

MASTER THESIS

TITLE:

**AN ASSESSMENT OF CAMEROON'S RENEWABLE ENERGY
RESOURCE POTENTIAL AND PROSPECTS FOR A SUSTAINABLE
ECONOMIC DEVELOPMENT**

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MASTERARBEIT

THEMA:

EINE BEWERTUNG DES POTENTIALS ERNEUERBARER ENERGIEN RESSOURCEN IN KAMERUN UND DIE AUSSICHTEN FÜR EINE NACHHALTIGE WIRTSCHAFTSENTWICKLUNG

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Declaration

I hereby declare that this thesis is the result of my original work carried out at the Brandenburg University of Technology Cottbus, Germany.

This research was an independent study under the supervision of Prof. Dr. rer. nat. Jürgen Ertel (Chair of Industrial Sustainability, Brandenburg University of Technology Cottbus, Germany) and Prof. Dr. Michael Scheffler (Chair of Lightweight Ceramics, Brandenburg University of Technology Cottbus, Germany).

This thesis has never been submitted in part or in whole for a degree at any institution. References to other sources or people's work have been duly cited and acknowledged.

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Dedication

I dedicate this piece of work to my mother Juliana Tansi.

“Dear Juliana Tansi,

I just thought I'd drop you a line and tell you how much you mean to me. I know you must think I just took your love for granted and I wanted to tell you that I am sorry that I never told you before...

Thanks, Mom, for carrying me under your heart all these months, putting up with the million and one things all expectant mothers just "go through"...

Thanks for enduring whatever degree of pain you went through to bring me into this world. And Mom, I do appreciate you sitting up nights trying to figure out why I was crying, after you did your best to keep me dry, fed, and comfortable... and the 5,000 diapers a year, thank you for each one of them... and the teeth cutting period... I must have driven you out of your mind... I'm sorry.

Now, too many years later, I thank you and I'm sorry I caused you so much pain, worry and headaches... and for all the sleep you lost. And Mom, thanks for all the love, attention, guidance, patience, and yes, the discipline.

If I ever did anything to make you feel that you failed somewhere, don't blame yourself. I had to find out some things on my own. I only pray I find the wisdom to do as well with my children.

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Abstract

Cameroon has vast renewable energy resource potentials, with a hydropower potential of about 55,200MW, second only to the Democratic Republic of Congo in Africa. So far, its energy needs are met by 4.8% hydropower (which accounts for less than 5% of its total hydropower potential), 0% wind and 0% solar. Cameroons' energy sector still goes through insufficient electrical energy production, especially during the heart of the dry season, which runs from December through March. Coincidentally, the wind and solar power potentials for Cameroon are at their peak during these months and could conveniently supplement for the shortfalls in generation during these periods.

In this research, technical analysis were carried out to determine the wind and solar energy resource potentials for Cameroon using the RETScreen software tool provided by CANMET Canada. These analysis revealed that the northern regions of Cameroon had higher wind and solar resource potentials than any other location in Cameroon. A 2MW installed wind energy capacity would be capable of generating well over 1.5GWh electrical energy per year, while a 2KW installed solar energy capacity will be capable of generating well over 3MWh electrical energy per year.

In the final sections, financial analysis were carried out to determine the economic viability of such projects and the possibility for self-financing. Emission analyses were also done based on the ability for such projects to offset greenhouse gas emissions and ensure sustainability in the energy sector. The analysis for Maroua revealed that 78.6tCO₂/yr for wind and 0.1tCO₂/yr for solar could be reduced by those installations.

Finally, the legislations and legal frameworks governing the energy sector in Cameroon were dissected to determine possible weaknesses and constraints limiting the use, promotion and development of the full potential of Cameroon's renewable energy resources.

Acronyms/Abbreviations

- **AES SONEL** National Electricity Company, Cameroon
- **ALUCAM** Aluminium Smelter Plant, Cameroon
- **ARSEL** Electricity Sector Regulatory Agency, Cameroon.
- **CANMET** Canada Centre for Mineral and Energy Technology
- **CBA** Cost Benefit Analysis
- **CDM** Clean Development Mechanism
- **CO₂** Carbon Dioxide
- **CRC** Carbon Reduction Commitment
- **DTIE** UNEP's Division of Technology, Industry and Economics
- **EEDRB** Energy and Environmental Data Reference Bank
- **EEF** The Energy and Environment Foundation
- **EIA** US Energy Information Administration
- **FCFA** Central African Franc
- **GDP** Gross Domestic Product
- **GEF** Global Environment Facility
- **GHG** Greenhouse Gases
- **GW** Gigawatt
- **GWh** Gigawatt Hour
- **IAEA** International Atomic Energy Agency
- **IEA** International Energy Agency

- **kWh** Kilowatt Hour
- **MWh** Megawatt Hour
- **NASA** National Aeronautics and Space Administration
- **NGO** Non-governmental Organization
- **NRCan** Natural Resources Canada
- **OECD** Organisation for Economic Co-operation and Development
- **PCF** World Bank's Prototype Carbon Fund
- **PV** Photovoltaic
- **R&D** Research and Development
- **RE** Renewable Energy
- **REEEP** Renewable Energy and Energy Efficiency Partnership
- **RETs** Renewable Energy Technologies
- **SONARA** National Oil Refining Company, Cameroon
- **SWERA** UNEP lead Solar and Wind Energy Resource Assessment Program
- **UNEP** United Nations Environment Program
- **UNFCCC** United Nations Framework Convention on Climate Change
- **WB** World Bank
- **WCED** World Commission on Environment and Development

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Chapter 1 : Introduction

1.1 The Republic of Cameroon

The Republic of Cameroon is a Central African Nation. Originally part of the German colony in West Africa, Cameroon became a republic in 1960. The country is in the shape of an elongated triangle and forms a bridge between West and Central Africa. It lies on the geographical coordinates of 6°N latitude and 12°E longitude. Cameroon shares national borders to the west with Nigeria and Equatorial Guinea. To the east, Cameroon shares borders with Tchad, the Central African Republic, and the Republic of Congo. To the south, Cameroon is bordered by Gabon, Equatorial Guinea and the Republic of Congo. (Figure 1-1). Cameroon is divided into 10 regions namely, Far North, North, Adamawa, North west, West, Centre, East, South, Littoral and South West Regions.

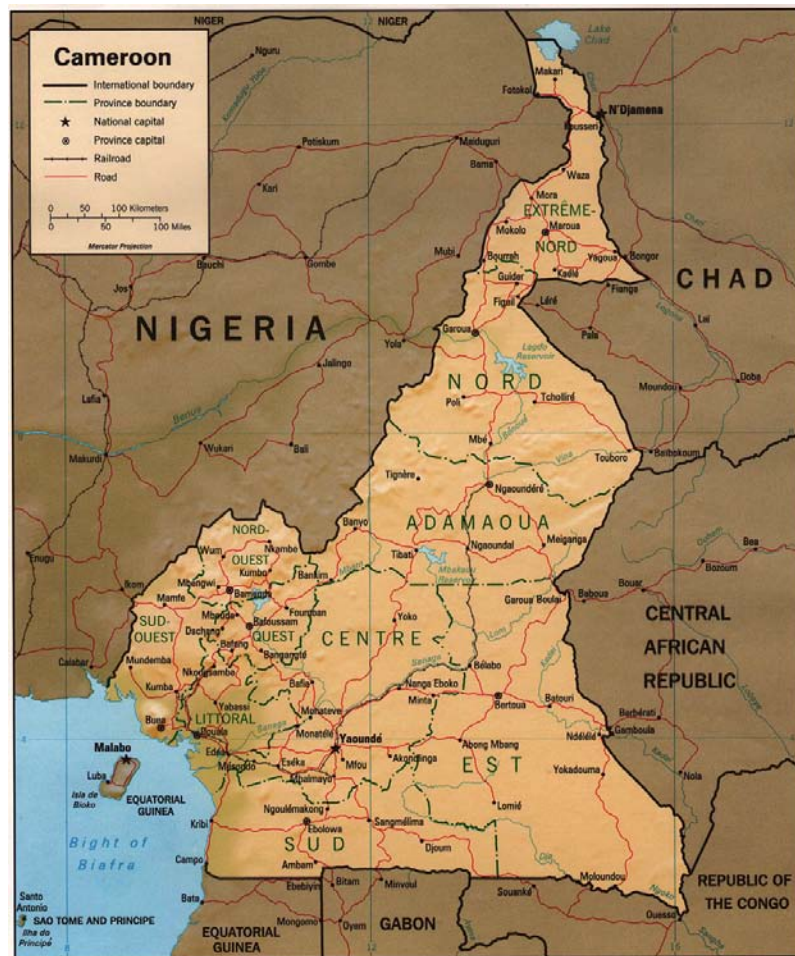


Figure 1-1: Map of Cameroon

Source:http://www.lib.utexas.edu/maps/africa/cameroon_rel98.jpg

Cameroon has a population of 16.32million inhabitants and a growth rate of about 2.02% (IERN, 2009). The human population of Cameroon is very unevenly distributed with an estimated population density of 34.45 persons per square kilometer (IAEA, 2005). Some areas of the country have populations exceeding 100 persons per square kilometer. The human population density in some parts of the country especially to the southeast, is very low: approximately below 1 person per square kilometer (IERN, 2009). According to the IEA, Cameroon has a total surface area of 63,701 square kilometers.

1.2 The Climate of Cameroon and Surface Meteorology

Cameroon has a tropical climate – humid in the south, but increasingly dry towards the north. Along the coast, the average annual rainfall is about 4,060mm. In the semiarid northwest, annual rainfall measures about 380mm. A dry season in the north lasts from October to April. The average temperature in the south is 25°C, on the plateau it is 21°C and in the north it is 32°C (maps of world, 2009). Cameroon has mean annual hours of sunshine per year of over 3000 hours and an average solar radiation intensity of 240W/m² (IEA, NASA). In the sunny part of the country, the average solar irradiance is estimated at 5.8kWh/day/m², while it is 4.9kWh/day/m² in the rest of the country.

1.3 The Energy Situation in Cameroon

“Energy in Cameroon plays a pivotal role in shaping the economy of the country. With reserves of oil and natural gas, Cameroon is following new policies to improve and develop the sources of energy. A rise in global competition has led to the expansion of the energy sector in Cameroon. Energy in Cameroon comprises of its oil and natural gas reserves, hydroelectric energy etc. The major energy sources of Cameroon include fuel wood, Hydropower and petroleum.

Cameroon began offshore oil production in 1977. Annual production has gradually fallen since 1985, and the decline is expected to continue as existing reserves are depleted. Output amounted to 76,600 barrels per day in 2001, down from 100,000 barrels per day in 1999. However, as of 2002, Cameroon was still sub-Saharan

Africa's fifth-largest crude oil producer. Hydroelectric energy is one of the major energies in Cameroon. Cameroon currently relies heavily on hydro power for its energy. Electrical energy is produced mostly by two major hydroelectric stations located on the Sanaga river. Nearly 60% of the power from these stations goes to the aluminum smelter at Edéa ALUCAM. Cameroon's installed electrical capacity was 819,000 kW in 2001; total production of electricity in 2000 was 3.5 billion kWh, of which 97.4% was from hydropower and the remainder from fossil fuels. Consumption amounted to 3.4 billion kWh in 2000" (Encyclopedia of the nations, 2009). The energy sector of Cameroon, is presently undergoing a smooth and steady development that helps to attract foreign investors, but the current situation is not good enough to prevent frequent power outages.

According to the IEA, the energy consumption of Cameroon is estimated at 3,490GWh. At present, 4.8% of its power needs are met by hydropower, 78% from biomass and the rest is generated from oil (Figure 1-2). Technical data from AES SONEL (the sole company in Cameroon responsible for generating, transmitting and distributing electrical energy) factsheet 2009, indicates an installed electricity capacity of 229MW including a 206 MW of thermal energy. AES SONEL generates 3,685GWh electrical energy annually, 2,799 GWh of which is sold to the public. AES SONEL has an access rate of 15%, including just 4% in rural areas. The rate of coverage of the country is 46%, with 20 agencies and 117 offices serving a total of 553,186 subscribers. AES SONEL has a total of 43 electricity generation facilities, generating 95% hydroelectricity and 5% conventional thermal energy. These facilities constitutes:

- 3 hydropower plants (Songloulou 400 MW, daily modulation basin, Edea, 265 MW, run-of river power plant and Lagdo, 72 MW, head reservoir)
- 3 dam- reservoirs for regulating River Sanaga: Bamendjin, Mbakaou, Lagdo, with a total of 7.3 Gm³
- 6 diesel thermal power plants connected to networks: Oyomabang, Bassa, Logbaba, Bafoussam, Limbe, and Djamboutou and
- 31 isolated power plants.

Energy generated from these plants is transmitted across the country in two separate networks: the northern network, powered by the Lagdo (80Mva) hydropower plant and

the Djamboutou (17Mva) diesel thermal power plant, and the southern grid is powered by the hydropower plants of Songloulou (456Mva) and Edéa (275Mva) and 4 thermal power plants: Oyomabang (40Mva), Bassa (25Mva) Logbaba (20Mva) and Bafoussam (16Mva).

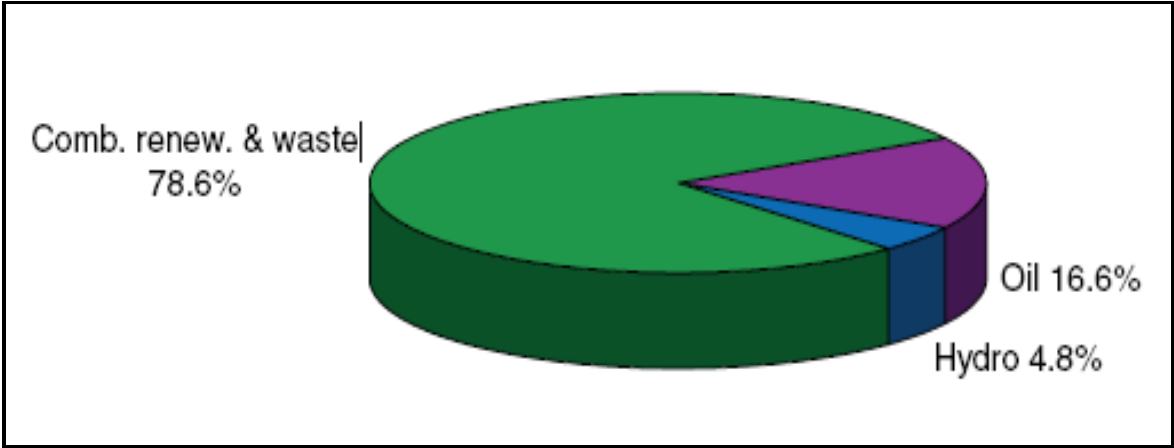


Figure 1-2: Share of Total Primary Energy Supply in Cameroon 2005

Source: IEA Energy statistics, www.iea.org/statistics/index

1.4 Renewable Energy

Renewable energy is energy generated from natural resources such as sunlight, wind, rain, tides, and geothermal heat, which are renewable (naturally replenished) (Wikipedia, 2009). In 2006, about 18% of global final energy consumption came from renewables, with 13% coming from traditional biomass, such as wood-burning and 3% from hydroelectricity. New renewables (small hydro, modern biomass, wind, solar, geothermal, and biofuels) accounted for 2.4% and are growing very rapidly. The share of renewables in electricity generation is around 18%, with 15% of global electricity coming from hydroelectricity and 3.4% from new renewables (REN21, 2007).

