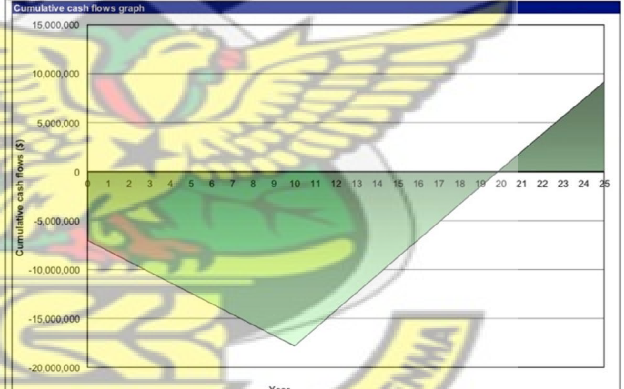
Project costs and savings/income summary			
Initial costs			
Power system	95.2%	$	22,252,848
Balance of system & misc.	4.8%	$	1,112,642
Total initial costs	**100.0%**	**$**	**23,365,490**
Annual costs and debt payments			
O&M		$	4,196
Fuel cost - proposed case		$	0
Debt payments - 10 yrs		$	2,894,725
Total annual costs		$	2,898,921
Periodic costs (credits)			
Annual savings and income			
Fuel cost - base case		$	0
Electricity export income		$	1,824,334
Total annual savings and income		$	1,824,334

Financial viability		
Pre-tax IRR - equity	%	2.9%
Pre-tax IRR - assets	%	-1.4%
After-tax IRR - equity	%	2.9%
After-tax IRR - assets	%	-1.4%
Simple payback	yr	12.8
Equity payback	yr	19.9
Net Present Value (NPV)	$	-9,288,811
Annual life cycle savings	$/yr	-1,225,598
Benefit-Cost (B-C) ratio		-0.33
Debt service coverage		0.63
Energy production cost	$/MWh	501.54

Yearly cash flows

Year #	Pre-tax $	After-tax $	Cumulative $
0	-7,009,647	-7,009,647	-7,009,647
1	-1,075,007	-1,075,007	-8,084,654
2	-1,075,468	-1,075,468	-9,160,122
3	-1,075,976	-1,075,976	-10,236,098
4	-1,076,534	-1,076,534	-11,312,632
5	-1,077,149	-1,077,149	-12,389,781
6	-1,077,824	-1,077,824	-13,467,605
7	-1,078,568	-1,078,568	-14,546,173
8	-1,079,385	-1,079,385	-15,625,558
9	-1,080,285	-1,080,285	-16,705,843
10	-1,081,274	-1,081,274	-17,787,118
11	1,812,363	1,812,363	-15,974,755
12	1,811,165	1,811,165	-14,163,589
13	1,809,849	1,809,849	-12,353,741
14	1,808,400	1,808,400	-10,545,341
15	1,806,807	1,806,807	-8,738,534
16	1,805,054	1,805,054	-6,933,480
17	1,803,126	1,803,126	-5,130,354
18	1,801,005	1,801,005	-3,329,349
19	1,798,672	1,798,672	-1,530,677
20	1,796,106	1,796,106	265,429
21	1,793,283	1,793,283	2,058,712
22	1,790,178	1,790,178	3,848,889
23	1,786,762	1,786,762	5,635,652
24	1,783,005	1,783,005	7,418,657
25	1,778,872	1,778,872	9,197,529

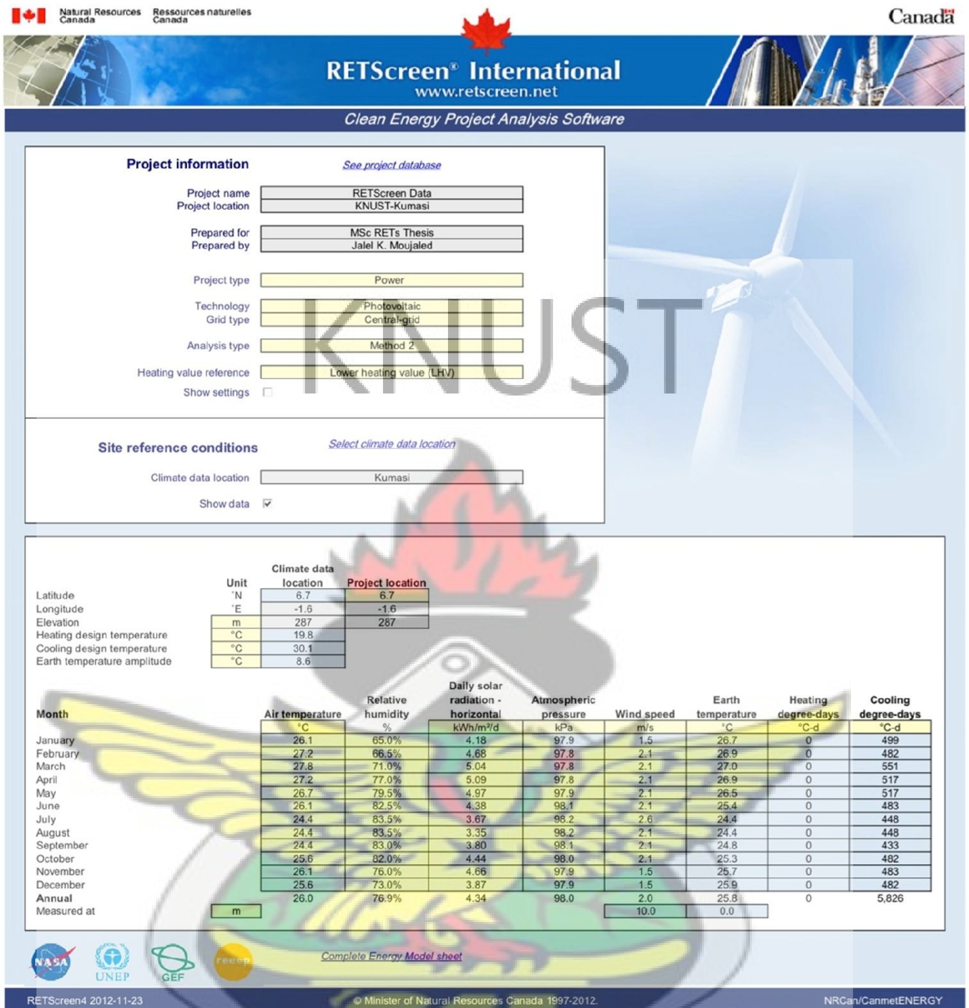
Cumulative cash flows graph



Ground-Measured Data
KNUST-Kumasi

6/18/2013
RETScreen4-1

Introductory page of RETScreen for RETScreen data



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RETScreen® International
www.retscreen.net
Clean Energy Project Analysis Software

Project information — See project database

Project name	RETScreen Data
Project location	KNUST-Kumasi
Prepared for	MSc RETs Thesis
Prepared by	Jalel K. Moujaled
Project type	Power
Technology	Photovoltaic
Grid type	Central-grid
Analysis type	Method 2
Heating value reference	Lower heating value (LHV)
Show settings	☐

Site reference conditions — Select climate data location

Climate data location	Kumasi
Show data	☑

	Unit	Climate data location	Project location
Latitude	˚N	6.7	6.7
Longitude	˚E	-1.6	-1.6
Elevation	m	287	287
Heating design temperature	°C	19.8	
Cooling design temperature	°C	30.1	
Earth temperature amplitude	°C	8.6	