Advantages and Benefits of Renewable Energies (ICRE, 2004)

- Renewable energy (RE) presents a more sustainable alternative to the use of finite sources of energy.
- They reduce the reliance on energy imports and diversify energy supply mixes by making use of locally available resources, thus contributing to energy security.

- Renewable resources possess the inability to emit carbon-based warming and polluting agents into the atmosphere.
- As REs have low to zero greenhouse gas emissions, they reduce human-induced climate impacts.
- REs help to reduce negative health impacts from airborne emissions.
- In industrialized countries, renewables have already spurred the development of new industries and services for planning, manufacturing, operating and maintenance and demonstrated their potential to create highly qualified employment in new small and medium-sized enterprises. They can create decentralized markets and contribute to local economic development by introducing new capital and innovation and by developing new sources of revenue for local communities in the developing world too.

In spite of all these advantages, renewables are usually found to be more expensive than conventional electricity sources when compared on a financial cost basis. Because of this, both monopoly and competitive electricity producers have concentrated their investment on conventional electricity technologies, with renewables usually accounting for only a small percentage of the generating stock (Berry and Jaccard, 2001).

There are three main reasons for the discrepancy between the social and economic benefits of renewables and their high financial cost relative to conventional, polluting generation sources (Berry and Jaccard, 2001) and these are:

- Some jurisdictions provide subsidies to conventional generation sources.
- The full costs of pollution (externalities) are not included in the financial cost of conventional electricity sources.
- Renewables are often associated with newer, higher cost technologies, whose relative costs will fall in time with widespread commercialization because of economies of learning and economies of scale in equipment manufacture.

1.5 Overview of Cameroon's Renewable Energy Resources

Renewable energy resources are diverse and vary from country to country. Cameroon's known renewable energy resources are hydro, biomass, wind and solar.

1.5.1 Hydropower

Hydroelectric resources remain the most readily exploitable form of energy in Cameroon, which, together with the Democratic Republic of Congo, is considered to have the greatest hydroelectric potential in Africa. Electrical energy is produced primarily by two hydroelectric stations on the Sananga River. In the 1980s, hydroelectric capacity was expanded by an additional complex on the Sananga River (Song-Loulou) and a 72 MW generator (built with Chinese aid) on the Bénoué. Cameroon's hydropower potential is estimated at 55,200MW and generates 294,000,000MWh per annum (294 TWh per annum) (Belda, 2007).

1.5.2 Biomass

Cameroon has the third largest biomass potential in sub-Saharan Africa. Biomass forms the dominant source of energy accounting for 66.7% of the total national energy consumption, with wood fuel being the dominant biomass form used in Cameroon. Biomass is used in both domestic and commercial sectors for cooking and many other heat applications. In this research, assessment of biomass energy resource potential in Cameroon will not be discussed in detail.

1.5.3 Wind

Wind energy in Cameroon has never been studied thoroughly, a few attempts have been made using wind speed data published by the Cameroonian meteorological services. From these assessments, final conclusions could not be drawn as to the possibilities of wind energy exploitation in the northern regions, but affirmatively, these results revealed that the far northern regions of Cameroon was favorable for the use of wind energy (Tchinda et al, 2000). Meteorological data from NASA, revealed that the northern regions of Cameroon have annual mean wind speeds that are equal to or exceed 3 m/s for over 80% of the time, and the Adamawa region has annual wind speeds that are equal to or exceed 2 m/s for over 60% of the time, while the rest of the country has wind speeds greater than or equal to 1m/s for over 50% of the time. In this research, a detailed analysis of this energy resource is presented in chapter 4 (technical analysis).

1.5.4 Solar

Cameroon being a tropical country is well endowed with solar energy resources, receiving mean annual hours of sunshine per year of over 3000 hours and an average solar radiation intensity of 240W/m^2 (IEA, 2009; NASA, 2009). Some important solar energy resources are available throughout the country. In the sunny part of the country, the average solar radiance is estimated at 5.8 kWh/day/ m^2 while it is 4.9 kWh/day/ m^2 in the rest of the country. Conditions therefore seem to be ideal throughout the country for the exploitation of Cameroon's solar energy resources through various conversion technologies. Solar energy already makes substantial (although unquantified) contributions to the nation's energy supply. Traditional applications of solar energy in Cameroon include sun drying of agricultural produce, fish, fuel wood and clothes. A detailed assessment of this resource is presented in chapter 4 (technical analysis).

Chapter 2 : Aims and Objectives

2.1 Rationale of the Study

Power shortages in Cameroon have been a key constraint to its economic growth. Cameroon has a total installed electricity production capacity of 935 MW, but the country's effective functioning productive capacity is, at present, only 450 MW (Fbo, 2008). This shortfall has been caused by various factors including among others; the reliance on aged facilities and equipments, the effects of harsh climatic conditions, and the lack of long term maintenance.

“Energy related threats such as the lack of sustainable secure and affordable energy supplies, together with the environmental damage incurred in producing, transporting and consuming energy, have been the main drive to the need for renewable energy development. With a world's population of 6 billion people heading to 11 billion, rising fuel costs, climate change concerns and the growing demand for electricity, renewable energy is fast becoming an increasingly valuable solution for the global energy problem.

The quest for energy has created greenhouse gases (GHG) emission problems which have contributed greatly to global warming. Emissions of GHG such as carbon dioxide, methane, and others, have increased dramatically in the last century through fossil fuel burning and land use changes. Human activity has pushed atmospheric concentrations of carbon dioxide, the chief greenhouse gas, to more than 30% above pre-industrial levels, 370 parts per million today compared to about 280 in 1750 (CDIAC 2001). These increases have already brought changes to the Earth's climate. Nine of the ten hottest years since 1860 (when temperature records began being kept) occurred between 1990 and 2000. Continued accumulation of GHG is expected to lead to rising temperatures, more severe weather events, increased ecosystem stresses, shifting precipitation patterns, increased ranges of infectious diseases, coastal flooding, and others impacts that we are only beginning to understand. These changes will bring uncertain, but potentially devastating, consequences to communities around the globe, both in the industrialized and developing worlds.

According to the Intergovernmental Panel on Climate Change (IPCC), the authoritative scientific voice on climate change, without active efforts to reduce emissions, the planet is expected to warm by an unprecedented 2.5 to 10° F during the 21st century. This rate of warming is much larger than the observed changes during the 20th century and is very likely to be without precedent during at least the last 10,000 years.” (Earthtrends, 2001). Impacts of climate change are expected to be severe. Taking unified global action against climate change, however, has proven contentious. A shift from the use of natural gases and fossil fuel towards green and renewable sources of energy is a big step to cutting the rate of GHG emissions.

Despite Cameroons vast renewable energy potentials, the performance of the power sector in Cameroon since 2001 has been a disaster to its economy, going through fluctuating and insufficient power generations. The sole dependence on hydropower for electricity in Cameroon has significantly contributed to its energy problems with increasing climatic changes leading to severe and prolonged draughts during the dry season in Cameroon which runs between November and April. The majority of people in Cameroon use biomass as their primary energy source (Figure 1-2), due in large to a lack of electricity accessibility.

2.2 Aims and Objectives of the Research

This research work attempts to evaluate the potential of wind and solar energy of Cameroon. It tries to establish the state of the art of electricity generation, transmission and distribution in Cameroon, the problems it faces and the inability to meet the current energy demand for Cameroon. In addition, the research seeks to examine and assess the renewable energy sector and the possibility to revitalize the energy sector in Cameroon in an environmentally friendly way. The research further examines the legal framework of Cameroon and other government initiatives in as much as energy and electricity are concerned. It also considers the potential role of renewable energy, especially wind and solar, in improving the performance of the energy and electricity sector in Cameroon. Thus, the specific considerations and objectives of this study are as follows:

- Identify and document the prevailing state of electricity generation, transmission, and distribution in Cameroon;
- Carry out a thorough assessment of the state of renewable energy development in Cameroon;
- Identify the principal reasons and hurdles inhibiting at least a 99.99% energy supply in Cameroon;
- Analyze the economic and sustainability likelihood for Cameroon buffered by a boost in its energy sector by benefiting from the employment and use of renewable energy technologies based on the implementation of strategies by using a techno-economic viability analysis for future RE projects with the RETScreen software tool;
- Recognize the legislations and initiatives formulated by the government of Cameroon in an attempt to ameliorate its energy sector;
- Determine the environmental benefits from using RE based on the amount of green house gas emissions that can be avoided;
- Proffer a plethora of recommendations that should serve as a comprehensive strategy for an effective and efficient management of the electricity sector for a sustainable development of Cameroon.

2.3 Thesis Outline.

Going backwards, this thesis begins with an introductory chapter, that presents the Republic of Cameroon and its energy situation. It also introduces renewable energy and gives an overview of the renewable energy resources in Cameroon.

This current chapter (chapter 2) provides substantial information on the perspectives, motives and objectives underlying this dissertation. The chapter ends with this outline. In the third chapter entitled “Methodology”, the methodology used in this thesis is outlined and justified. It introduces the software tool (RETScreen) used in this research to analyze the wind and solar potentials for Cameroon.

The fourth chapter provides the centre point of this research. It begins with an introduction of the various study areas used, followed by the five step procedures used in the analysis. It further describes the technical specifications of the wind turbine and

characteristic values used in the analyzes for the wind resource followed by results and discussions for each of the locations analyzed. The remainder of the chapter looks at the solar resource, giving the technical specifications for the solar module and characteristic values used to analyzed the solar resource. The chapter ends with a general discussion for the solar resource.

Chapter 5 provides an assessment of the financial viability for running running potential wind power projects for three selected locations (Maroua, Garoua and Ngoundere) and a potential solar power project for Garoua. It begins with an assessment of the costs associated with purchasing, installing and running of such projects. This is followed by financial analysis to determine if these projects could be developed on a commercial scale and evaluate the possibility of self-financing which is the basis for its economic importance.

In chapter 6, estimates of the greenhouse gas emission reduction (mitigation) potential of the proposed project are presented in a conceptualized way.

A seventh chapter evaluates the environmental importance of RE with respect to GHG emissions.

Finally, legislations and policies are fundamental to the effective and the efficient management of renewable energy and energy as a whole. Therefore, the final section of this dissertation explores and analysis the policy and legal frameworks regulating the energy sector in Cameroon. It evaluates in general terms initiatives enacted by the government of Cameroon to reduce the energy problems.

In the final section, chapters 8 and 9 provides conclusions and recommendations for a possible enhancement of Cameroons' economy by the use of renewable energy, especially wind and solar.

Specifically, this thesis aims to provide the fundamental potential of Cameroons renewable energy resources and the possibility to bypass the constraints limiting the use, promotion and development of its full potentials. The research will serve as a guide to all actors or stakeholders that have a stake in the regulation and use of renewable energy in Cameroon. These stakeholders include international donor agencies, the corporate world, Non-governmental organizations (NGOs) and government policy makers.

Chapter 3 : Methodology

3.1 Introduction

The term methodology, in a broad perspective, refers to the process, principles and procedures by which we approach problems and seek answers (Bogdan and Taylor, 1975). Methodology comprises data collection, organization and interpretation (Riley, 1963). It applies to how research is being conducted. The methodology employed in this research is mainly through literature reviews, the use of the RETScreen software tool for analysis and interviews. Neither field surveys nor site visits were undertaken for this work.

It is evident that our assumptions, interest and goals influences methodological choices (Bogdan and Taylor, 1975), and thereby the results. It is extremely important to present how the different studies have been conducted. Apart from personal observations and relevant information compiled from articles, government reports, papers and books, information presented herein was obtained from/through the following stakeholders.

- Representatives from all relevant government personnel;
- NGO's;
- Staff and researchers.

Discussions were generated to identify constraints with regards to the energy sector in Cameroon. These together with information obtained from secondary data were transcribed and analyzed.

3.2 Literature Review

The wind power potential has never been considered as an alternative source of energy in Cameroon. For that reason many researches took place to utilize renewable energy especially wind energy in a full-fledged manner. In 2002, Tchinda and Kaptoum discussed the prospect of wind power in the Adamawa and northern Cameroon regions. It was observed that the northern region has annual mean wind speeds that are equal to or exceed 2 m/s for over 53% of the time, while the Adamawa region has

annual wind speeds that are equal to or exceed 1 m/s for over 29% of the time. In their research, calculations of the mean wind power density from a hypothetical aero generator or water pumping system and the mean wind power from circular areas were also made. In the northern regions, a very fruitful result would be achieved if windmills were installed for producing wind energy for drinking water, irrigation and electricity for small households, they concluded.

For the realization of this research work, relevant information in the international scientific arena was collected, through diverse studies of literature from textbooks/literature, international scientific journals, internet websites, reports by governmental agencies and NGO's. Substantial knowledge was gathered and a review of what other scientists have written on issues concurring with the research topic was made.

Major literature reviews were conducted to assemble information in the following areas. The first was related to a description of the state and situation of energy generation and consumption in Cameroon. The second was aimed at presenting the rationale, objectives and outline of the workflow in this research. The third area was used to give a detailed description of the tool used in the technical analysis to assess the potential of RE generation in Cameroon (RETScreen International 4). Furthermore a fourth section reviewed what the government of Cameroon has done in a bid to improve the state of the energy sector. A final literature review was undertaken to analysis and compare how sustainable the economy of Cameroon will be, employing the use of wind and solar to generate energy to the current means. In addition, the effects and improvements that will result from combining these technologies to the current situation on the ground.

Software analysis

Prior to settling to the RETScreen, this research work was aimed at developing a model for assessing the practicality of using renewable resources for electricity production in Cameroon. In order to achieve this, wind speed and solar irradiance data for major locations in Cameroon from the NASA Langley Research Centre Atmospheric Science Data centre were to be used. This was to be estimated using

complicated calculations and complex equations in understanding and constructing wind turbine generators as well as solar modules. Also, this had to involve a lot of assumptions which could yield many errors and produce false results. In order to minimize the error margin and obtain a more precise resultant value which will be as close to the true value that would be obtained on the ground, it was imperative to employ a standardized tool which is internationally accepted. An appropriate tool was to have access to a rich database, be able to provide detailed information on equipment suppliers and service providers around the globe. Secondly, this tool must be user friendly and flexible without compromising on the technical details. The goal of the latter is to be able to run models developed in this research to the appreciation and understanding of the not so technical mind (specifically people without engineering and financial backgrounds).

Several RETs and related software were identified and reviewed such as Hybrid2, ViPOR, RET Finance, HOMER and PV WATTS. With the above points, the number of software was narrowed down. The RETScreen software was selected because it helps rapidly evaluates whether a proposed clean energy project makes sense and is worth further consideration. Other software were equally good such as HOMER, but was much more technical and less user friendly than the RETScreen software tool.

3.3 RETScreen 4 International

The RETScreen 4 International Clean Energy Project Analysis Software is an innovative energy awareness, decision support and capacity building tool. It is managed under the leadership and ongoing financial support of CANMET ENERGY research centre of Natural Resources Canada's NRCan. RETScreen is developed in collaboration with a number of other governmental and multilateral organizations, and with technical support from large network of experts from industry, government and academia, such as NASA, REEEP, UNEP, DTIE, GEF, SWERA, PCF, EEF, WB and Leonardo ENERGY Initiative. (RETScreen, 2005). The first version of the RETScreen software was released in May 1998. Since then, it has become the most popular and widely used RE feasibility analysis software in the world, with more than 186,000 downloads in 122 countries (RETScreen, 2005). The latest version RETScreen 4

international is a major development of the legacy versions consisting of 35 languages covering more than two thirds of the world's population.

3.3.1 RETScreen Objectives

The RETScreen International Clean Energy Decision Support Centre seeks to build the capacity of planners, decision-makers and industry to implement renewable energy, cogeneration and energy efficiency projects. This objective is achieved by developing decision making tools (i.e. RETScreen software) that reduce the cost of pre-feasibility studies; disseminating knowledge to help people make better decisions; and by training people to better analyze the technical and financial viability of possible projects. The broad aim of the centre's partners is to foster increased market uptake of renewable energy technologies (RETs) that reduce the reliance on conventional energy sources and which help to protect the global environment. The centre's main strategies for achieving its objectives are as follows:

- Develop enabling tools;
- Transfer knowledge; and
- Provide project implementation.

A key principle is that the enabling tools developed by the centre must make it easier for people to consider renewable energy projects at the critically important initial planning stage, which is generally the best opportunity for introducing new technologies (RETScreen, 2005). The enabling tools are also intended to significantly reduce the duration and cost of the analysis itself, so that more RET projects can be considered and ultimately, more will be built.

According to CANMET, 1991 numerous opportunities are currently being missed around the world for implementing commercially viable clean energy projects because various decision-makers still do not routinely consider them. National and regional planners, industrial engineers, commercial and institutional building architects and utility and community energy planners, for example, often fail to appreciate the benefits of energy efficient and renewable energy technologies (RETs) at the critically important initial planning stage, even when the technologies have proven to be cost effective and reliable in similar situations elsewhere (CANMET, 1991). If clean

energy technologies are not considered and put on the table upfront in the decision-making process, it is usually next to impossible for them to be considered in the program development or project implementation stages. This results to projects being missed that could help countries meet energy needs locally, and in a sustainable way, while reducing GHG emissions, saving money, increasing energy security and self reliance. These were the main objectives that led to the development of the RETScreen.

3.3.2 Software and Data

RETScreen is the most comprehensive product of its kind, allowing engineers, architects, and financial planners to model and analyze any clean energy project. Decision-makers can conduct a five step standard analysis, including energy analysis, cost analysis, emission analysis, financial analysis, and sensitivity/risk analysis.

The technologies included in RETScreen's project models are all-inclusive, and include both traditional and non-traditional sources of clean energy as well as conventional energy sources and technologies. A sampling of these project models include: energy efficiency (from large industrial facilities to individual houses), heating and cooling (e.g., biomass, heat pumps, and solar air/water heating), power (including renewables like solar, wind, wave, hydro, geothermal, etc. but also conventional technologies such as gas/steam turbines and reciprocating engines), and combined heat and power (or cogeneration).

Fully integrated into these analytical tools are product, project, hydrology and climate databases (the latter with 4,700 ground-station locations plus NASA satellite data covering the entire surface of the planet), as well as links to worldwide energy resource maps. And, to help the user rapidly commence analysis, RETScreen has built in an extensive database of generic clean energy project templates. There is no other tool that helps conduct such an extensive analysis.

3.3.3 RETScreen 4 Features

In RETScreen 4, the software's capabilities have been expanded from renewable energy, cogeneration and discreet energy, to include a full range of financially viable

clean power, heating and cooling technologies and energy efficiency measures. This has been improved through the expansion of climate data, required by the tool, covering the entire surface of the planet, including central-grid connected, isolated-grid connected and off-grid areas. The key output of this significant efforts in version 4 are as follows:

- Development of a new suite of models to evaluate energy efficiency measures for residential, commercial and institutional buildings; communities; and industrial facilities and processes.
- Expansion of the RETScreen climate database to 4,700 ground stations locations around the globe and incorporation of the improved NASA surface meteorology and solar energy dataset for populated areas directly into the RETScreen software.
- Integration of the existing RETScreen models for renewable energy (eg wind energy) and combined heat and power (CHP), along with the new models for energy efficiency measures, all into one software file, and expansion of the capabilities of existing models to evaluate technologies such as ocean current and wave power.
- Translation of the integrated single software file and databases into 30 languages (eg Chinese, French, German)
- Broad dissemination of the tool via the RETScreen website.

The main principles and standard features of RETScreen models can be summarized as follows:

- Technical, financial and GHG analysis;
- Input requirements are simplified as much as possible while still allowing for sufficient detail and accuracy, as appropriate for pre-feasibility and feasibility studies;
- Financial analysis is based on the life cycle of the RE equipments;
- The analysis approach for all technology models is standardized to provide a consistent “look and feel”, improve ease of use and allow for objective comparisons of different RETs.

3.3.4 RETScreen's Five Step Analysis

RETScreen 4's five-step standard analysis runs under Microsoft Excel, which provides a familiar interface (Figure 3-1). Behind Excel, RETScreen contains over 70,000 lines of code, making it powerful and flexible.

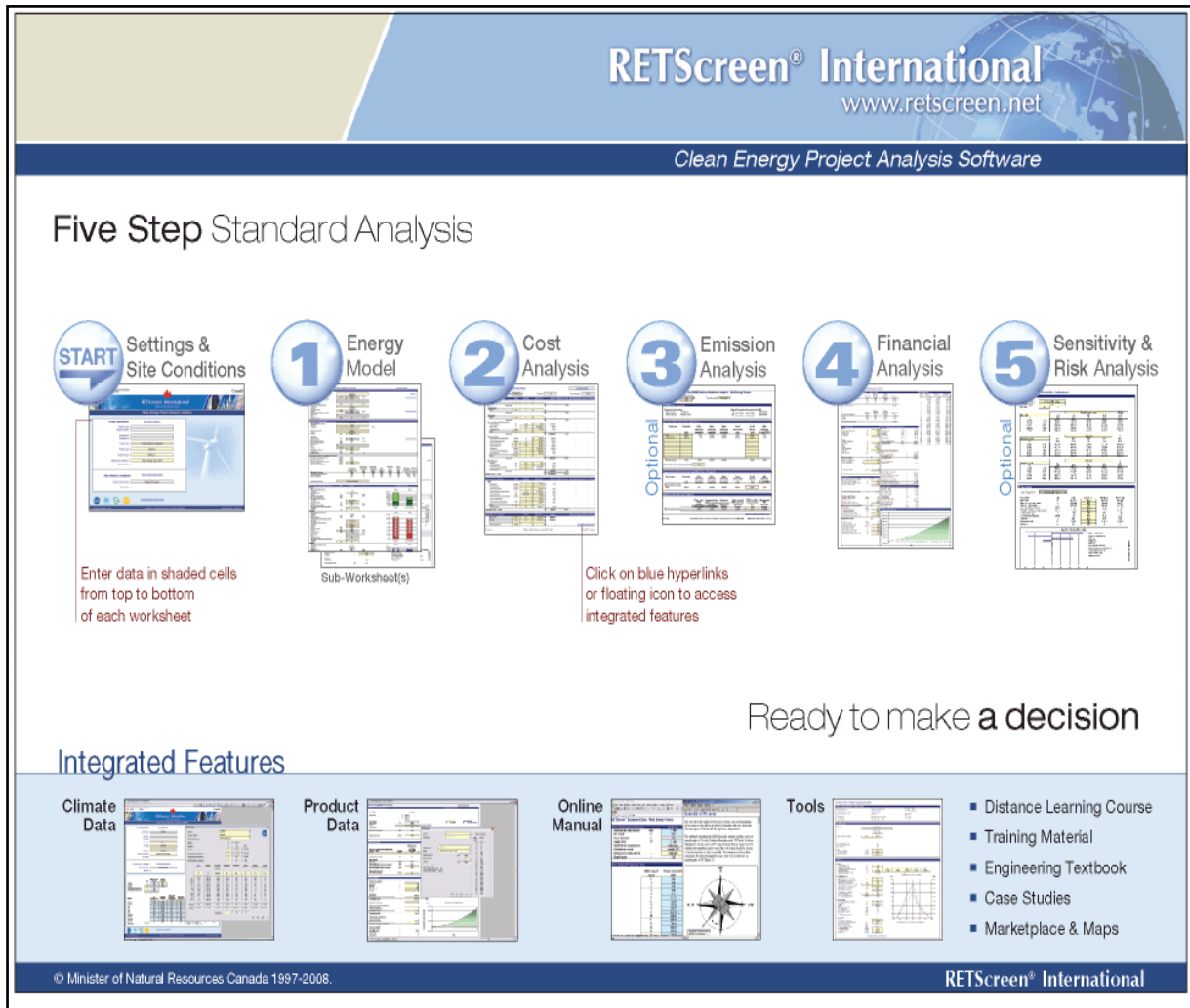


Figure 3-1: RETScreen's Five Step Analysis.

(Source: RETScreen, 2009)

The "Start" sheet appears when RETScreen is opened. Here the user specifies the project name and type, the language, the currency, the unit system, and the climate data. The user can choose between "Method 1", a simplified single spreadsheet, or "Method 2", a more detailed approach. Then the five-step RETScreen analysis begins. First, an energy model determines the energy benefits of the proposed project compared to a conventional alternative. Second, the incremental costs of the clean

energy project are evaluated. Third, an optional greenhouse gas analysis calculates the emissions reductions associated with the project, according to a standardized methodology developed in collaboration with the United Nations Environment Program and the World Bank's Prototype Carbon Fund. Fourth, a financial summary indicates whether the project is financially attractive, considering cash flows, taxation, incentives, and emissions reductions credits. And fifth, a sensitivity and risk analysis reveals how changes in inputs affect the viability of the project, in part through a "Monte Carlo" simulation that reruns the analysis 500 times with random variations in key parameters (RETScreen, 2005)

In addition to RETScreen's climate database, there is a product database of over 7,000 clean energy devices, ranging from wind turbines to fuel cells. A thousand page help manual guides the user and explains clean energy technology. A host of tools performs detailed engineering calculations directly applicable to RETScreen - for example, for sizing a ground heat exchanger or estimating the thermal properties of a building envelope - and helps with unit conversions, steam properties, GHG equivalencies and more.

Apart from software, RETScreen offers a comprehensive distance learning course, training material in many languages, a detailed textbook revealing the algorithms behind RETScreen and providing background information on clean energy technologies, case studies, and links to energy resource maps (RETScreen, 2005).

Chapter 4 : Technical Analysis

4.1. Introduction

For a comprehensive analysis of the renewable energy resource potential of Cameroon, two major sources of renewable energy were considered. These were wind and solar. Due in a large part to time constraint and the scope of a master thesis, other sources of renewable energy such as biomass, combine heat and power, nuclear and geothermal heat were not considered. Hydro was not considered based on the fact that it has already been developed in Cameroon and is the main source of electricity generation. The locations for this research were carefully selected. Firstly, the major criterion for selection was the availability of meteorological data for the location. Meteorological data for these locations were obtained through the RETScreen software from NASA. Secondly, for the analysis to cover much of Cameroon, one location was selected for each of the ten regions of Cameroon (Table 4-1, Figure 4-1). Because meteorological data could not be readily obtained for a location in the western region of Cameroon, Bafia, a location in the Centre region which is quite close to the western region, and with available data was used to assess the potential for western region.

Table 4-1: Locations used for analysis

Site	Region	Location
1	Extreme North	Maroua
2	North	Garoua
3	Adamawa	Ngaoundéré
4	North West	Bamenda
5	West	Bafia*
6	Centre	Yaoundé
7	Littoral	Douala
8	East	Bertoua
9	South	Ebolowa
10	South West	Fontem



Figure 4-1: Map View of Locations Used for Technical Analysis

4.1.1 Far North Region - Maroua

Maroua is a town located in the far northern region of Cameroon. It is situated in the foothills of the Mandara Mountains along the Mayo (‘River’) Kaliao (Britannica, 2009). An important marketing centre, it lies at the intersection of roads from Mokolo (northwest), Bogo (northeast), and Garoua (southeast). Maroua is a major trade centre and is Cameroon’s largest cotton producer. It consists of a textile industry and a cotton industry SODECOTTON. It also consists of a nearby national park, WAZA. Maroua has a population of 415,251 inhabitants with an annual growth rate of 5.45% (World Gazetteer, 2009). Maroua is located in the extreme North region of Cameroon (Figure 4-1), and at a distance of about 809.69km, with an approximate travel/road distance around 931.14 to 1012.11km from Yaoundé¹ (Globefeed, 2009).

¹ Yaoundé - Capital of Cameroon.

Site Reference and Climate Data:

The following data for Maroua was obtained from NASA, through the RETScreen software tool.

Table 4-2: Site reference and climate data for Maroua

	Unit	Climate data location	Project location			
Latitude	°N	10.6	10.6			
Longitude	°E	14.3	14.3			
Elevation	m	387	387			
Month		Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed
		°C	%	kWh/m ² /d	kPa	m/s
January		26.3	17.2%	5.61	96.8	4.1
February		28.3	14.3%	6.24	96.7	4.0
March		31.3	22.5%	6.56	96.4	4.4
April		30.9	44.3%	6.31	96.3	4.6
May		29.1	59.3%	5.96	96.5	4.2
June		26.9	70.2%	5.50	96.7	3.5
July		25.1	78.0%	5.03	96.8	3.2
August		24.9	78.3%	4.85	96.8	3.1
September		25.8	72.4%	5.34	96.7	2.8
October		28.1	48.6%	5.70	96.6	3.2
November		29.0	23.2%	5.85	96.6	3.8
December		27.0	19.4%	5.56	96.8	4.3
Annual		27.7	45.8%	5.70	96.6	3.8
Measured at	m					10.0

4.1.2 North Region – Garoua

Garoua, the capital city of the North region is a town located in the northeastern Cameroon (Figure 4-1) at 9.30°N latitude and 13.39°E longitude. It lies along the right bank of the Benue-River, northeast of Yaoundé. Garoua is the chief commercial centre of the North region and is situated at the junction of the Maroua-Ngouandere road and the Benue waterway. Garoua has long developed as a river port with river steamers and barges bringing petroleum and cement to the city and in return, carry hides and skin, cotton and peanuts 1,900km down the Benue to Nigeria² (Britannica, 2009).

² This shipment is done during a brief period (August-September).

Garoua is connected to the entire nation by road, an airfield and a railway line. The city has a population of 546,060 inhabitants with an annual growth rate of 5.46% (World Gazetteer, 2009). Garoua has a weaving factory supplied by nearby cotton plantations, a textile research company and other industries such as leatherwork and spinning.

Site Reference and Climate Data

The following data for Garoua were obtained from NASA, through the RETScreen software tool.

Table 4-3: Site reference and climate data for Garoua.