Month	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	26.1	65.0%	4.18	97.9	1.5	26.7	0	499
February	27.2	66.5%	4.68	97.8	2.1	26.9	0	482
March	27.8	71.0%	5.04	97.8	2.1	27.0	0	551
April	27.2	77.0%	5.09	97.8	2.1	26.9	0	517
May	26.7	79.5%	4.97	97.9	2.1	26.5	0	517
June	26.1	82.5%	4.38	98.1	2.1	25.4	0	483
July	24.4	83.5%	3.67	98.2	2.6	24.4	0	448
August	24.4	83.5%	3.35	98.2	2.1	24.4	0	448
September	24.4	83.0%	3.80	98.1	2.1	24.8	0	433
October	25.6	82.0%	4.44	98.0	2.1	25.3	0	482
November	26.1	76.0%	4.66	97.9	1.5	25.7	0	483
December	25.6	73.0%	3.87	97.9	1.5	25.9	0	482
Annual	26.0	76.9%	4.34	98.0	2.0	25.8	0	5,826
Measured at (m)					10.0	0.0		

NASA UNEP GEF reeep — Complete Energy Model sheet

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RETScreen Data
KNUST-Kumasi

6/18/2013
RETScreen4-1

Energy Model page of RETScreen for RETScreen data

RETScreen Energy Model - Power project

☐ Show alternative units

Proposed case power system

Technology		Photovoltaic
Analysis type		○ Method 1 ⦿ Method 2
Resource assessment		
Solar tracking mode		Fixed
Slope	°	15.0
Azimuth	°	0.0

☑ Show data

Month	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d	Electricity export rate $/MWh	Electricity exported to grid MWh
January	4.18	4.47	300.0	548.4
February	4.68	4.87	300.0	535.0
March	5.04	5.05	300.0	612.0
April	5.09	4.89	300.0	575.3
May	4.97	4.61	300.0	561.0
June	4.38	4.03	300.0	477.9
July	3.67	3.44	300.0	428.3
August	3.35	3.22	300.0	403.2
September	3.80	3.75	300.0	452.0
October	4.44	4.55	300.0	559.3
November	4.66	4.98	300.0	587.9
December	3.87	4.16	300.0	512.5
Annual	**4.34**	**4.33**	**300.00**	**6,252.6**

Annual solar radiation - horizontal	MWh/m²	1.58	
Annual solar radiation - tilted	MWh/m²	1.58	
Photovoltaic			
Type		poly-Si	
Power capacity	kW	5,000.64	See product database
Manufacturer		BP Solar	
Model		poly-Si - DC Power Wall	20836 unit(s)
Efficiency	%	11.3%	
Nominal operating cell temperature	°C	45	
Temperature coefficient	% / °C	0.40%	
Solar collector area	m²	44,097	
Miscellaneous losses	%	5.0%	
Inverter			
Efficiency	%	95.0%	
Capacity	kW	1000.0	
Miscellaneous losses	%	5.0%	
Summary			
Capacity factor	%	14.3%	
Electricity exported to grid	MWh	6,252.6	

RETScreen Data
KNUST-Kumasi

6/18/2013
RETScreen4-1

Cost Analysis page of RETScreen for RETScreen data

RETScreen Cost Analysis - Power project

Settings

- ○ Method 1
- ◉ Method 2
- ◉ Notes/Range
- ○ Second currency
- ○ Cost allocation

Notes/Range: None

Initial costs (credits)	Unit	Quantity	Unit cost	Amount	Relative costs
Feasibility study					
Site investigation	p-d			$ -	
Resource assessment	project			$ -	
Environmental assessment	p-d			$ -	
Preliminary design	p-d			$ -	
Detailed cost estimate	p-d			$ -	
GHG baseline study & MP	project			$ -	
Report preparation	p-d			$ -	
Project management	p-d			$ -	
Travel & accommodation	p-trip			$ -	
User-defined	cost			$ -	
				$ -	
Subtotal:				$ -	0.0%
Development					
Contract negotiations	p-d			$ -	
Permits & approvals	p-d			$ -	
Site survey & land rights	p-d			$ -	
GHG validation & registration	project			$ -	
Project financing	p-d			$ -	
Legal & accounting	p-d			$ -	
Project management	p-d			$ -	
Travel & accommodation	p-trip			$ -	
User-defined	cost			$ -	
				$ -	
Subtotal:				$ -	0.0%
Engineering					
Site & building design	p-d			$ -	
Mechanical design	p-d			$ -	
Electrical design	p-d			$ -	
Civil design	p-d			$ -	
Tenders & contracting	p-d			$ -	
Construction supervision	p-d			$ -	
User-defined	cost			$ -	
				$ -	
Subtotal:				$ -	0.0%
Power system					
Photovoltaic	kW	5,000.64	$ 4,450	$ 22,252,848	
Road construction	km			$ -	
Transmission line	km			$ -	
Substation	project			$ -	
Energy efficiency measures	project			$ -	
User-defined	cost			$ -	
				$ -	
Subtotal:				$ 22,252,848	95.2%
Balance of system & miscellaneous					
Specific project costs		Fuel handling system			
Delivery equipment	project			$ -	
Preparation equipment	project			$ -	
Storage equipment	project			$ -	
Distribution equipment	project			$ -	
Building & yard construction	m²			$ -	
Spare parts	%			$ -	
Transportation	project			$ -	
Training & commissioning	p-d			$ -	
Fixed O&M Costs	cost	1	$ 1,112,642	$ 1,112,642	
Contingencies	%		$ 23,365,490	$ -	
Interest during construction			$ 23,365,490	$ -	
Subtotal:		Enter number of months		$ 1,112,642	4.8%
Total initial costs				$ 23,365,490	100.0%

Annual costs (credits)	Unit	Quantity	Unit cost	Amount
O&M				
Land lease & resource rental	project			$ -
Property taxes	project			$ -
Insurance premium	project			$ -
Parts & labour	project			$ -
GHG monitoring & verification	project			$ -
Community benefits	project			$ -
General & administrative	%		$ -	$ -
Variable O&M Costs	cost	1	$ 4,314	$ 4,314
Contingencies	%		$ 4,314	$ -
Subtotal:				$ 4,314

Periodic costs (credits)	Unit	Year	Unit cost	Amount
User-defined	cost			$ -
				$ -
End of project life	cost			$ -

RETScreen Data
KNUST-Kumasi

6/18/2013
RETScreen4-1

Financial Analysis page of RETScreen for RETScreen data

RETScreen Financial Analysis - Power project

Financial parameters

General		
Fuel cost escalation rate	%	0.0%
Inflation rate	%	10.0%
Discount rate	%	12.5%
Project life	yr	25

Finance		
Incentives and grants	$	
Debt ratio	%	70.0%
Debt	$	16,355,843
Equity	$	7,009,647
Debt interest rate	%	12.00%
Debt term	yr	10
Debt payments	$/yr	2,894,725

Income tax analysis ☐

Annual income

Electricity export income		
Electricity exported to grid	MWh	6,253
Electricity export rate	$/MWh	300.00
Electricity export income	$	1,875,786
Electricity export escalation rate	%	

GHG reduction income ☐

Customer premium income (rebate) ☐

Other income (cost) ☐

Clean Energy (CE) production income ☐

Project costs and savings/income summary

Initial costs			
Power system	95.2%	$	22,252,848
Balance of system & misc.	4.8%	$	1,112,642
Total initial costs	**100.0%**	**$**	**23,365,490**

Annual costs and debt payments		
O&M	$	4,314
Fuel cost - proposed case	$	0
Debt payments - 10 yrs	$	2,894,725
Total annual costs	**$**	**2,899,040**

Periodic costs (credits)

Annual savings and income		
Fuel cost - base case	$	0
Electricity export income	$	1,875,786
Total annual savings and income	**$**	**1,875,786**

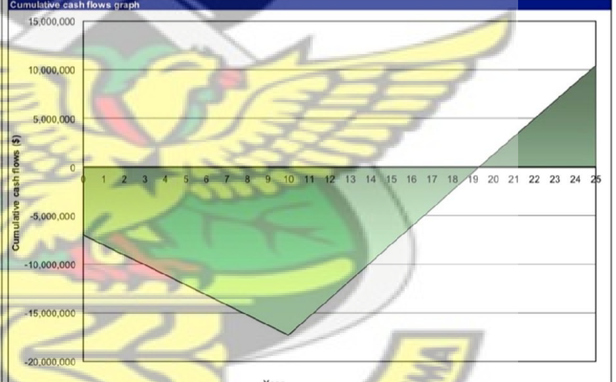
Financial viability

Pre-tax IRR - equity	%	3.3%
Pre-tax IRR - assets	%	-1.2%
After-tax IRR - equity	%	3.3%
After-tax IRR - assets	%	-1.2%
Simple payback	yr	12.5
Equity payback	yr	19.3
Net Present Value (NPV)	$	-8,901,098
Annual life cycle savings	$/yr	-1,174,441
Benefit-Cost (B-C) ratio		-0.27
Debt service coverage		0.64
Energy production cost	$/MWh	487.83

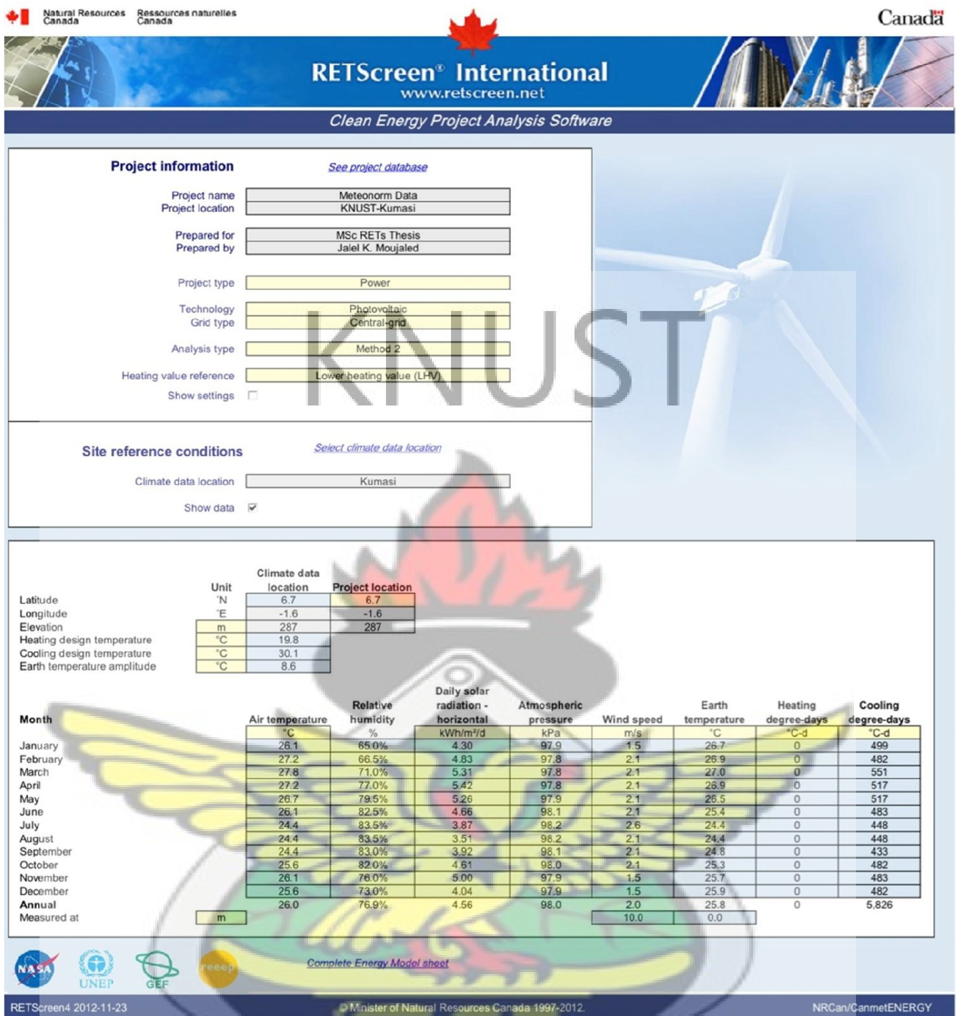
Yearly cash flows

Year #	Pre-tax $	After-tax $	Cumulative $
0	-7,009,647	-7,009,647	-7,009,647
1	-1,023,685	-1,023,685	-8,033,332
2	-1,024,160	-1,024,160	-9,057,492
3	-1,024,682	-1,024,682	-10,082,174
4	-1,025,256	-1,025,256	-11,107,430
5	-1,025,888	-1,025,888	-12,133,318
6	-1,026,583	-1,026,583	-13,159,900
7	-1,027,347	-1,027,347	-14,187,247
8	-1,028,188	-1,028,188	-15,215,435
9	-1,029,112	-1,029,112	-16,244,547
10	-1,030,130	-1,030,130	-17,274,677
11	1,863,477	1,863,477	-15,411,200
12	1,862,246	1,862,246	-13,548,954
13	1,860,892	1,860,892	-11,688,063
14	1,859,402	1,859,402	-9,828,660
15	1,857,764	1,857,764	-7,970,897
16	1,855,962	1,855,962	-6,114,935
17	1,853,979	1,853,979	-4,260,956
18	1,851,799	1,851,799	-2,409,157
19	1,849,400	1,849,400	-559,757
20	1,846,761	1,846,761	1,287,004
21	1,843,859	1,843,859	3,130,863
22	1,840,666	1,840,666	4,971,529
23	1,837,154	1,837,154	6,808,683
24	1,833,291	1,833,291	8,641,974
25	1,829,042	1,829,042	10,471,016

Cumulative cash flows graph



Introductory page of RETScreen for METEONORM data



Natural Resources Canada / Ressources naturelles Canada — Canada

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Clean Energy Project Analysis Software

Project information — See project database

Project name: Meteonorm Data
Project location: KNUST-Kumasi
Prepared for: MSc RETs Thesis
Prepared by: Jalel K. Moujaled
Project type: Power
Technology: Photovoltaic
Grid type: Central-grid
Analysis type: Method 2
Heating value reference: Lower heating value (LHV)
Show settings: ☐