	Unit	Climate data location	Project location		
Latitude	°N	9.3	9.3		
Longitude	°E	13.4	13.4		
Elevation	m	424	424		
Month		Air temperature	Relative humidity	Daily solar radiation - horizontal	Wind speed
		°C	%	kWh/m ² /d	m/s
January		26.4	17.8%	6.07	3.8
February		28.2	16.1%	6.36	3.8
March		30.1	31.1%	6.50	4.1
April		28.9	56.7%	6.24	4.3
May		27.1	69.6%	5.78	3.9
June		25.5	76.7%	5.37	3.3
July		24.4	80.2%	4.94	3.1
August		24.2	80.3%	4.83	2.9
September		24.8	77.0%	5.16	2.7
October		26.1	61.5%	5.70	3.0
November		28.0	29.0%	6.17	3.5
December		26.9	20.4%	5.93	4.0
Annual		26.7	51.6%	5.75	3.5
Measured at	m				10.0

4.1.3 Adamawa Region - Ngaoundéré

Ngaoundéré is a town located in north central Cameroon at 7.32°N latitude and 13.58°E longitude. It is the capital of the Adamawa region of Cameroon. According to the World Gazetteer 2009, Ngaoundéré has an estimated population of 298,016 inhabitants with an annual growth rate of 5.8%. Ngaoundéré has a moderate climate with humidity between 20 and 80%. Its air temperature ranges between 22°C and

27°C, with an annual average horizontal solar radiation of 5.65 kWh/m²/yr, and an annual average wind speed of 3.3m/s measured at a height of 10m (NASA 2009). Industries in the city include dairying, preparation of hides and skin, perfume manufacture and cotton ginning. Major beauxite deposits are exploited to the south.

Site Reference and Climate Data:

The following data for Ngaoundéré were obtained from NASA, through the RETScreen software tool.

Table 4-4: Site reference and climate data for Ngaoundéré.

	Unit	Climate data location	Project location		
Latitude	°N	7.3	7.3		
Longitude	°E	13.6	13.6		
Elevation	m	808	808		
Month		Air temperature	Relative humidity	Daily solar radiation - horizontal	Wind speed
		°C	%	kWh/m ² /d	m/s
January		24.8	21.4%	6.48	3.4
February		26.3	21.4%	6.74	3.4
March		26.9	42.9%	6.53	3.7
April		25.6	66.1%	5.83	3.9
May		24.4	73.9%	5.42	3.6
June		23.2	78.0%	5.02	3.1
July		22.2	80.9%	4.67	2.9
August		22.1	81.8%	4.66	2.8
September		22.5	79.2%	4.85	2.6
October		23.1	70.7%	5.25	2.8
November		24.7	42.1%	6.16	3.2
December		24.8	26.4%	6.27	3.5
Annual		24.2	57.3%	5.65	3.3
Measured at	m				10.0

4.1.4 North West Region – Bamenda

Bamenda is the capital of the North West region, one of two English speaking regions of Cameroon. Located around latitude 6.0°N and 10.2°E longitude, at an approximate distance of about 366 km northwest of the Cameroonian capital Yaoundé. Bamenda has an estimated population of 515,593 inhabitants with an average annual growth rate of 6.31% (World Gazetteer, 2009). The city is well connected to the entire nation with road links to Yaoundé and Douala, and an airport with no scheduled services. It is known for its cool climate and scenic hilly locations. The town has an average annual

air temperature of 22.7°C and an average annual horizontal solar radiation of 4.96 kWh/m²/yr (NASA, 2009). Comparatively, Bamenda has very low wind speeds in the range of 1.5-2.5m/s measured at a height of 10m. The city's humidity ranges between 40% and 80%.

Site Reference and Climate Data:

The following data for Bamenda were obtained from NASA, through the RETScreen software tool.

Table 4-5: Site reference and climate data for Bamenda.

	Unit	Climate data location	Project location		
Latitude	°N	6.0	6.0		
Longitude	°E	10.2	10.2		
Elevation	m	785	785		
Month		Air temperature	Relative humidity	Daily solar radiation - horizontal	Wind speed
		°C	%	kWh/m ² /d	m/s
January		24.2	48.9%	6.14	2.1
February		24.6	53.1%	6.19	2.2
March		23.8	72.8%	5.50	2.1
April		23.2	81.2%	5.01	1.9
May		23.0	82.1%	4.83	1.8
June		22.0	84.3%	4.42	2.0
July		21.1	84.9%	4.02	1.9
August		21.2	84.8%	3.92	2.0
September		21.5	85.6%	4.21	1.8
October		21.9	83.4%	4.39	1.6
November		22.2	75.8%	5.21	1.7
December		23.3	57.7%	5.79	1.8
Annual		22.6	74.7%	4.96	1.9
Measured at	m				10.0

4.1.5 West Region - Bafia

The West region is a 14,000 km² of territory located in the central western portion of the Republic of Cameroon. It borders the North West region to the northwest, the Adamawa region to the northeast, the Central region to the south east, the Littoral region to the southwest, and the South West region to the west. It is located at geographical coordinates 5.5°N and 10.5°E. The West region is the smallest in area of Cameroon's 10 regions, yet it has the highest population density of about 97 persons/km² (Wikipedia, 2009). The capital of the West region is Bafoussam, which, is

the largest city in the area. Climatically, the West region has a moderate to high humidity, with temperatures averaging a cool 22°C. Rainfall in the region is moderate. The region has a moderate insolation ranging from 3 to 6.5 kWh/m²/d and low wind speeds in the range 2m/s to 2.7m/s. The region has an average annual precipitation of 175mm.

For the west region, a location with meteorological data could not be obtained directly from NASA through the RETScreen software. Instead, Bafia was used to represent the West region of Cameroon in this analysis.

Bafia

Bafia is a small town in the Centre region of Cameroon, located at latitude 4.75°N and 11.23°E. It has an estimated population of 77,713 inhabitants with an annual growth rate of 4.25% (World Gazetteer, 2009), this makes Bafia the third largest area of the region after Yaoundé and Mbalmayo. It is located north west of Yaoundé at an approximate distance of about 103.12 km. The town is very close to the West region just about 35 km from the regional boundary and about 91 km from Bangangte and some 120 km from Bafoussam.

Bafia has a moderate climate with high humidity ranging from 60% to 85%. The average air temperature for the town is 23°C and obtains between 4 and 6 kWh/m²/d daily solar radiation. Wind speeds in this area are not high, in the range of 1.5-2.0m/s.

Site Reference and Climate Data

The following data for Bafia were obtained from NASA, through the RETScreen software tool.

Table 4-6: Site reference and climate data for Bafia.

	Unit	Climate data location	Project location		
Latitude	°N	4.8	4.8		
Longitude	°E	11.2	11.2		
Elevation	m	616	616		
Month		Air temperature	Relative humidity	Daily solar radiation - horizontal	Wind speed
		°C	%	kWh/m ² /d	m/s
January		24.2	61.1%	5.73	2.0

February		24.7	63.9%	5.86	2.1
March		24.1	77.6%	5.45	1.9
April		24.0	81.5%	5.19	1.8
May		23.8	81.7%	4.94	1.6
June		22.8	83.2%	4.61	1.7
July		22.0	82.8%	4.33	1.8
August		22.0	83.2%	4.37	1.9
September		22.3	84.8%	4.63	1.8
October		22.6	83.8%	4.55	1.6
November		22.9	79.7%	4.97	1.5
December		23.5	68.1%	5.46	1.7
Annual		23.2	77.7%	5.00	1.8
Measured at	m				10.0

4.1.6 Centre Region – Yaoundé

Yaoundé is the administrative capital of the Republic of Cameroon and the second largest city after Douala. Yaoundé is located in the centre south around geographical coordinates 3.87°N latitude and 11.52°E longitude (Figure 4-1). It consist of some of the major economic areas of Cameroon with major industries including tobacco, dairy products, breweries, glass goods, clay and lumber (Britannica, 2009). The city houses major government offices and ministries and is home to foreign embassies. It is also a site for some major universities and several professional schools. It has a major airport (Yaoundé Nsimalen International Airport), and is connected by railway lines to Douala and the northern part of the country. Yaoundé has an estimated 1,743,482 inhabitants with an annual growth rate of 4.27% (World Gazetteer, 2009).

Yaoundé has a moderate climate, with an average temperature of 23°C, with temperature heights of up to 30°C. Yaoundé is one of the areas with the lowest recorded wind speeds of between 1m/s to 2m/s. The city has very high humidity (above 70%) and insolation values in the range of 3.5 – 5.5kWh/m²/d.

Site Reference and Climate Data:

The following data for Yaoundé were obtained from NASA, through the RETScreen software tool.

Table 4-7: Site reference and climate data for Yaoundé.

	Unit	Climate data location	Project location		
Latitude	°N	3.9	3.9		
Longitude	°E	11.5	11.5		
Elevation	m	539	539		
Month		Air temperature	Relative humidity	Daily solar radiation - horizontal	Wind speed
		°C	%	kWh/m ² /d	m/s
January		23.2	76.0%	5.43	1.7
February		23.7	77.3%	5.49	1.9
March		23.9	80.9%	5.20	1.6
April		24.1	81.6%	4.97	1.3
May		23.9	82.0%	4.65	1.2
June		23.0	83.1%	4.26	1.4
July		22.2	81.8%	4.00	1.5
August		22.3	82.5%	3.98	1.7
September		22.5	84.7%	4.27	1.6
October		22.7	84.8%	4.14	1.3
November		22.9	83.0%	4.56	1.2
December		23.0	79.4%	5.12	1.3
Annual		23.1	81.4%	4.67	1.5
Measured at	m				10.0

4.1.7 Littoral Region - Douala

The city of Douala is the commercial and economic capital of Cameroon and is the largest city of the nation. It is situated on the southeastern shore of the Wouri river estuary, on the Atlantic coast about 210km west of Yaoundé (Britannica, 2009). Douala has a richly diverse population that represents more than 130 ethnic groups (IVC, 2009). The city has the largest port in West Africa and is served by an international airport. Located southwest of the nation around 4.06°N latitude and 9.7°E longitude, it is connected by road to all major towns in Cameroon. The city has an estimated population of about 2,054,147 inhabitants with an average annual growth rate of 4.05% (World Gazetteer, 2009).

Douala is one of the major industrial centres in Central Africa and houses breweries, textile factories, palm oil, soap and food processing plants. It also produces building materials, metal work, plastics, glass, paper, bicycles and timber products (Britannica, 2009). Douala houses some major government offices, a university and some professional schools. The city of Douala and its environs consumes almost all of the

electricity generated in Cameroon. ALUCAM³ located in Edea Douala alone consumes about 60% of the total electricity generated in Cameroon. (Reuters, 2009; Africa-Times, 2009).

Douala has a relatively high humidity (above 70%) with very low wind speeds between 1.5m/s and 2.5m/s. The city has an annual average solar radiation of about 4.28kWh/m²/yr (NASA, 2009). Air temperatures for the city varies between 22°C to 30°C.

Site Reference and Climate Data

The following data for Douala were obtained from NASA, through the RETScreen software tool.

Table 4-8: Site reference and climate data for Douala

	Unit	Climate data location	Project location		
Latitude	°N	4.1	4.1		
Longitude	°E	9.7	9.7		
Elevation	m	390	390		
Month		Air temperature	Relative humidity	Daily solar radiation - horizontal	Wind speed
		°C	%	kWh/m ² /d	m/s
January		24.5	73.9%	5.41	2.0
February		24.8	76.2%	5.36	2.0
March		24.7	82.3%	4.88	1.8
April		24.7	84.1%	4.55	1.5
May		24.5	84.9%	4.37	1.5
June		23.7	85.9%	3.91	1.8
July		22.8	85.5%	3.41	2.1
August		22.8	85.8%	3.04	2.2
September		23.0	87.0%	3.44	2.0
October		23.4	86.9%	3.70	1.6
November		23.7	84.3%	4.30	1.5
December		24.1	78.7%	5.05	1.6
Annual		23.9	83.0%	4.28	1.8
Measured at	m				10.0

4.1.8 Eastern Region - Bertoua

Bertoua is a town in the southeastern part of Cameroon. Located around latitude 4.58°N and 13.68°E longitude (Figure 4-1), it is situated in the transition zone between

³ An aluminum smelting company

the southern forest and the northern Savanna (Britannica, 2009). Bertoua is the capital city of the eastern region of Cameroon, and has an estimated population of about 281,139 inhabitants with an average annual growth rate of 6.26% (World Gazetteer, 2009). The city is well connected with the rest of the country by road and is served by an airport. The eastern region of Cameroon houses Cameroon’s timber industry, and has been subjected to wild and uncontrolled deforestation. Timber alone generates more than a quarter of Cameroon’s nonpetroleum export revenues, and timber production in the country has increased by 35% since 1980 (WRI, 2000). Apart from timber exploitation in the region, Bertoua houses a cassava processing complex and a peanut oil factory (Britannica, 2009).

Bertoua has a moderate climate with temperatures averaging a yearly 23.6°C. The wind resource in the area is not very rich with wind speeds in the range 1.5-2.5m/s (NASA, 2009). The town has a moderate humidity between 40% and 80% with an average annual solar radiation of 5.02kWh/m²/yr.

Site Reference and Climate Data:

The following data for Bertoua were obtained from NASA, through the RETScreen software tool.

Table 4-9: Site reference and climate data for Bertoua.

	Unit	Climate data location	Project location		
Latitude	°N	4.6	4.6		
Longitude	°E	13.7	13.7		
Elevation	m	692	692		
Month		Air temperature	Relative humidity	Daily solar radiation - horizontal	Wind speed
		°C	%	kWh/m ² /d	m/s
January		24.7	48.9%	5.86	2.2
February		25.2	53.4%	6.01	2.4
March		24.5	71.6%	5.60	2.3
April		24.3	76.3%	5.29	2.1
May		24.0	76.5%	4.83	1.9
June		23.1	77.7%	4.36	1.8
July		22.4	76.8%	4.20	1.8
August		22.4	78.8%	4.35	1.8
September		22.6	80.9%	4.62	1.8
October		22.9	79.1%	4.56	1.7
November		23.0	74.6%	5.04	1.7
December		23.8	58.6%	5.54	1.9

Annual		23.6	71.2%	5.02	1.9
Measured at	m				10.0

4.1.9 South Region – Ebolowa

Ebolowa is a town located in south Cameroon, some 112km south-southwest of Yaoundé. Located around 2.93°N latitude and 11.14°E longitude, Ebolowa is situated at the intersection of roads to Yaoundé and the neighboring country of Gabon to the south (Britannica 2009). Ebolowa is the capital city of the south region and has an estimated population of 123,116 inhabitants and an annual growth rate of 5.62% (World Gazetteer, 2009). Ebolowa is a centre for cocoa and palm oil trade with nearby experimental plantations for cocoa and palm oil. The town is well connected to the rest of the country and is served by an airport (Britannica, 2009).

Ebolowa has a moderate climate averaging an annual 23.4°C temperature. Humidity in the region is relatively high above 75%. The area has very low prospects for wind energy with wind speeds below 2m/s and an annual average of 1.4m/s. Ebolowa has an average annual solar radiation of 4.63kWh/m²/yr.

Site Reference and Climate Data:

The following data for Ebolowa were obtained from NASA, through the RETScreen software tool.

Table 4-10: Site reference and climate data for Ebolowa.