Site reference conditions — Select climate data location

Climate data location: Kumasi
Show data: ☑

	Unit	Climate data location	Project location
Latitude	°N	6.7	6.7
Longitude	°E	-1.6	-1.6
Elevation	m	287	287
Heating design temperature	°C	19.8	
Cooling design temperature	°C	30.1	
Earth temperature amplitude	°C	8.6	

Month	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	26.1	65.0%	4.30	97.9	1.5	26.7	0	499
February	27.2	66.5%	4.83	97.8	2.1	26.9	0	482
March	27.8	71.0%	5.31	97.8	2.1	27.0	0	551
April	27.2	77.0%	5.42	97.8	2.1	26.9	0	517
May	26.7	79.5%	5.26	97.9	2.1	26.5	0	517
June	26.1	82.5%	4.66	98.1	2.1	25.4	0	483
July	24.4	83.5%	3.87	98.2	2.6	24.4	0	448
August	24.4	83.5%	3.51	98.2	2.1	24.4	0	448
September	24.4	83.0%	3.92	98.1	2.1	24.8	0	433
October	25.6	82.0%	4.61	98.0	2.1	25.3	0	482
November	26.1	76.0%	5.00	97.9	1.5	25.7	0	483
December	25.6	73.0%	4.04	97.9	1.5	25.9	0	482
Annual	26.0	76.9%	4.56	98.0	2.0	25.8	0	5,826
Measured at (m)					10.0	0.0		

Complete Energy Model sheet

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Meteonorm Data — 6/18/2013
KNUST-Kumasi — RETScreen4-1

Energy Model page of RETScreen for METEONORM data

RETScreen Energy Model - Power project

Show alternative units

Proposed case power system

Technology		Photovoltaic
Analysis type		Method 1 / ⦿ Method 2
Resource assessment		
Solar tracking mode		Fixed
Slope	°	15.0
Azimuth	°	0.0

☑ Show data

Month	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d	Electricity export rate $/MWh	Electricity exported to grid MWh
January	4.30	4.60	300.0	564.0
February	4.83	5.04	300.0	552.2
March	5.31	5.33	300.0	643.1
April	5.42	5.20	300.0	609.8
May	5.26	4.87	300.0	590.1
June	4.66	4.26	300.0	504.0
July	3.67	3.61	300.0	449.1
August	3.51	3.37	300.0	421.5
September	3.92	3.87	300.0	466.1
October	4.61	4.74	300.0	580.6
November	5.00	5.37	300.0	631.0
December	4.04	4.35	300.0	535.7
Annual	**4.56**	**4.55**	**300.00**	**6,547.1**

Annual solar radiation - horizontal	MWh/m²	1.66	
Annual solar radiation - tilted	MWh/m²	1.66	
Photovoltaic			
Type		poly-Si	
Power capacity	kW	5,000.64	*See product database*
Manufacturer		BP Solar	
Model		poly-Si - DC Power Wall	20836 unit(s)
Efficiency	%	11.3%	
Nominal operating cell temperature	°C	45	
Temperature coefficient	% / °C	0.40%	
Solar collector area	m²	44,097	
Miscellaneous losses	%	5.0%	
Inverter			
Efficiency	%	95.0%	
Capacity	kW	1000.0	
Miscellaneous losses	%	5.0%	
Summary			
Capacity factor	%	14.9%	
Electricity exported to grid	MWh	6,547.1	

Meteonorm Data
KNUST-Kumasi

6/18/2013
RETScreen4-1

Cost Analysis page of RETScreen for METEONORM data

RETScreen Cost Analysis - Power project

Settings			
◯ Method 1	◉ Notes/Range		
◉ Method 2	◯ Second currency	Notes/Range	None
	◯ Cost allocation		

Initial costs (credits)	Unit	Quantity	Unit cost	Amount	Relative costs
Feasibility study					
Site investigation	p-d			$ -	
Resource assessment	project			$ -	
Environmental assessment	p-d			$ -	
Preliminary design	p-d			$ -	
Detailed cost estimate	p-d			$ -	
GHG baseline study & MP	project			$ -	
Report preparation	p-d			$ -	
Project management	p-d			$ -	
Travel & accommodation	p-trip			$ -	
User-defined	cost			$ -	
				$ -	
Subtotal:				$ -	0.0%
Development					
Contract negotiations	p-d			$ -	
Permits & approvals	p-d			$ -	
Site survey & land rights	p-d			$ -	
GHG validation & registration	project			$ -	
Project financing	p-d			$ -	
Legal & accounting	p-d			$ -	
Project management	p-d			$ -	
Travel & accommodation	p-trip			$ -	
User-defined	cost			$ -	
				$ -	
Subtotal:				$ -	0.0%
Engineering					
Site & building design	p-d			$ -	
Mechanical design	p-d			$ -	
Electrical design	p-d			$ -	
Civil design	p-d			$ -	
Tenders & contracting	p-d			$ -	
Construction supervision	p-d			$ -	
User-defined	cost			$ -	
				$ -	
Subtotal:				$ -	0.0%
Power system					
Photovoltaic	kW	5,000.64	$ 4,450	$ 22,252,848	
Road construction	km			$ -	
Transmission line	km			$ -	
Substation	project			$ -	
Energy efficiency measures	project			$ -	
User-defined	cost			$ -	
				$ -	
Subtotal:				$ **22,252,848**	95.2%
Balance of system & miscellaneous					
Specific project costs		Fuel handling system			
Delivery equipment	project			$ -	
Preparation equipment	project			$ -	
Storage equipment	project			$ -	
Distribution equipment	project			$ -	
Building & yard construction	m²			$ -	
Spare parts	%			$ -	
Transportation	project			$ -	
Training & commissioning	p-d			$ -	
Fixed O&M Costs	cost	1	$ 1,112,642	$ 1,112,642	
Contingencies	%		$ 23,365,490	$ -	
Interest during construction			$ 23,365,490	$ -	
Subtotal:		Enter number of months		$ **1,112,642**	4.8%
Total initial costs				$ **23,365,490**	100.0%

Annual costs (credits)	Unit	Quantity	Unit cost	Amount
O&M				
Land lease & resource rental	project			$ -
Property taxes	project			$ -
Insurance premium	project			$ -
Parts & labour	project			$ -
GHG monitoring & verification	project			$ -
Community benefits	project			$ -
General & administrative	%		$ -	$ -
Variable O&M Costs	cost	1	$ 4,517	$ 4,517
Contingencies	%		$ 4,517	$ -
Subtotal:				$ 4,517

Periodic costs (credits)	Unit	Year	Unit cost	Amount
User-defined	cost			$ -
				$ -
End of project life	cost			$ -

Meteonorm Data
KNUST-Kumasi

6/18/2013
RETScreen4-1

Financial Analysis page of RETScreen METEONORM data

RETScreen Financial Analysis - Power project

Financial parameters

General		
Fuel cost escalation rate	%	0.0%
Inflation rate	%	10.0%
Discount rate	%	12.5%
Project life	yr	25
Finance		
Incentives and grants	$	
Debt ratio	%	70.0%
Debt	$	16,355,843
Equity	$	7,009,647
Debt interest rate	%	12.00%
Debt term	yr	10
Debt payments	$/yr	2,894,725

Income tax analysis ☐

Annual income

Electricity export income		
Electricity exported to grid	MWh	6,547
Electricity export rate	$/MWh	300.00
Electricity export income	$	1,964,123
Electricity export escalation rate	%	

GHG reduction income ☐

Customer premium income (rebate) ☐

Other income (cost) ☐

Clean Energy (CE) production income ☐

Project costs and savings/income summary

Initial costs			
Power system	95.2%	$	22,252,848
Balance of system & misc.	4.8%	$	1,112,642
Total initial costs	**100.0%**	**$**	**23,365,490**
Annual costs and debt payments			
O&M		$	4,517
Fuel cost - proposed case		$	0
Debt payments - 10 yrs		$	2,894,725
Total annual costs		**$**	**2,899,243**
Periodic costs (credits)			
Annual savings and income			
Fuel cost - base case		$	0
Electricity export income		$	1,964,123
Total annual savings and income		**$**	**1,964,123**

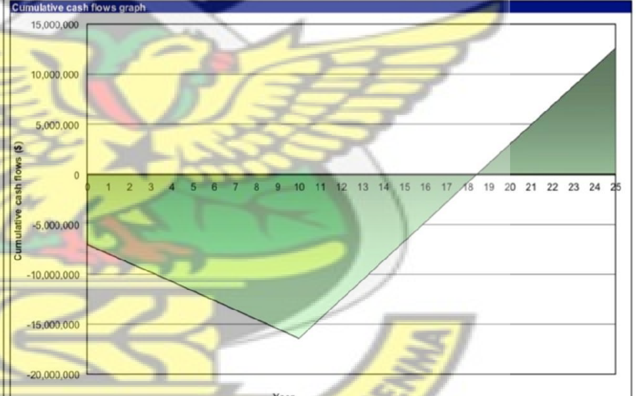
Financial viability

Pre-tax IRR - equity	%	4.0%
Pre-tax IRR - assets	%	-0.7%
After-tax IRR - equity	%	4.0%
After-tax IRR - assets	%	-0.7%
Simple payback	yr	11.9
Equity payback	yr	18.4
Net Present Value (NPV)	$	-8,235,430
Annual life cycle savings	$/yr	-1,086,611
Benefit-Cost (B-C) ratio		-0.17
Debt service coverage		0.67
Energy production cost	$/MWh	501.54

Yearly cash flows

Year #	Pre-tax $	After-tax $	Cumulative $
0	-7,009,647	-7,009,647	-7,009,647
1	-935,571	-935,571	-7,945,218
2	-936,068	-936,068	-8,881,286
3	-936,615	-936,615	-9,817,901
4	-937,216	-937,216	-10,755,117
5	-937,877	-937,877	-11,692,995
6	-938,605	-938,605	-12,631,600
7	-939,405	-939,405	-13,571,005
8	-940,286	-940,286	-14,511,291
9	-941,254	-941,254	-15,452,544
10	-942,319	-942,319	-16,394,864
11	1,951,234	1,951,234	-14,443,629
12	1,949,945	1,949,945	-12,493,684
13	1,948,528	1,948,528	-10,545,156
14	1,946,968	1,946,968	-8,598,188
15	1,945,253	1,945,253	-6,652,935
16	1,943,366	1,943,366	-4,709,570
17	1,941,290	1,941,290	-2,768,280
18	1,939,006	1,939,006	-829,274
19	1,936,495	1,936,495	1,107,221
20	1,933,732	1,933,732	3,040,953
21	1,930,693	1,930,693	4,971,646
22	1,927,350	1,927,350	6,898,996
23	1,923,672	1,923,672	8,822,668
24	1,919,627	1,919,627	10,742,295
25	1,915,178	1,915,178	12,657,473

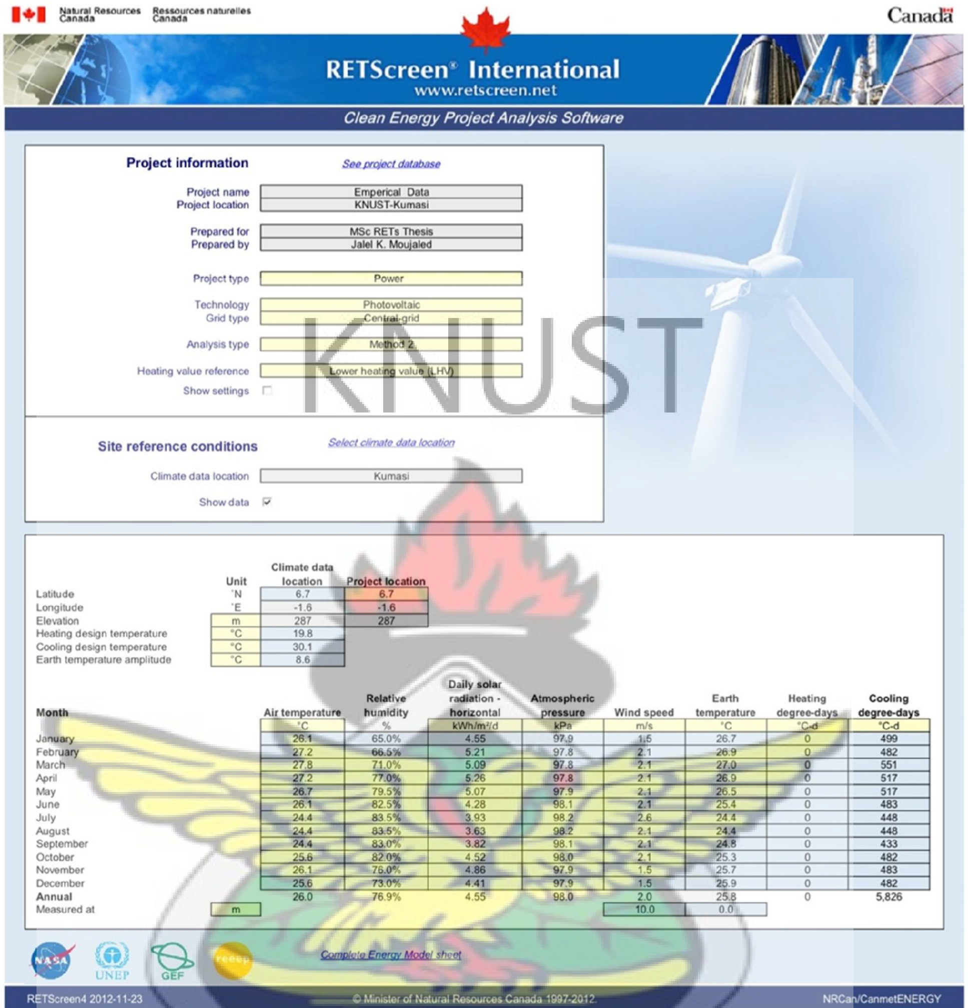
Cumulative cash flows graph



Meteonorm Data
KNUST-Kumasi

6/18/2013
RETScreen4-1

Introductory page of RETScreen for GMA data



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Clean Energy Project Analysis Software

Project information — *See project database*

Project name	Emperical Data
Project location	KNUST-Kumasi
Prepared for	MSc RETs Thesis
Prepared by	Jalel K. Moujaled
Project type	Power
Technology	Photovoltaic
Grid type	Central-grid
Analysis type	Method 2
Heating value reference	Lower heating value (LHV)
Show settings	☐