	Unit	Climate data location	Project location		
Latitude	°N	2.9	2.9		
Longitude	°E	11.1	11.1		
Elevation	m	503	503		
Month		Air temperature	Relative humidity	Daily solar radiation - horizontal	Wind speed
		°C	%	kWh/m ² /d	m/s
January		23.3	78.8%	5.30	1.6
February		23.7	79.6%	5.36	1.8
March		24.2	80.2%	5.19	1.5
April		24.4	80.6%	4.94	1.3
May		24.2	81.1%	4.61	1.2
June		23.2	80.8%	4.25	1.3
July		22.7	78.2%	4.16	1.5
August		22.8	78.9%	4.04	1.7
September		22.9	82.6%	4.27	1.6
October		23.0	83.6%	4.18	1.3
November		23.2	82.8%	4.39	1.2

December		23.2	80.9%	4.97	1.3
Annual		23.4	80.7%	4.63	1.4
Measured at	m				10.0

4.1.10 South West Region – Fontem

The South West region is one of two English speaking regions of Cameroon. An important economic centre, it consist of a petroleum refinery (SONARA), a sea port, a university, and various plantations for rubber, cocoa and banana. It is also a great centre for touristic attractions as it carries one of Africa’s largest volcanoes – Mount Cameroon.

Fontem is one of two locations used in this research which is not the capital city of its region. The selection was dependent on the availability of meteorological data for the region/location from NASA through the RETScreen software. The town is located in Manyu, in the South West region of Cameroon. Its geographical coordinates are 5.47°N latitude and 9.88°E longitude. Fontem has an estimated population of 20,342 inhabitants with a 1.83% annual growth rate (World Gazetter, 2009).

Fontem has an annual average air temperature of 22.9°Cwith very low wind speeds averaging 1.8m/s. The humidity of the area is relatively high above 60%. Solar radiation in the area is in the range between 3 and 6kWh/m²/d.

Site Reference and Climate Data:

The following data for Fontem were obtained from NASA, through the RETScreen software tool.

Table 4-11: Site reference and climate data for Fontem.

	Unit	Climate data location	Project location		
Latitude	°N	5.5	5.5		
Longitude	°E	9.9	9.9		
Elevation	m	616	616		
Month		Air temperature	Relative humidity	Daily solar radiation - horizontal	Wind speed
		°C	%	kWh/m ² /d	m/s
January		24.0	59.3%	5.81	2.0
February		24.3	63.9%	5.77	2.1
March		23.7	79.1%	5.35	1.9
April		23.6	83.8%	4.99	1.6
May		23.5	84.5%	4.68	1.6
June		22.5	86.5%	4.32	1.9
July		21.7	86.8%	3.86	1.9

August		21.7	86.3%	3.58	2.0
September		22.0	87.3%	4.09	1.8
October		22.4	86.3%	4.32	1.5
November		22.6	81.4%	4.88	1.6
December		23.1	68.1%	5.48	1.6
Annual		22.9	79.5%	4.75	1.8
Measured at	m				10.0

For each location selected, two separate analysis were carried out; a 2,000kW(2MW) central-grid connected wind energy analysis and a 2,000W (2kW) isolated-grid connected solar energy analysis. The procedure for both analysis using the RETScreen software tool were similar and only differed in the type (wind or solar), value, number of units, location and data. The following step by step procedure was used for the analysis.

- i. As part of the RETScreen Clean Energy Project Analysis software, the *Start* worksheet was used to enter general information about the project, as well as site reference conditions regarding climate. It was also used to select standard settings used to perform the analysis (Figure 4-2).

Figure 4-2: RETScreens' Start worksheet showing project information.

ii. After all the general information for the analysis were entered, the energy model worksheet was used to evaluate various types of energy efficiency measures projects. This was then used to investigate the viability of energy efficiency in the locations selected for wind and solar. This could also be used for improvements in a wide range of residential, commercial, institutional buildings, and industrial facilities, from single-family homes and apartment complexes, to office buildings, hospitals, large pulp and paper mills.

The software can also be used to assess projects incorporating a variety of energy efficiency measures associated with building envelope, ventilation, lights, electrical equipment, hot water, pumps, fans, motors, process electricity, process heat, process steam, steam losses, heat recovery, compressed air, refrigeration, and more. It is useful for both new construction and retrofits. Whole facilities can be modelled, or sub-systems and rooms can be studied individually.

In this case, the energy model worksheet was used to evaluate the potential output for a single 2MW wind turbine and 10 units of 200W solar modules solar energy output (Figure 4-3).

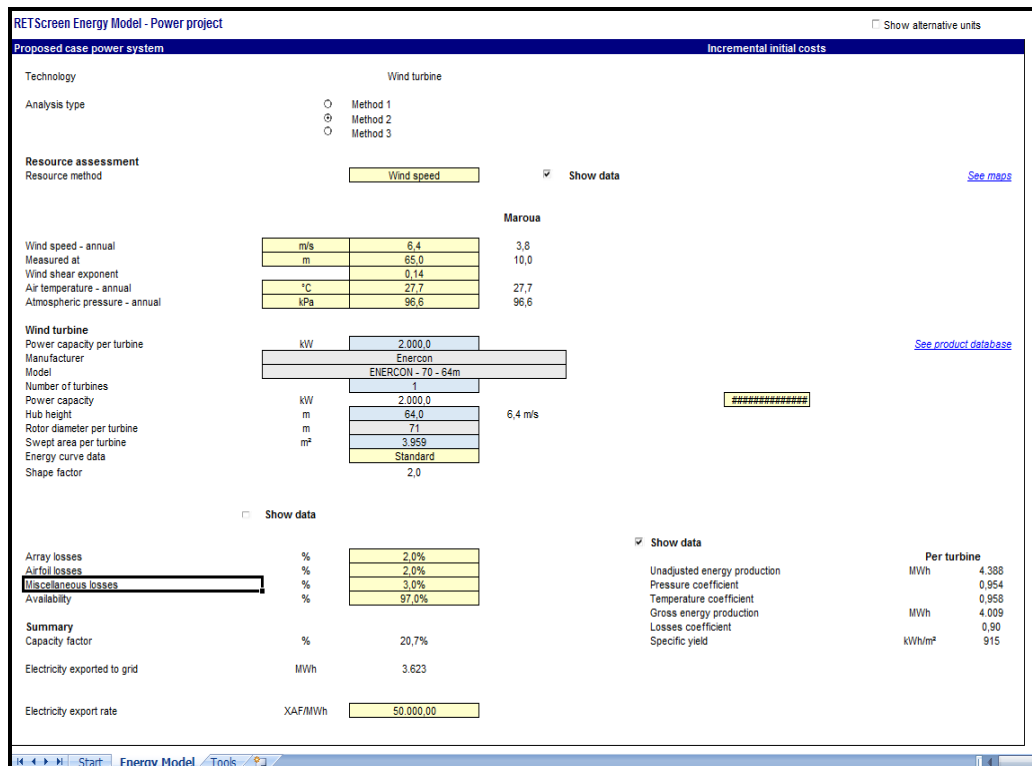


Figure 4-3: RETScreens Energy Model Worksheet.

iii. Other steps involved in the analysis depend on which method selected. For this analysis method 2 was selected, to give a more detailed analysis, performed based on annual climate data and wind turbine(s) equipment data. With method 2 selected, the analysis consisted of three worksheets: the start sheet, the energy model worksheet and a final (optional) tools worksheet. The tools worksheet generally helps the user calculate a number of different values such as the amount of methane gas available from a landfill site (Figure 4-4).

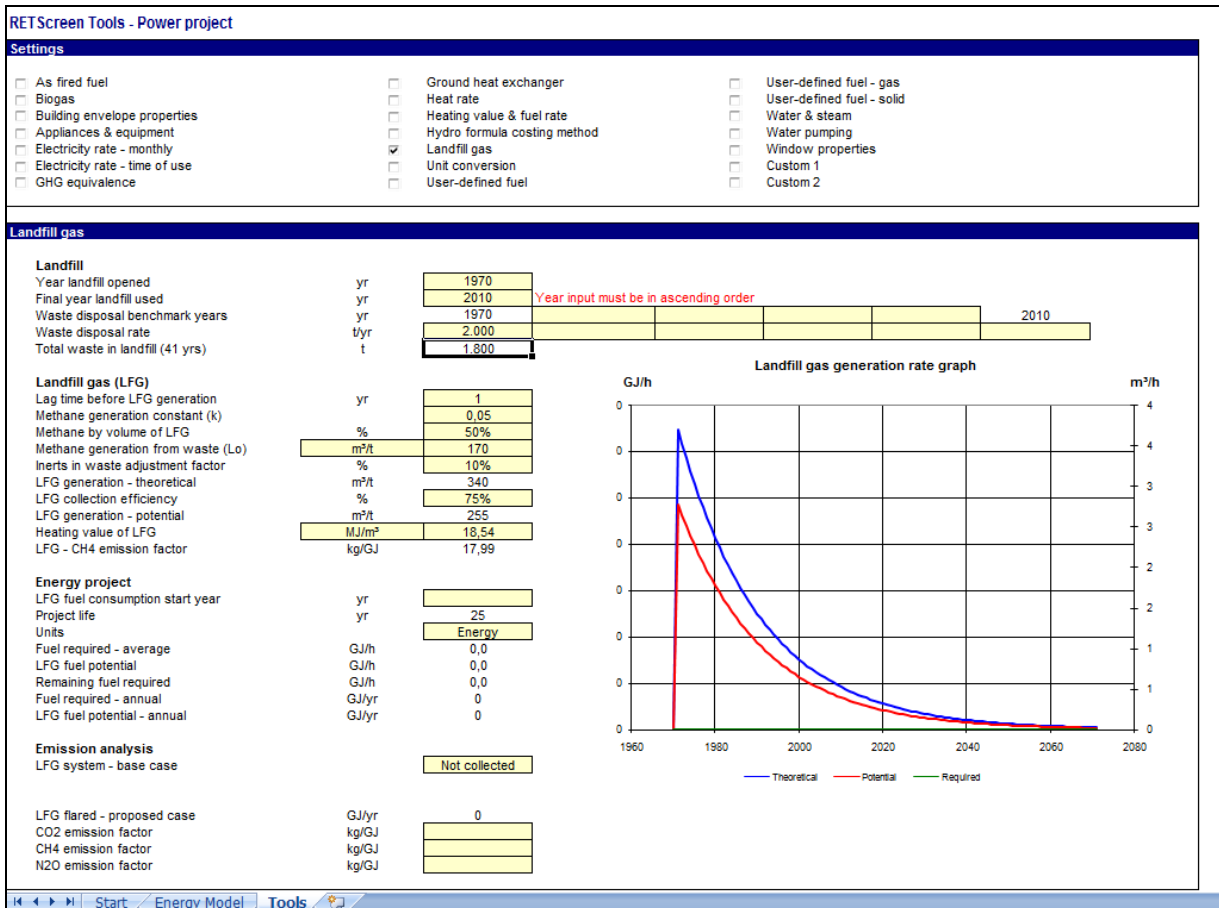


Figure 4-4: RETScreen's Tools Worksheet

iv. Other worksheet/steps involved in the analysis included among others emission analysis, financial, cost and risk analysis. These were illustrated in their respective sections.

4.2. Central-grid Connected 2,000kW Wind Energy

Wind Energy Background

The kinetic energy in the wind is a promising source of renewable energy with significant potential in many parts of the world. The energy that can be captured by wind turbines is highly dependent on the local average wind speed. Regions that normally present the most attractive potential are located near coasts, inland areas with open terrain or on the edge of bodies of water. Some mountainous areas also have good potential. In spite of these geographical limitations for wind energy project siting, there is ample terrain in most areas of the world to provide a significant portion of the local electricity needs with wind energy projects (Rangi et al., 1992).

An assessment was made to determine the feasibility of installing and generating electrical energy from the wind resource in each of these locations from a single wind turbine, connected to the central-grid. Data obtained from NASA indicated an average annual wind speed value of between 1.4m/s and 3.8m/s at a height of 10m. Across the nation, higher values were observed towards the northern part of the country (Figure 4-6). Maroua had the highest value of 3.8m/s while Ebolowa to the south, had the lowest wind speed value of 1.4m/s (Figure 4-5).

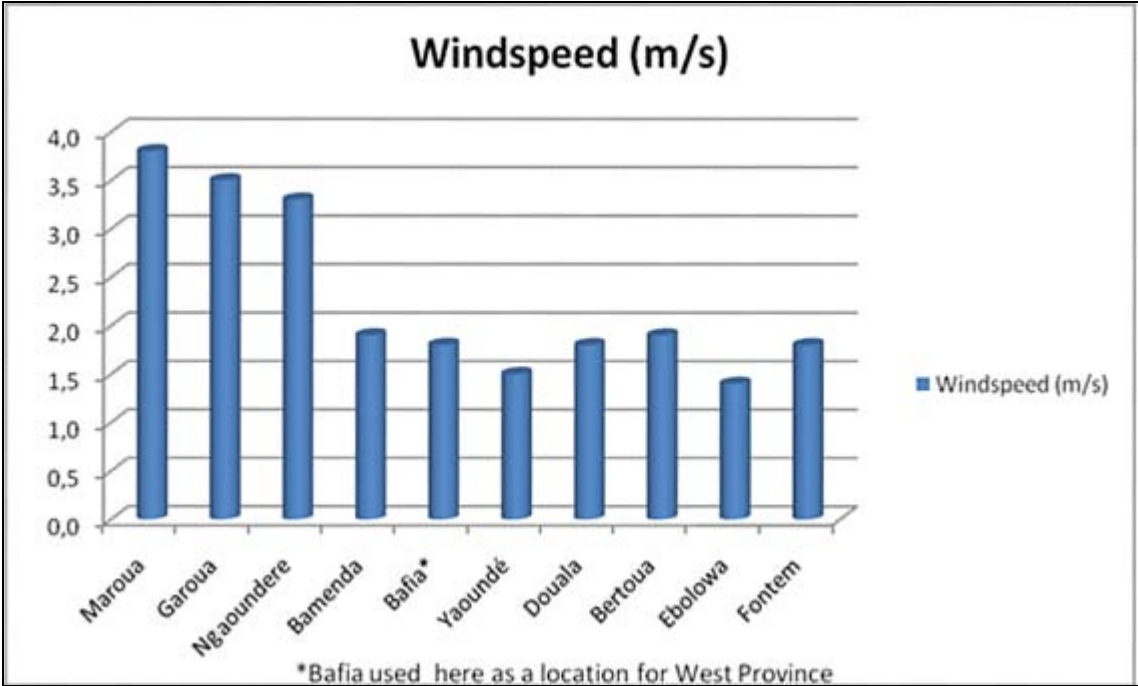


Figure 4-5: Graph of Average Annual wind speeds for various locations used.