Site reference conditions — *Select climate data location*

Climate data location	Kumasi
Show data	☑

	Unit	Climate data location	Project location
Latitude	°N	6.7	6.7
Longitude	°E	-1.6	-1.6
Elevation	m	287	287
Heating design temperature	°C	19.8	
Cooling design temperature	°C	30.1	
Earth temperature amplitude	°C	8.6	

Month	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	26.1	65.0%	4.55	97.9	1.5	26.7	0	499
February	27.2	66.5%	5.21	97.8	2.1	26.9	0	482
March	27.8	71.0%	5.09	97.8	2.1	27.0	0	551
April	27.2	77.0%	5.26	97.8	2.1	26.9	0	517
May	26.7	79.5%	5.07	97.9	2.1	26.5	0	517
June	26.1	82.5%	4.28	98.1	2.1	25.4	0	483
July	24.4	83.5%	3.93	98.2	2.6	24.4	0	448
August	24.4	83.5%	3.63	98.2	2.1	24.4	0	448
September	24.4	83.0%	3.82	98.1	2.1	24.8	0	433
October	25.6	82.0%	4.52	98.0	2.1	25.3	0	482
November	26.1	76.0%	4.86	97.9	1.5	25.7	0	483
December	25.6	73.0%	4.41	97.9	1.5	25.9	0	482
Annual	26.0	76.9%	4.55	98.0	2.0	25.8	0	5,826
Measured at (m)					10.0	0.0		

NASA UNEP GEF reeep — *Complete Energy Model sheet*

RETScreen4 2012-11-23 © Minister of Natural Resources Canada 1997-2012. NRCan/CanmetENERGY

Emperical Data
KNUST-Kumasi

6/18/2013
RETScreen4-1

Energy Model page of RETScreen for GMA data

RETScreen Energy Model - Power project ☐ Show alternative units

Proposed case power system

Technology		Photovoltaic
Analysis type		○ Method 1 ⊙ Method 2
Resource assessment		
Solar tracking mode		Fixed
Slope	°	15.0
Azimuth	°	0.0

☑ Show data

Month	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d	Electricity export rate $/MWh	Electricity exported to grid MWh
January	4.55	4.90	300.0	598.4
February	5.21	5.45	300.0	594.8
March	5.09	5.11	300.0	618.3
April	5.26	5.05	300.0	593.1
May	5.07	4.69	300.0	570.6
June	4.28	3.94	300.0	467.8
July	3.93	3.67	300.0	455.4
August	3.63	3.48	300.0	434.7
September	3.82	3.77	300.0	454.1
October	4.52	4.64	300.0	569.5
November	4.86	5.21	300.0	613.3
December	4.41	4.79	300.0	586.4
Annual	**4.55**	**4.55**	**300.00**	**6,556.3**

Annual solar radiation - horizontal	MWh/m²	1.66	
Annual solar radiation - tilted	MWh/m²	1.66	
Photovoltaic			
Type		poly-Si	
Power capacity	kW	5,000.64	See product database
Manufacturer		BP Solar	
Model		poly-Si - DC Power Wall	20836 unit(s)
Efficiency	%	11.3%	
Nominal operating cell temperature	°C	45	
Temperature coefficient	% / °C	0.40%	
Solar collector area	m²	44,097	
Miscellaneous losses	%	5.0%	
Inverter			
Efficiency	%	95.0%	
Capacity	kW	1000.0	
Miscellaneous losses	%	5.0%	
Summary			
Capacity factor	%	15.0%	
Electricity exported to grid	MWh	6,556.3	

Emperical Data 6/18/2013
KNUST-Kumasi RETScreen4-1

Cost Analysis page of RETScreen for GMA data

RETScreen Cost Analysis - Power project

Settings			
○ Method 1	◉ Notes/Range		
◉ Method 2	○ Second currency	Notes/Range	None
	○ Cost allocation		

Initial costs (credits)	Unit	Quantity	Unit cost	Amount	Relative costs
Feasibility study					
Site investigation	p-d			$ -	
Resource assessment	project			$ -	
Environmental assessment	p-d			$ -	
Preliminary design	p-d			$ -	
Detailed cost estimate	p-d			$ -	
GHG baseline study & MP	project			$ -	
Report preparation	p-d			$ -	
Project management	p-d			$ -	
Travel & accommodation	p-trip			$ -	
User-defined	cost			$ -	
				$ -	
Subtotal:				$ -	0.0%
Development					
Contract negotiations	p-d			$ -	
Permits & approvals	p-d			$ -	
Site survey & land rights	p-d			$ -	
GHG validation & registration	project			$ -	
Project financing	p-d			$ -	
Legal & accounting	p-d			$ -	
Project management	p-d			$ -	
Travel & accommodation	p-trip			$ -	
User-defined	cost			$ -	
				$ -	
Subtotal:				$ -	0.0%
Engineering					
Site & building design	p-d			$ -	
Mechanical design	p-d			$ -	
Electrical design	p-d			$ -	
Civil design	p-d			$ -	
Tenders & contracting	p-d			$ -	
Construction supervision	p-d			$ -	
User-defined	cost			$ -	
				$ -	
Subtotal:				$ -	0.0%
Power system					
Photovoltaic	kW	5,000.64	$ 4,450	$ 22,252,848	
Road construction	km			$ -	
Transmission line	km			$ -	
Substation	project			$ -	
Energy efficiency measures	project			$ -	
User-defined	cost			$ -	
				$ -	
Subtotal:				$ 22,252,848	95.2%
Balance of system & miscellaneous					
Specific project costs		Fuel handling system			
Delivery equipment	project			$ -	
Preparation equipment	project			$ -	
Storage equipment	project			$ -	
Distribution equipment	project			$ -	
Building & yard construction	m²			$ -	
Spare parts	%			$ -	
Transportation	project			$ -	
Training & commissioning	p-d			$ -	
Fixed O&M Costs	cost	1	$ 1,112,642	$ 1,112,642	
Contingencies	%		$ 23,365,490	$ -	
Interest during construction			$ 23,365,490	$ -	
Subtotal:		Enter number of months		$ 1,112,642	4.8%
Total initial costs				$ 23,365,490	100.0%
Annual costs (credits)	**Unit**	**Quantity**	**Unit cost**	**Amount**	
O&M					
Land lease & resource rental	project			$ -	
Property taxes	project			$ -	
Insurance premium	project			$ -	
Parts & labour	project			$ -	
GHG monitoring & verification	project			$ -	
Community benefits	project			$ -	
General & administrative	%		$ -	$ -	
Variable O&M Costs	cost	1	$ 4,524	$ 4,524	
Contingencies	%		$ 4,524	$ -	
Subtotal:				$ 4,524	
Periodic costs (credits)	**Unit**	**Year**	**Unit cost**	**Amount**	
User-defined	cost			$ -	
				$ -	
End of project life	cost			$ -	

Emperical Data
KNUST-Kumasi

Financial Analysis page of RETScreen GMA data

RETScreen Financial Analysis - Power project

Financial parameters

General		
Fuel cost escalation rate	%	0.0%
Inflation rate	%	10.0%
Discount rate	%	12.5%
Project life	yr	25
Finance		
Incentives and grants	$	
Debt ratio	%	70.0%
Debt	$	16,355,843
Equity	$	7,009,647
Debt interest rate	%	12.00%
Debt term	yr	10
Debt payments	$/yr	2,894,725

Income tax analysis ☐

Annual income

Electricity export income		
Electricity exported to grid	MWh	6,556
Electricity export rate	$/MWh	300.00
Electricity export income	$	1,966,897
Electricity export escalation rate	%	

GHG reduction income ☐

Customer premium income (rebate) ☐

Other income (cost) ☐

Clean Energy (CE) production income ☐

Project costs and savings/income summary

Initial costs			
Power system	95.2%	$	22,252,848
Balance of system & misc.	4.8%	$	1,112,642
Total initial costs	**100.0%**	**$**	**23,365,490**
Annual costs and debt payments			
O&M		$	4,524
Fuel cost - proposed case		$	0
Debt payments - 10 yrs		$	2,894,725
Total annual costs		**$**	**2,899,249**
Periodic costs (credits)			
Annual savings and income			
Fuel cost - base case		$	0
Electricity export income		$	1,966,897
Total annual savings and income		**$**	**1,966,897**

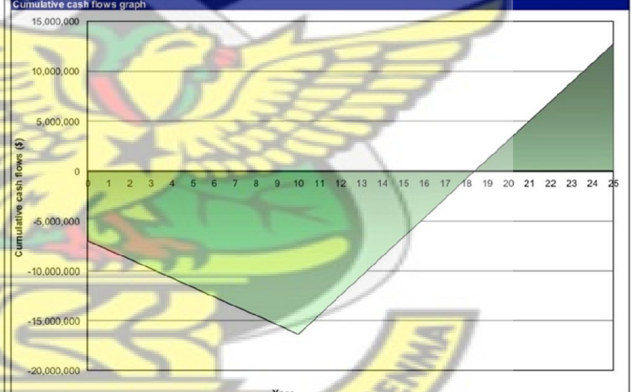
Financial viability

Pre-tax IRR - equity	%	4.0%
Pre-tax IRR - assets	%	-0.7%
After-tax IRR - equity	%	4.0%
After-tax IRR - assets	%	-0.7%
Simple payback	yr	11.9
Equity payback	yr	18.4
Net Present Value (NPV)	$	-8,214,528
Annual life cycle savings	$/yr	-1,083,853
Benefit-Cost (B-C) ratio		-0.17
Debt service coverage		0.68
Energy production cost	$/MWh	501.54

Yearly cash flows

Year \#	Pre-tax $	After-tax $	Cumulative $
0	-7,009,647	-7,009,647	-7,009,647
1	-932,804	-932,804	-7,942,452
2	-933,302	-933,302	-8,875,754
3	-933,849	-933,849	-9,809,603
4	-934,452	-934,452	-10,744,055
5	-935,114	-935,114	-11,679,168
6	-935,842	-935,842	-12,615,011
7	-936,644	-936,644	-13,551,655
8	-937,525	-937,525	-14,489,180
9	-938,495	-938,495	-15,427,675
10	-939,562	-939,562	-16,367,237
11	1,953,990	1,953,990	-14,413,247
12	1,952,699	1,952,699	-12,460,548
13	1,951,279	1,951,279	-10,509,269
14	1,949,718	1,949,718	-8,559,551
15	1,948,000	1,948,000	-6,611,551
16	1,946,110	1,946,110	-4,665,441
17	1,944,031	1,944,031	-2,721,410
18	1,941,745	1,941,745	-779,665
19	1,939,230	1,939,230	1,159,565
20	1,936,463	1,936,463	3,096,028
21	1,933,419	1,933,419	5,029,447
22	1,930,072	1,930,072	6,959,519
23	1,926,389	1,926,389	8,885,908
24	1,922,338	1,922,338	10,808,246
25	1,917,882	1,917,882	12,726,128

Cumulative cash flows graph



Emperical Data
KNUST-Kumasi

6/18/2013
RETScreen4-1

Introductory page of RETScreen for SODA-HelioClim-3 data

Natural Resources Canada | Ressources naturelles Canada | Canada

RETScreen® International

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Clean Energy Project Analysis Software

Project information

See project database

Project name	SODA-HelioClim3 Data
Project location	KNUST-Kumasi
Prepared for	MSc RETs Thesis
Prepared by	Jalel K. Moujaled
Project type	Power
Technology	Photovoltaic
Grid type	Central-grid
Analysis type	Method 2
Heating value reference	Lower heating value (LHV)
Show settings	☐

Site reference conditions

Select climate data location

Climate data location	Kumasi
Show data	☑

	Unit	Climate data location	Project location
Latitude	˚N	6.7	6.7
Longitude	˚E	-1.6	-1.6
Elevation	m	287	287
Heating design temperature	°C	19.8	
Cooling design temperature	°C	30.1	
Earth temperature amplitude	°C	8.6	

Month	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	26.1	65.0%	5.71	97.9	1.5	26.7	0	499
February	27.2	66.5%	5.63	97.8	2.1	26.9	0	482
March	27.8	71.0%	5.84	97.8	2.1	27.0	0	551
April	27.2	77.0%	5.72	97.8	2.1	26.9	0	517
May	26.7	79.5%	5.35	97.9	2.1	26.5	0	517
June	26.1	82.5%	3.90	98.1	2.1	25.4	0	483
July	24.4	83.5%	4.04	98.2	2.6	24.4	0	448
August	24.4	83.5%	4.19	98.2	2.1	24.4	0	448
September	24.4	83.0%	4.17	98.1	2.1	24.8	0	433
October	25.6	82.0%	5.44	98.0	2.1	25.3	0	482
November	26.1	76.0%	5.30	97.9	1.5	25.7	0	483
December	25.6	73.0%	5.19	97.9	1.5	25.9	0	482
Annual	26.0	76.9%	5.04	98.0	2.0	25.8	0	5,826
Measured at (m)					10.0	0.0		

Complete Energy Model sheet

NASA UNEP GEF reeep

RETScreen4 2012-11-23 NRCan/CanmetENERGY

SODA-HelioClim3 Data
KNUST-Kumasi

6/18/2013
RETScreen4-1

Energy Model page of RETScreen for SODA-HelioClim-3 data

RETScreen Energy Model - Power project

☐ Show alternative units

Proposed case power system

Technology		Photovoltaic
Analysis type		○ Method 1 ⊙ Method 2

Resource assessment

Solar tracking mode		Fixed
Slope	°	15.0
Azimuth	°	0.0

☑ Show data

Month	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d	Electricity export rate $/MWh	Electricity exported to grid MWh
January	5.71	6.27	300.0	755.4
February	5.63	5.92	300.0	642.6
March	5.84	5.87	300.0	704.2
April	5.72	5.48	300.0	639.9
May	5.35	4.94	300.0	598.4
June	3.90	3.62	300.0	431.7
July	4.04	3.76	300.0	466.7
August	4.19	4.00	300.0	495.7
September	4.17	4.11	300.0	494.1
October	5.44	5.63	300.0	683.7
November	5.30	5.72	300.0	670.1
December	5.19	5.73	300.0	694.9
Annual	**5.04**	**5.08**	**300.00**	**7,277.3**

Annual solar radiation - horizontal	MWh/m²	1.84
Annual solar radiation - tilted	MWh/m²	1.86