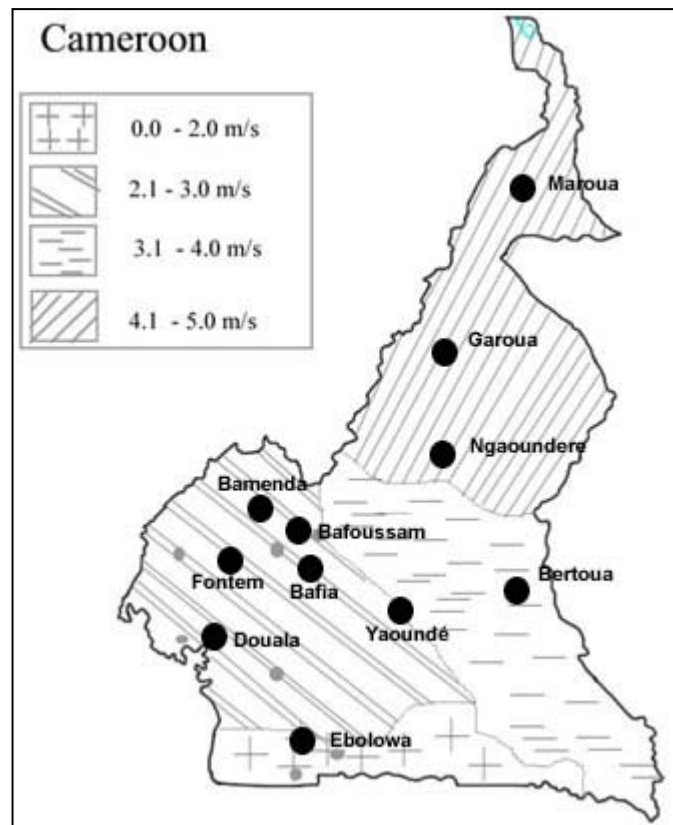


Figure 4-6: Mean monthly wind speeds in Cameroon (10m above ground)

(Source: developed using wind speed data obtained from NASA)

Energy from these winds can be converted into electrical and mechanical energy by a wind turbine. The most common wind turbines in operation today generate power from a three blade horizontal axis, mounted on a steel tower (El Bassam, 2004). These have been in use since 1977 and have become the industrial standards. These consist mainly of a gearbox, a generator and other equipments as shown in Figure 4-6. Most modern wind turbines have efficiencies of less than 50% with maximum efficiencies of 44%, and a design lifetime of 20 years. Wind turbines are rated by their maximum output in kilowatts (kW) or megawatts (1,000kW or 1MW). For commercial utility sized projects, the most common wind turbines sold are in the range of 600kW to 5MW – large enough to supply electricity to 600-5,000 modern homes. A typical 600kW turbine has a rotor diameter of 45m and is mounted on a 50m or taller concrete or steel tower depending on the local wind resources and topography. The newest megawatt-size types have rotor diameters up to 120m (Figure 4-6) (El Bassam, 2004).

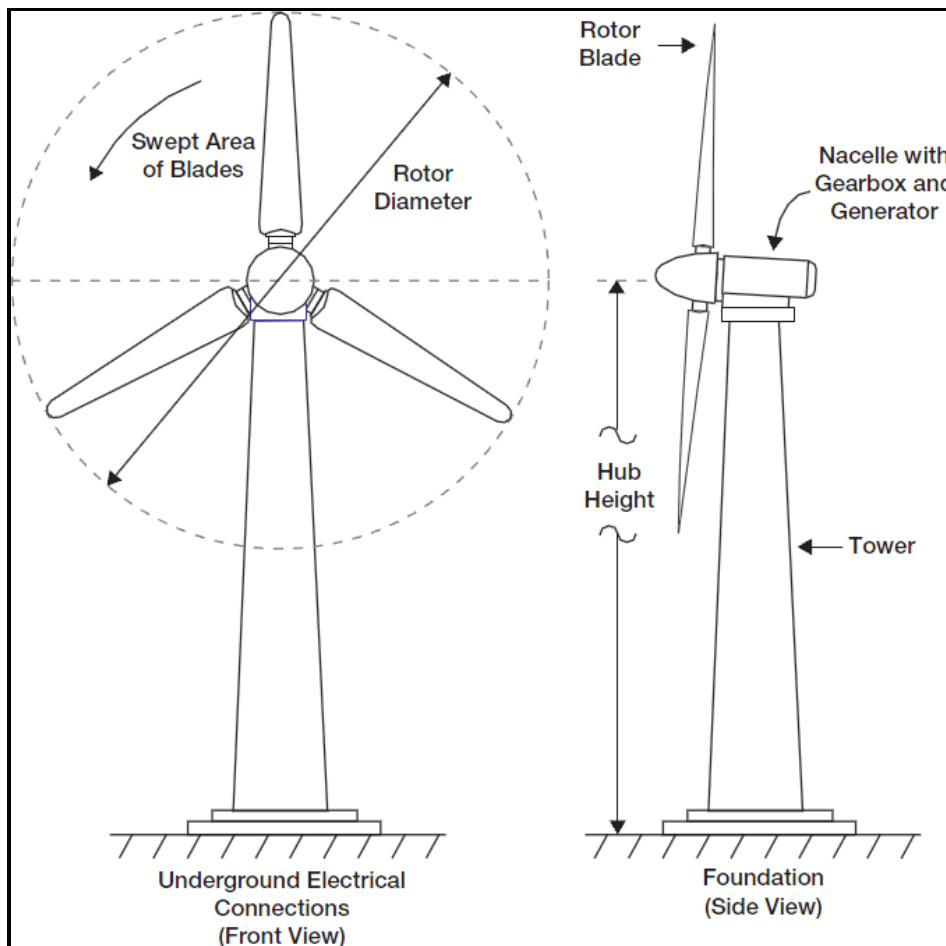


Figure 4-7: Cross Section of a Wind Turbine.

(Source: RETScreen, 2009).

These analyses considered a wind farm consisting of a single 2MW wind turbine from ENERCON. Later on, calculations were made to determine the number of such turbines needed to generate an annual 3,490GWh electricity equivalent to the energy consumption of Cameroon in each of the locations used. The turbine used for the analysis was ENERCON's E-82.

ENERCON's E-82 2MW Wind turbine:

The wind turbine is specially designed for medium wind speeds, the ENERCON E-82 wind turbine with the new rotor blade design and tower versions up to 138m hub height, guarantees excellent yields in the 2 MW category, even at inland sites. According to information obtained from ENERCON, a typical E-82 wind turbine has the following technical specifications.

Rated power: 2,000 kW

Rotor diameter: 82 m

Hub height: 78 m – 138 m
Wind class (IEC): IEC/NVN II
Turbine concept: Gearless, variable speed, variable pitch control

Rotor

Type: Upwind rotor with active pitch control

Direction of rotation: Clockwise

Number of blades: 3

Swept area: 5,281 m²

Blade material: Fibreglass (epoxy resin); integrated lightning protection

Rotational speed: Variable, 6 –19.5 rpm

Pitch control: ENERCON blade pitch system, one independent pitching system per rotor blade with allocated emergency supply drive train with generator

Hub: Rigid

Grid feeding: ENERCON converter

Remote monitoring: ENERCON SCADA

Main bearings: Dual-row tapered/single-row cylindrical roller bearings

Generator: ENERCON direct-drive synchronous annular generator

Braking systems: – 3 independent blade pitch systems with emergency supply
 – Rotor brake
 – Rotor lock

Yaw control: Active via adjustment gears, load-dependent damping cut-out wind speed: 28 – 34 m/s (with ENERCON storm control)

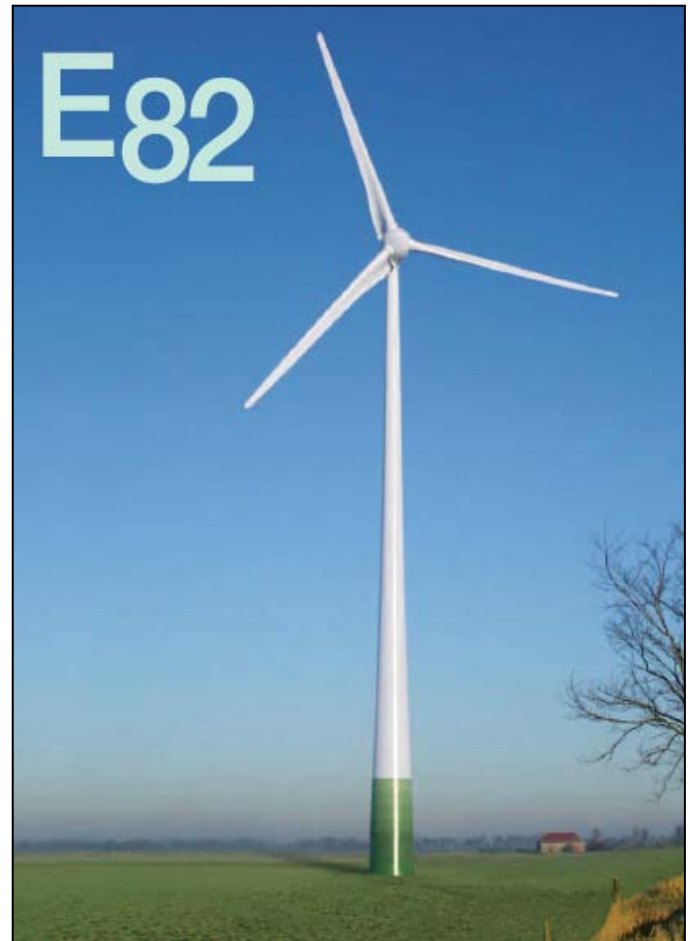


Figure 4-8: ENERCONS E-82 Wind turbine.

Table 4-12: Power curve data for wind turbine

Wind speed	Power P [kW]	Power coefficient [-]
0	0.0	0.0
1	0.0	0.0
2	3.0	0.12
3	25.0	0.29
4	82.0	0.40
5	174.0	0.43
6	321.0	0.46
7	532.0	0.48
8	815.0	0.89

9	1,180.0	0.50
10	1,612.0	0.50
11	1,890.0	0.44
12	2,000.0	0.36
13	2,050.0	0.29
14	2,050.0	0.23
15	2,050.0	0.19
16	2,050.0	0.15
17	2,050.0	0.13
18	2,050.0	0.11
19	2,050.0	0.09
20	2,050.0	0.08
21	2,050.0	0.07
22	2,050.0	0.06
23	2,050.0	0.05
24	2,050.0	0.05
25 - 30	2,050.0	0.04

The generation of power from a wind turbine requires a continuous flow of wind at a rated speed, which is difficult to accomplish because wind, by its very nature, is not constant and does not prevail at a steady rate, but in fact fluctuates over short periods of time (RETScreen, 2009). Wind turbines produce electricity using the kinetic (renewable) energy from the wind. The energy performance of a wind power system is influenced by a number of factors. For example, these may include resource elements such as the wind speed or wind power density at hub height, the wind shear exponent, the air temperature and the atmospheric pressure. Other factors include design and operation elements such as the wind turbine power capacity and energy curve data, hub height, swept area, number of turbines, array losses, airfoil losses, miscellaneous losses (e.g. parasitic electricity losses, transmission line losses, losses due to low wind energy absorption rate) and the wind turbine availability.

For this research, the project was assessed through 2030, giving a project analysis period of 20 years. Assuming an inflation rate of 1.5% (Alumnieeni, 2009) and a 9% discount rate (RETScreen, 2005), and based on experiences assembled from similar projects elsewhere, initial feasibility studies for a single project was estimated at 1,715,445,000 FCFA (approximately €2,619,000)

The following summarizes the characteristics used in this research work to assess the wind energy resource in each of the 10 locations used.

Base case:	Central-grid
Capacity:	2,000kW (2MW)
Capacity factor:	Calculated by RETScreen per site
Total (initial incremental) cost:	FCFA 1,715,445,000 (approx. €2,619,000)
Cost for exporting electricity	FCFA 40/kWh (€0.06/kWh) ⁴
Array losses:	0.0%
Airfoil losses:	1.0%
Miscellaneous losses:	2.0%
Availability:	98%
Capacity factor:	9.9% (calculated)

With these values, the analyses were carried out as illustrated in section 4.1. The analyses indicated that the northern regions of Cameroon were the sole areas where wind energy proved to be resourceful. From the northern regions moving down towards the south, the wind speeds decreases further south and hence the capacity for wind energy approaches zero (Figure 4-6). The following results were obtained for all the regions assessed.

Results and Discussions.

Table 4-13: Wind analysis results.

Region	Location	Annual electricity exported to grid [MWh]	No of plants to generate 3,490GWh
Extreme North	Maroua	1,732	2,016
North	Garoua	1,368	2,552
Adamawa	Ngaoundéré	876	3,985
North West	Bamenda	0	0
West	Bafia*	0	0
Centre	Yaoundé	0	0
Littoral	Douala	0	0

⁴ FCFA 40/kWh is not the actual electricity cost in Cameroon. This was used as a baseline case scenario to obtain the minimum possible limits. Actual electricity costs are given in chapters 5 and 7 according to the Cameroonian laws governing the sale of electricity.

East	Bertoua	0	0
South	Ebolowa	0	0
South West	Fontem	0	0

Extreme North - Maroua

For Maroua, RETScreen determined that the wind speed at a height of 64m above the ground (equivalent to the hub height of the wind turbine) would be 4.7m/s. The software further assessed that a wind plant at this location would generate 1,732MWh electricity per year. A monthly assessment gave the results shown in Table 4-14 below.

Table 4-14: Monthly assessment results - Maroua

Month	Maroua wind speed (m/s)	Electricity exported to grid. MWh.
January	4.1	187
February	4.0	155
March	4.4	222
April	4.6	241
May	4.2	198
June	3.5	115
July	3.2	88
August	3.1	81
September	2.8	0
October	3.2	87
November	3.8	145
December	4.3	213
Annual	3.8	1,732

Following the above results, it is obvious that Maroua has a moderate prospect for electricity generating capacity from wind. Comparatively though, it is the best location for wind energy in Cameroon. Peak months could be noted in April when the winds are strongest whereas in the month of September, the winds are low and therefore would not be capable of generation. Based on this result, 2,016 of such wind plants would be required to generate 3,490GWh energy for Cameroon in this location and operating under the same circumstances.

North - Garoua

For Garoua, RETScreen determined that the wind speed at a height of 64m above the ground would be 4.4m/s. The software further assessed that the wind turbine used for

this analysis would generate 1,368MWh electricity per year, a little less than Maroua. A monthly assessment gave the results shown in Table 4-15 below.

Table 4-15: Monthly assessment results - Garoua

Month	Garoua wind speed m/s	Electricity exported to grid MWh
January	3.8	151
February	3.8	135
March	4.1	183
April	4.3	203
May	3.9	161
June	3.3	95
July	3.1	81
August	2.9	0
September	2.7	0
October	3.0	73
November	3.5	114
December	4.0	172
Annual	3.5	1,368

From the above results, it is easy to point out that Garoua can be used as a source for wind energy generation. Similarly to Maroua, peak months could be noted in April when the winds are strongest, where as in the months of August and September, the winds are low and therefore would not be capable of generation. Based on this result, a calculated 2,552 of such wind plants would be required to generate 3,490GWh energy for Cameroon in this location, operating under the same circumstances.

Adamawa – Ngaoundéré

From the meteorological data for Ngaoundéré given in Table 4-4 above, it can be realized that the further down south, the lower the wind speeds become and hence the lower the potential for wind energy in these regions. RETScreen determined that the wind speed for this location at a height of 64m above the ground would be 4.0m/s. The software further assessed that this wind plant would generate 876MWh electricity per year, which is approximately equal to half the value that a similar wind plant would generate in Maroua, operating under the same circumstances. A monthly assessment gave the results shown in Table 4-16 below.

Table 4-16: Monthly assessment results - Ngaoundéré.

Month	Ngaoundéré wind speed m/s	Electricity exported to grid MWh
January	3.4	104
February	3.4	93
March	3.7	134
April	3.9	150
May	3.6	125
June	3.1	75
July	2.9	0
August	2.8	0
September	2.6	0
October	2.8	0
November	3.2	81
December	3.5	114
Annual	3.3	876

Following the above results, it can be concluded that Ngaoundéré would not be a good location for wind energy generation. The wind resource in this area is low and would definitely not be financially viable for a wind project. Similarly, to Maroua and Garoua, peak wind strengths could be noted in April when the winds are strongest whereas in the months of July, August, September and October the winds are low and therefore would not be capable of generating electricity with this same wind plant.