Photovoltaic

Type		poly-Si	
Power capacity	kW	5,000.64	See product database
Manufacturer		BP Solar	
Model		poly-Si - DC Power Wall	20836 unit(s)
Efficiency	%	11.3%	
Nominal operating cell temperature	°C	45	
Temperature coefficient	% / °C	0.40%	
Solar collector area	m²	44,097	
Miscellaneous losses	%	5.0%	

Inverter

Efficiency	%	95.0%
Capacity	kW	1000.0
Miscellaneous losses	%	5.0%

Summary

Capacity factor	%	16.6%
Electricity exported to grid	MWh	7,277.3

SODA-HelioClim3 Data
KNUST-Kumasi

6/18/2013
RETScreen4-1

Cost Analysis page of RETScreen for SODA-HelioClim-3 data

RETScreen Cost Analysis - Power project

Settings			
○ Method 1	◉ Notes/Range		
◉ Method 2	○ Second currency	Notes/Range	None
	○ Cost allocation		

Initial costs (credits)	Unit	Quantity	Unit cost	Amount	Relative costs
Feasibility study					
Site investigation	p-d			$ -	
Resource assessment	project			$ -	
Environmental assessment	p-d			$ -	
Preliminary design	p-d			$ -	
Detailed cost estimate	p-d			$ -	
GHG baseline study & MP	project			$ -	
Report preparation	p-d			$ -	
Project management	p-d			$ -	
Travel & accommodation	p-trip			$ -	
User-defined	cost			$ -	
				$ -	
Subtotal:				$ -	0.0%
Development					
Contract negotiations	p-d			$ -	
Permits & approvals	p-d			$ -	
Site survey & land rights	p-d			$ -	
GHG validation & registration	project			$ -	
Project financing	p-d			$ -	
Legal & accounting	p-d			$ -	
Project management	p-d			$ -	
Travel & accommodation	p-trip			$ -	
User-defined	cost			$ -	
				$ -	
Subtotal:				$ -	0.0%
Engineering					
Site & building design	p-d			$ -	
Mechanical design	p-d			$ -	
Electrical design	p-d			$ -	
Civil design	p-d			$ -	
Tenders & contracting	p-d			$ -	
Construction supervision	p-d			$ -	
User-defined	cost			$ -	
				$ -	
Subtotal:				$ -	0.0%
Power system					
Photovoltaic	kW	5,000.64	$ 4,450	$ 22,252,848	
Road construction	km			$ -	
Transmission line	km			$ -	
Substation	project			$ -	
Energy efficiency measures	project			$ -	
User-defined	cost			$ -	
				$ -	
Subtotal:				$ **22,252,848**	95.2%
Balance of system & miscellaneous					
Specific project costs		Fuel handling system			
Delivery equipment	project			$ -	
Preparation equipment	project			$ -	
Storage equipment	project			$ -	
Distribution equipment	project			$ -	
Building & yard construction	m²			$ -	
Spare parts	%			$ -	
Transportation	project			$ -	
Training & commissioning	p-d			$ -	
Fixed O&M Costs	cost	1	$ 1,112,642	$ 1,112,642	
Contingencies	%		$ 23,365,490	$ -	
Interest during construction			$ 23,365,490	$ -	
Subtotal:		Enter number of months		$ **1,112,642**	4.8%
Total initial costs				$ **23,365,490**	100.0%

Annual costs (credits)	Unit	Quantity	Unit cost	Amount
O&M				
Land lease & resource rental	project			$ -
Property taxes	project			$ -
Insurance premium	project			$ -
Parts & labour	project			$ -
GHG monitoring & verification	project			$ -
Community benefits	project			$ -
General & administrative	%		$ -	$ -
Variable O&M Costs	cost	1	$ 5,021	$ 5,021
Contingencies	%		$ 5,021	$ -
Subtotal:				$ 5,021

Periodic costs (credits)	Unit	Year	Unit cost	Amount
User-defined	cost			$ -
				$ -
End of project life	cost			$ -

SODA-HelioClim3 Data
KNUST-Kumasi

6/18/2013
RETScreen4-1

Financial Analysis page of RETScreen SODA-HelioClim-3 data

RETScreen Financial Analysis - Power project

Financial parameters

General		
Fuel cost escalation rate	%	0.0%
Inflation rate	%	10.0%
Discount rate	%	12.5%
Project life	yr	25
Finance		
Incentives and grants	$	
Debt ratio	%	70.0%
Debt	$	16,355,843
Equity	$	7,009,647
Debt interest rate	%	12.00%
Debt term	yr	10
Debt payments	$/yr	2,894,725
Income tax analysis		☐

Annual income

Electricity export income		
Electricity exported to grid	MWh	7,277
Electricity export rate	$/MWh	300.00
Electricity export income	$	2,183,183
Electricity export escalation rate	%	
GHG reduction income		☐
Customer premium income (rebate)		☐
Other income (cost)		☐
Clean Energy (CE) production income		☐

Project costs and savings/income summary

Initial costs			
Power system	95.2%	$	22,252,848
Balance of system & misc.	4.8%	$	1,112,642
Total initial costs	**100.0%**	**$**	**23,365,490**
Annual costs and debt payments			
O&M		$	5,021
Fuel cost - proposed case		$	0
Debt payments - 10 yrs		$	2,894,725
Total annual costs		**$**	**2,899,747**
Periodic costs (credits)			
Annual savings and income			
Fuel cost - base case		$	0
Electricity export income		$	2,183,183
Total annual savings and income		**$**	**2,183,183**

Financial viability

Pre-tax IRR - equity	%	5.6%
Pre-tax IRR - assets	%	0.3%
After-tax IRR - equity	%	5.6%
After-tax IRR - assets	%	0.3%
Simple payback	yr	10.7
Equity payback	yr	16.6
Net Present Value (NPV)	$	-6,584,705
Annual life cycle savings	$/yr	-868,809
Benefit-Cost (B-C) ratio		0.06
Debt service coverage		0.75
Energy production cost	$/MWh	501.54

Yearly cash flows

Year \#	Pre-tax $	After-tax $	Cumulative $
0	-7,009,647	-7,009,647	-7,009,647
1	-717,066	-717,066	-7,726,713
2	-717,618	-717,618	-8,444,331
3	-718,226	-718,226	-9,162,557
4	-718,894	-718,894	-9,881,451
5	-719,629	-719,629	-10,601,080
6	-720,438	-720,438	-11,321,518
7	-721,328	-721,328	-12,042,846
8	-722,306	-722,306	-12,765,152
9	-723,382	-723,382	-13,488,534
10	-724,566	-724,566	-14,213,101
11	2,168,856	2,168,856	-12,044,244
12	2,167,424	2,167,424	-9,876,820
13	2,165,848	2,165,848	-7,710,973
14	2,164,114	2,164,114	-5,546,858
15	2,162,208	2,162,208	-3,384,651
16	2,160,110	2,160,110	-1,224,541
17	2,157,803	2,157,803	933,262
18	2,155,265	2,155,265	3,088,527
19	2,152,473	2,152,473	5,241,000
20	2,149,402	2,149,402	7,390,402
21	2,146,024	2,146,024	9,536,426
22	2,142,308	2,142,308	11,678,733
23	2,138,220	2,138,220	13,816,954
24	2,133,724	2,133,724	15,950,678
25	2,128,778	2,128,778	18,079,456

Cumulative cash flows graph