For the other regions, North West, Centre, Littoral, West, East, South and South West, the analyses yielded zero results meaning the resource potential for wind energy at these locations was far below average. A 0MWh generation of electricity for this particular wind plant, operating under the same conditions, was obtained for the analysis at each of the locations. Table 4-17 below provides results for the analysis for Bamenda. The reasons for these results vary and depend largely on the wind resource. According to information from RETScreen 2005, a good wind resource is critical to the success of a commercial wind energy project. The energy available from the wind is not linearly related to the wind speed, but rather increases in proportion to the cube of the wind speed. At minimum, the annual average wind speed for a wind energy project should exceed 4m/s, or 14km/h, at a height of 10m above the ground. Commercial wind farms are usually sited at locations with average wind speeds significantly higher than this.

For this analysis, the wind speeds in the seven regions mentioned are not high enough and fall below the 4m/s range which accounts for the fact that a wind turbine installed at those locations would not be capable of generating electrical energy. As such, a wind energy project in these locations would not be commercially viable.

Table 4-17: Monthly assessment results - Bamenda

Month	Bamenda wind speed m/s	Electricity exported to grid MWh
January	2.1	0
February	2.2	0
March	2.1	0
April	1.9	0
May	1.8	0
June	2.0	0
July	1.9	0
August	2.0	0
September	1.8	0
October	1.6	0
November	1.7	0
December	1.8	0
Annual	1.9	0

Results for the analyses of the other locations were not included in the write up because they were not different from that of Bamenda shown above.

4.3 Isolated-grid Connected 2,000W Solar Energy

Solar Energy Background

Solar radiation as a source of energy is, of course, the epitome of the clean sustainable energy technology. Except for residues possibly arising out of the manufacture of solar components (e.g. semiconductors), solar technologies have very low environmental impacts. The environmental impacts of solar systems in operation are very low and the source is inexhaustible (Edward, 2000).

The energy incident on the Earth from the wide electromagnetic spectrum emitted by the sun may be converted to useful heat, to electricity, or used to create a fuel.

A similar analysis to that of the wind resource was done for each of the ten locations to assess the solar potential in these areas. This was different from the wind energy analysis because the entire nation showed some potential for solar energy above

average, although the results were most positive still in the northern regions and less positive down south. The analysis considered a pole installation of the solar module directly on the ground surface such that it gets the most direct sun exposure – this ensures a maximum year round effectiveness. Data from NASA indicated an average annual solar irradiance for Cameroon in the range of 4.28kWh/m² /d to 5.75kWh/m²/d. Comparatively, Garoua had the highest radiation value of 5.75kWh/m²/d while Douala had the lowest value 4.28kWh/m²/d (Figure 4-8). It was also observed that the radiation values fluctuate and vary depending on the time and season of the year. High radiation values were commonly observed between the months of October and June with the highest value obtained in the month of March. Vice versa, low values were observed between the months of July and September with the lowest value measured in August (Figure 4-9).

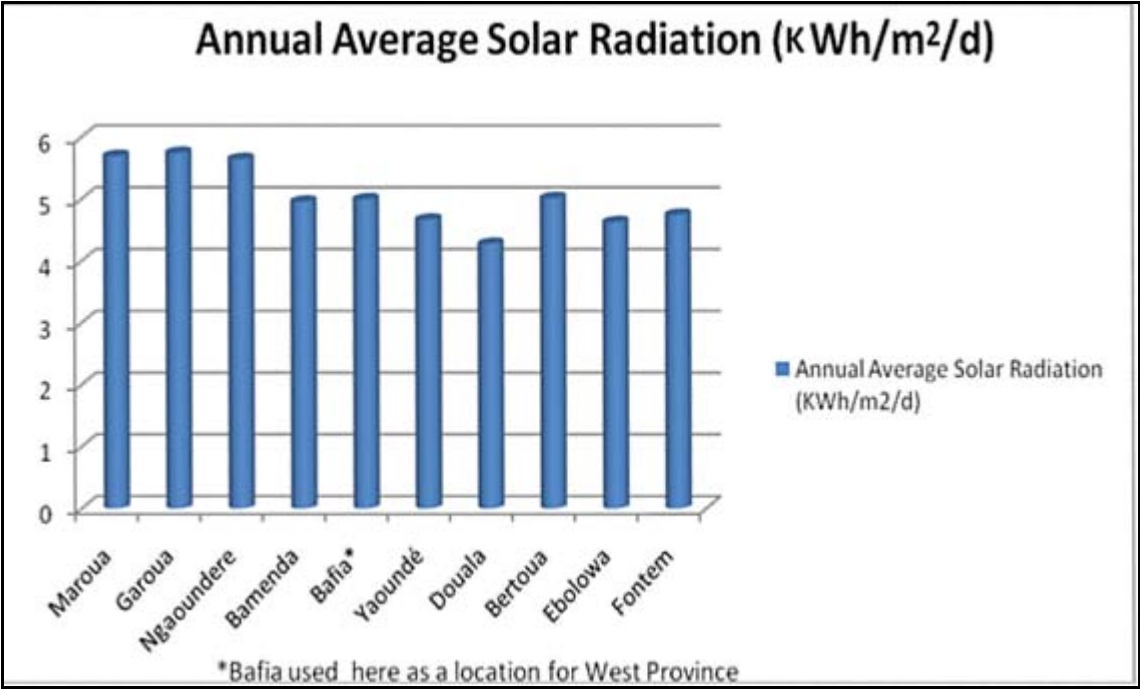


Figure 4-9: Average annual solar radiation for locations used

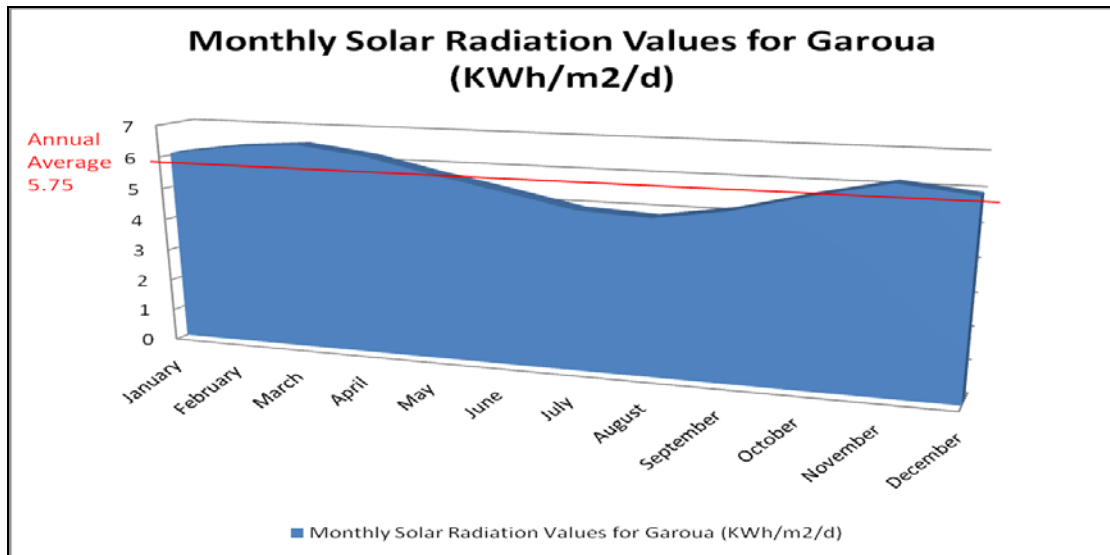


Figure 4-10: Monthly solar radiation values for Garoua

The analysis considered a solar energy farm consisting of 10 200W solar modules from BP Solar. Later on, calculations were made to determine the number of such panels needed to generate an annual 3,490GWh electricity equivalent to the energy consumption of Cameroon. The solar module that was used for the analysis is BP Solar’s high-efficiency photovoltaic module SX3200 using silicon nitride multicrystalline silicon cells (Figure 4-10).

BP Solar’s SX3200 solar modules

According to information from BP Solar, a brand new SX3200 solar module has the following technical specifications.

Figure 4-11: BP's SX3200 Solar Module.

Performance

- Rated power (Pmax): 200W
- Power tolerance: ±9%
- Nominal voltage: 16V
- Limited Warranty: 25 years

Electrical Characteristics

- Maximum power (Pmax): 200W
- Voltage at Pmax (Vmp): 24.5V
- Current at Pmax (Imp): 8.16A
- Warranted minimum Pmax: 182.0W
- Short-circuit current (Isc): 8.7A
- Open-circuit voltage (Voc): 30.8V
- Temperature coefficient of Isc: (0.065±0.015)%/ °C
- Temperature coefficient of Voc: -(111±10)mV/°C



Temperature coefficient of power: $-(0.5 \pm 0.05)\%/^{\circ}\text{C}$
NOCT (sir 20°C ; sun $0.8\text{kW}/\text{m}^2$; wind $1\text{m}/\text{s}$): $47 \pm 2^{\circ}\text{C}$
Maximum series fuse rating: 15A
Maximum system voltage: 600V (U.S. NEC rating)

Mechanical Characteristics

Dimensions Length: 1,680mm (66.14")

Width: 837mm (32.95")

Depth: 50mm (1.97")

Weight 15.4 kg (33.95 pounds)

Solar Cells: 50 cells (156mm x 156mm) in a 5x10 matrix connected in series

Output Cables: RHW-2 AWG# 12 (4mm^2), cable with polarized weatherproof DC rated multicontact connectors; asymmetrical lengths - 1250mm (-) and 800mm (+)

Diodes IntegraBus™ technology: includes Schottky by-pass diodes integrated into the printed circuit board bus

Construction Front: High-transmission 3mm (1/8th in) tempered glass; Back: White or Black Tedlar; Encapsulant: EVA

Frame B Anodized aluminium alloy type 6063T6 Universal frame; Color: bronze

Module warranty: BP's SX3200 has a 25-year limited warranty of 80% power output; 12-year limited warranty of 90% power output; and a 5-year limited warranty of materials and workmanship.

This data represents the performance of typical SX 3200 products, and is based on measurements made in accordance with ASTM E1036 corrected to SRC (STC). During the stabilization process that occurs during the first few months of deployment, module power may decrease by up to 1% from the typical maximum power (P_{max}).

In principle, sunlight can be converted to electricity at an efficiency close to the Carnot 95% limit for the sun modeled as a black-body at $T_1=6000\text{K}$ ⁵, and a cell operating at room temperature ($T_2=300\text{K}$) (Mario et al., 2006). The efficiency of solar cells is greatly dependent on the material used and its ability to convert the full spectrum of sunlight. Record efficiencies for solar modules have been measured at 42.8% for crystalline silicon compared to 15% for conventional solar cells.

⁵ Temperature of the sun surface in Kelvin (K).

The project was assessed for an analysis period of 20 years. An inflation rate of 1.5% for Cameroon (Alumniéni, 2009) and a 9% discount rate (RETScreen, 2009) was used. Based on product information obtained and experience from similar projects elsewhere from RETScreen, the following characteristics were used for the assessment of the solar resource.

Base case:	Isolated-grid
Number of modules:	10
Capacity:	2,000W
Capacity factor:	19.3% (calculated)
Miscellaneous losses:	1.0%
Inverter efficiency:	95%
Total (initial incremental) cost:	FCFA 2,820,500 (approx. €4,287.16)
Cost for exporting electricity	FCFA 40/kWh (€0.06/kWh) ⁶

Results and Discussions

With the above values, the RETScreen software tool was used as illustrated in section 4.1 to do the assessment. The analysis indicated that 10 units of BP Solar’s 200W high efficiency photovoltaic modules (SX3200) installed at the locations used, functioning at a capacity factor of 19.3% would generate electricity equivalent to the values shown below (Table 4-18).

Table 4-18: Solar analysis results.

Region	Location	Annual solar radiation - horizontal kWh/m ² /yr	Annual electricity exported to grid [MWh]
Extreme North	Maroua	5.44	3,342
North	Garoua	5.75	3,376
Adamawa	Ngaoundéré	5.65	3,340
North West	Bamenda	4.96	2,953
West	Bafia*	5.00	2,927
Centre	Yaoundé	4.67	2,730
Littoral	Douala	4.28	2,521
East	Bertoua	5.02	2,936
South	Ebolowa	4.63	2,689
South West	Fontem	4.75	2,819

⁶ FCFA 40/kWh is not the actual electricity cost in Cameroon. This was used as a baseline case scenario to obtain the minimum possible limits. Actual electricity costs are given in chapters 5 and 7 according to the Cameroonian laws governing the sale of electricity.

For the solar resource, a more detailed analysis was performed based on monthly climate data for all the locations and photovoltaic equipment data as described above. Once the location was selected, RETScreen loaded the climate data for each location. The software further did the assessments and yielded the following results.

Extreme North region – Maroua

Table 4-19: Monthly assessment results - Maroua (Solar)

Maroua	Month	Daily solar radiation - horizontal	Daily solar radiation - tilted	Electricity exported to grid
		kWh/m ² /d	kWh/m ² /d	MWh
	January	5.61	6.19	0.322
	February	6.24	6.46	0.301
	March	6.56	6.25	0.320
	April	6.31	5.53	0.278
	May	5.96	4.91	0.256
	June	5.50	4.43	0.226
	July	5.03	4.15	0.222
	August	4.85	4.20	0.226
	September	5.34	4.92	0.253
	October	5.70	5.69	0.296
	November	5.85	6.37	0.316
	December	5.56	6.28	0.325
	Annual	5.70	5.44	3.342
Annual solar radiation - horizontal	MWh/m ²	2.08		
Annual solar radiation - tilted	MWh/m ²	1.99		

North region - Garoua

Table 4-20: Monthly assessment results - Garoua (Solar)

	Month	Daily solar radiation - horizontal	Daily solar radiation - tilted	Electricity exported to grid
		kWh/m ² /d	kWh/m ² /d	MWh
	January	6.07	6.70	0.347
	February	6.36	6.53	0.304
	March	6.50	6.15	0.317
	April	6.24	5.44	0.276
	May	5.78	4.74	0.250
	June	5.37	4.31	0.221
	July	4.94	4.05	0.217
	August	4.83	4.16	0.225
	September	5.16	4.72	0.245
	October	5.70	5.65	0.297
	November	6.17	6.69	0.333
	December	5.93	6.68	0.345

	Annual	5.75	5.48	3.376
Annual solar radiation - horizontal	MWh/m ²	2.10		
Annual solar radiation – tilted	MWh/m ²	2.00		

Adamawa region – Ngaoundéré.

Table 4-21: Monthly assessment results - Ngaoundéré (Solar).

	Month	Daily solar radiation - horizontal	Daily solar radiation - tilted	Electricity exported to grid
		kWh/m²/d	kWh/m²/d	MWh
	January	6.48	7.08	0.368
	February	6.74	6.86	0.321
	March	6.53	6.11	0.320
	April	5.83	5.05	0.260
	May	5.42	4.43	0.237
	June	5.02	4.01	0.209
	July	4.67	3.81	0.207
	August	4.66	3.99	0.217
	September	4.85	4.40	0.232
	October	5.25	5.12	0.274
	November	6.16	6.56	0.332
	December	6.27	6.98	0.363
	Annual	5.65	5.36	3.340
Annual solar radiation - horizontal	MWh/m ²	2.06		
Annual solar radiation - tilted	MWh/m ²	1.96		

North West region – Bamenda

Table 4-22: Monthly assessment results - Bamenda (Solar)

	Month	Daily solar radiation - horizontal	Daily solar radiation - tilted	Electricity exported to grid
		kWh/m²/d	kWh/m²/d	MWh
	January	6.14	6.58	0.345
	February	6.19	6.20	0.295
	March	5.50	5.10	0.274
	April	5.01	4.35	0.228
	May	4.83	3.97	0.214
	June	4.42	3.56	0.187
	July	4.02	3.32	0.182
	August	3.92	3.38	0.186
	September	4.21	3.81	0.203
	October	4.39	4.21	0.229
	November	5.21	5.39	0.279
	December	5.79	6.28	0.332
	Annual	4.96	4.67	2.953

Annual solar radiation - horizontal	MWh/m ²	1.81		
Annual solar radiation - tilted	MWh/m ²	1.70		

West region - Bafia

Table 4-23: Monthly assessment results - Bafia (Solar).

	Month	Daily solar radiation - horizontal kWh/m ² /d	Daily solar radiation - tilted kWh/m ² /d	Electricity exported to grid MWh
	January	5,73	6,03	0,318
	February	5,86	5,80	0,277
	March	5,45	5,02	0,269
	April	5,19	4,47	0,233
	May	4,94	4,02	0,216
	June	4,61	3,67	0,192
	July	4,33	3,52	0,191
	August	4,37	3,72	0,203
	September	4,63	4,16	0,220
	October	4,55	4,35	0,236
	November	4,97	5,07	0,263
	December	5,46	5,82	0,308
	Annual	5,00	4,63	2,927
Annual solar radiation - horizontal	MWh/m ²	1,83		
Annual solar radiation - tilted	MWh/m ²	1,69		

Centre region – Yaoundé

Table 4-24: Monthly assessment results - Yaoundé (Solar)

	Month	Daily solar radiation - horizontal kWh/m ² /d	Daily solar radiation - tilted kWh/m ² /d	Electricity exported to grid MWh
	January	5,43	5,64	0,300
	February	5,49	5,38	0,260
	March	5,20	4,77	0,257
	April	4,97	4,27	0,223
	May	4,65	3,79	0,204
	June	4,26	3,41	0,178
	July	4,00	3,27	0,178
	August	3,98	3,40	0,186
	September	4,27	3,83	0,203
	October	4,14	3,93	0,214
	November	4,56	4,59	0,240
	December	5,12	5,38	0,287

	Annual	4,67	4,30	2,730
Annual solar radiation - horizontal	MWh/m ²	1,70		
Annual solar radiation - tilted	MWh/m ²	1,57		

Littoral region – Douala

Table 4-25: Monthly assessment results - Douala (Solar).

	Month	Daily solar radiation - horizontal	Daily solar radiation - tilted	Electricity exported to grid
		kWh/m²/d	kWh/m²/d	MWh
	January	5,41	5,62	0,298
	February	5,36	5,25	0,252
	March	4,88	4,48	0,241
	April	4,55	3,94	0,206
	May	4,37	3,59	0,193
	June	3,91	3,17	0,166
	July	3,41	2,84	0,156
	August	3,04	2,65	0,146
	September	3,44	3,10	0,165
	October	3,70	3,50	0,191
	November	4,30	4,31	0,225
	December	5,05	5,30	0,282
	Annual	4,28	3,97	2,521
Annual solar radiation - horizontal	MWh/m ²	1,56		
Annual solar radiation - tilted	MWh/m ²	1,45		

East region – Bertoua

Table 4-26: Monthly assessment results - Bertoua (Solar).

	Month	Daily solar radiation - horizontal	Daily solar radiation - tilted	Electricity exported to grid
		kWh/m²/d	kWh/m²/d	MWh
	January	5,86	6,17	0,324
	February	6,01	5,95	0,283
	March	5,60	5,16	0,276
	April	5,29	4,55	0,236
	May	4,83	3,94	0,211
	June	4,36	3,49	0,183
	July	4,20	3,42	0,186
	August	4,35	3,70	0,202
	September	4,62	4,15	0,219
	October	4,56	4,36	0,236
	November	5,04	5,15	0,267
	December	5,54	5,91	0,312

	Annual	5,02	4,65	2,936
Annual solar radiation - horizontal	MWh/m ²	1,83		
Annual solar radiation - tilted	MWh/m ²	1,70		

South region – Ebolowa

Table 4-27: Monthly assessment results - Ebolowa (Solar)

	Month	Daily solar radiation - horizontal	Daily solar radiation - tilted	Electricity exported to grid
		kWh/m²/d	kWh/m²/d	MWh
	January	5,30	5,45	0,291
	February	5,36	5,22	0,252
	March	5,19	4,74	0,255
	April	4,94	4,23	0,220
	May	4,61	3,74	0,201
	June	4,25	3,38	0,177
	July	4,16	3,36	0,182
	August	4,04	3,43	0,187
	September	4,27	3,82	0,202
	October	4,18	3,95	0,215
	November	4,39	4,38	0,229
	December	4,97	5,17	0,276
	Annual	4,63	4,24	2,689
Annual solar radiation - horizontal	MWh/m ²	1,69		
Annual solar radiation - tilted	MWh/m ²	1,55		

South West region – Fontem

Table 4-28: Monthly assessment results - Fontem (Solar)

	Month	Daily solar radiation - horizontal	Daily solar radiation - tilted	Electricity exported to grid
		kWh/m²/d	kWh/m²/d	MWh
	January	5,81	6,16	0,325
	February	5,77	5,73	0,274
	March	5,35	4,95	0,266
	April	4,99	4,32	0,226
	May	4,68	3,85	0,208
	June	4,32	3,48	0,183
	July	3,86	3,19	0,175
	August	3,58	3,10	0,171
	September	4,09	3,70	0,196
	October	4,32	4,13	0,225

	November	4,88	5,00	0,260
	December	5,48	5,88	0,312
	Annual	4,75	4,45	2,819
Annual solar radiation - horizontal	MWh/m ²	1,74		
Annual solar radiation - tilted	MWh/m ²	1,62		

For all the locations used, Garoua had the best results for the solar resource. Operating under the same conditions, 10 units of BP Solar's SX3200 would export an average of 3.376MWh electricity to the grid.

Chapter 5 : Economic and Sustainability Analysis

5.1 Introduction

“The importance of mineral and energy mineral resources cannot be overestimated. Most critical among the resources is energy. Energy is the key which unlocks all other natural resources. Without it the wheels of industry do not turn, no metals are mined and smelted. No cars, trucks, trains, ships or airplanes could be built and if built, they could not move without energy. Without energy, houses will remain cold and unlighted, food will be uncooked. Fields could not be ploughed nor planted with the ease and on the vast scale they are today by means of relatively little human labor. Military defense as we know it today would not exist. Without energy resources we would literally be back in the stone age. And without the use of energy and metals as we use them today, it is probable that the world’s population would be reduced at least one-half, some estimates say 90%” (Youngquist, 1997).

Hot newspaper captions such as “Power shortages hit Rio's Cameroon aluminium plant, ALUCAM output nearly 40% below capacity”, is no good news for any economy in the world. ALUCAM is one of Cameroon's largest industrial projects with a turnover of 149 billion FCFA (\$307.5 million) in 2008, representing 7% of industrial output and 5% of export revenues. Growing household electricity demands, has led to power rationing and frequent blackouts in Cameroon, and as a consequence has forced companies in Cameroon to produce below capacity. This is not good news for the company and its shareholders neither is it any good news for the Cameroonian economy or the government which will also lose money in terms of export taxes. There would be no forward direction for Cameroon’s economy, if a strong and steady supply of energy is not guaranteed. Such a source of energy would definitely be environmentally friendly, sustainable and cost effective.

5.2 Renewable Energy and Economic Development.

Many experts have already pointed out the relationship between energy and economy. In this line, Gerhard et al., 1988 shares the same view with Youngquist as he puts it, that, the development of a national economy is closely related to its energy

consumption. For large scale industrialization of a country, it is imperative that animal and human muscle power be substituted by machines, which require energy in the form of electricity or fuel to function. The complete development of renewable energy technologies will not only provide the economy and households with electrical energy to function, but it will guarantee sustainability in the energy sector.

Also, the construction and maintenance of wind farms, solar plants and other renewable energy projects create hundreds of thousands of jobs. Installing new wind farms, for instance, creates temporary construction employment as laborers, carpenters and millwrights build the forms and pour the concrete for the foundations of wind turbines; operating engineers run the cranes that lift the towers; and electricians perform the wiring. Permanent employment is also created operating and maintaining these same machines.

According to CALPIRG 2002, Studies performed by the California Energy Commission (2002), the Union of Concerned Scientists (2006), the University of California-Berkeley (2004/2008) and the Centre for Energy Efficiency and Renewable Technologies (2009), all confirm that renewable energy resources generate greater employment than equivalent investments in fossil fuels. While the job impacts vary according to specific technologies, a general rule of thumb is four to six times as many jobs per MW as conventional coal or natural gas power supplies (REPP, 2005). For example, natural gas power plants generate only about one job per megawatt (MW) during construction and ongoing operations and maintenance, while equivalent investments in solar photovoltaic power technologies would generate over seven jobs per MW.

5.3 Cost Analysis

In order to determine the influence that renewable energies would be able to exert in to the economy of Cameroon, it is imperative that a good analysis be done as to how much cost is required to guarantee the complete installation, running and functioning of the wind and solar devices used in the analysis above. In this section, the costs presented were obtained from various sources and a comparison was made to obtain

the best (affordable) costs, yet maintaining a high quality of products. Sources included RETScreen, product websites as well as retailer websites for each device.

The total initial costs of power projects (Table 5-1) below was obtained from RETScreen and is provided to help the user estimate the proposed project's overall total initial costs (i.e. feasibility, development, engineering, energy equipment and balance of system) and to provide a reference to allow the user to check the cost estimates. This table was developed using empirical data from a large number of existing projects.

Table 5-1: Total initial costs of power projects.

Technology	Typical total initial costs (€/kW)					
	Average		Minimum		Maximum	
	€/kW	FCFA/kW	€/kW	FCFA/kW	€/kW	FCFA/kW
Fuel cell	8,712	579,348	6,552	4,357,080	1,123	7,356,960
Gas turbine	1,224	813,960	432	287,280	2,016	1,320,480
Gas turbine(combined)	864	574,560	504	335,160	1,224	801,720
Geothermal power	2,592	1,723,680	936	622,440	3,816	2,499,480
Hydro turbine	1,584	1,053,360	288	191,520	3,384	2,216,520
Ocean current power	0	0	0	0	0	0
Photovoltaic	6,552	4,357,080	5,472	3,638,880	1,648	10,799,640
Reciprocating engine	1,008	670,320	504	335,160	1,512	990,360
Solar thermal power	4,968	3,303,720	3,384	2,250,360	6,336	4,150,080
Steam turbine	792	526,680	360	239,400	1,224	801,720
Tidal power	2,952	1,963,080	2,520	1,675,800	3,312	2,169,360
Wave power	0	0	0	0	0	0
Wind turbine	1,368	909,720	792	526,680	2,232	1,461,960

Note: Typical initial costs values in Euros as of January 1, 2006.

Following the above costs, the average cost of €1,368/kW (909,720FCFA/kW) was used for the analysis, i.e. a total initial cost for the installation of 2,000kW power wind turbine project would be €2,736,000 (1,819,440,000 FCFA).

The cost used for analyzing the solar energy resource potential was obtained from the solarbiz.com website and an additional cost for feasibility, development and engineering was calculated. A final initial cost for the 2kW solar power project of € 4,287.16 (2,820,500 FCFA) was used.

Costs for exporting electricity to the grid were estimated at €1.00MWh (40,000 FCFA/MWh), which normally is not the cost for electricity in Cameroon, but rather a minimum baseline cost used to obtain results that would be feasible enough and avoid

exaggerations compared to real life situations. Electricity costs in Cameroon according to “Decision No. 17/DG/ARSEL of 25 January 2002 to fix prices exclusive of tax of electricity sold by AES-SONEL” are given in chapter 7.

5.4 Financial Analysis

The technical analysis could only determine areas in Cameroon where energy from wind and solar could be obtained using the designated devices. It was realized that there were areas where the same wind turbine would generate more electricity such as Maroua than in others. Similarly, Garoua would in turn generate more electricity with the solar devices than any other location in Cameroon. In this section, the financial analysis gives an assessment of the viability, stability and profitability of a project for each of these locations.

Generally, a financial analysis (accounting analysis, or financial statement analysis) is performed by professionals who prepare reports using ratios that make use of information taken from financial statements and other reports. These reports are usually presented to top management as one of their bases in making business decisions. Based on these reports, management may:

- Continue or discontinue its main operation or part of its business;
- Make or purchase certain materials in the manufacture of its product;
- Acquire or rent/lease certain machineries and equipment in the production of its goods;
- Issue stocks or negotiate for a bank loan to increase its working capital;
- Make decisions regarding investing or lending capital;
- Take other decisions that allow management to make an informed selection on various alternatives in the conduct of its business.

In this research, the analysis was carried out to determine the ability of the potential projects to earn income and sustain an economic growth for a 20 year project analysis period. This was done using the RETScreen software which facilitates the project evaluation process with its financial parameters input items (e.g. discount rate, debt ratio, etc.), and its calculated financial viability output items (e.g. IRR, simple payback, NPV, etc.).

5.4.1 Wind

The following financial parameters were used for the analysis to determine the viability of the wind energy resource potential. The assessments were done only for three locations based on the results of the technical analysis, i.e. Maroua, Garoua and Ngaoundéré.

Table 5-2: Financial parameters, wind analysis.

Financial parameters	Units	Value used	Description
Inflation rate	%	1,5%	Projected annual average rate of inflation over the life of the project.
Project life	yr	20	Duration over which the financial viability of the project is evaluated.
Debt ratio	%	10%	Reflects the financial leverage created for a project.
Debt interest rate	%	8.00%	Annual rate of interest paid to the debt holder at the end of each year of the term of the debt
Debt term	yr	15	Number of years over which the debt is repaid
Initial costs			
Power system (96.5%)	€	2,736,000	Cost of the proposed power system
Other (3.5%)	€	100,000	Other costs such as installtion etc
Total initial costs(100.0%)	€	2,836,000	Complete cost to purchase, transport and install equipement.
Incentives and grants			
	€	0	Any contribution, grant, subsidy, etc. that is paid for the initial costs (excluding credits) of the project
Annual costs and debt payments			
OandM (savings) costs	€	15,000	Annual operation and Maintenance costs
Fuel cost - proposed case	€	0	
Debt payments - 15 yrs	€	33,133	Annual amount paid for debts
Total annual costs	€	48,133	Total annual expenditures
Annual savings and income			
Fuel cost - base case	€	0	
Electricity export income	€	166,228	Annual income from sale of electricity (example for Maroua) .

RETScreen used the above financial parameters alongside the energy generated per year to assess the financial viability for each location and the following results were obtained.

Maroua.

The following cash flow graph for Maroua was obtained and the explanations given below.

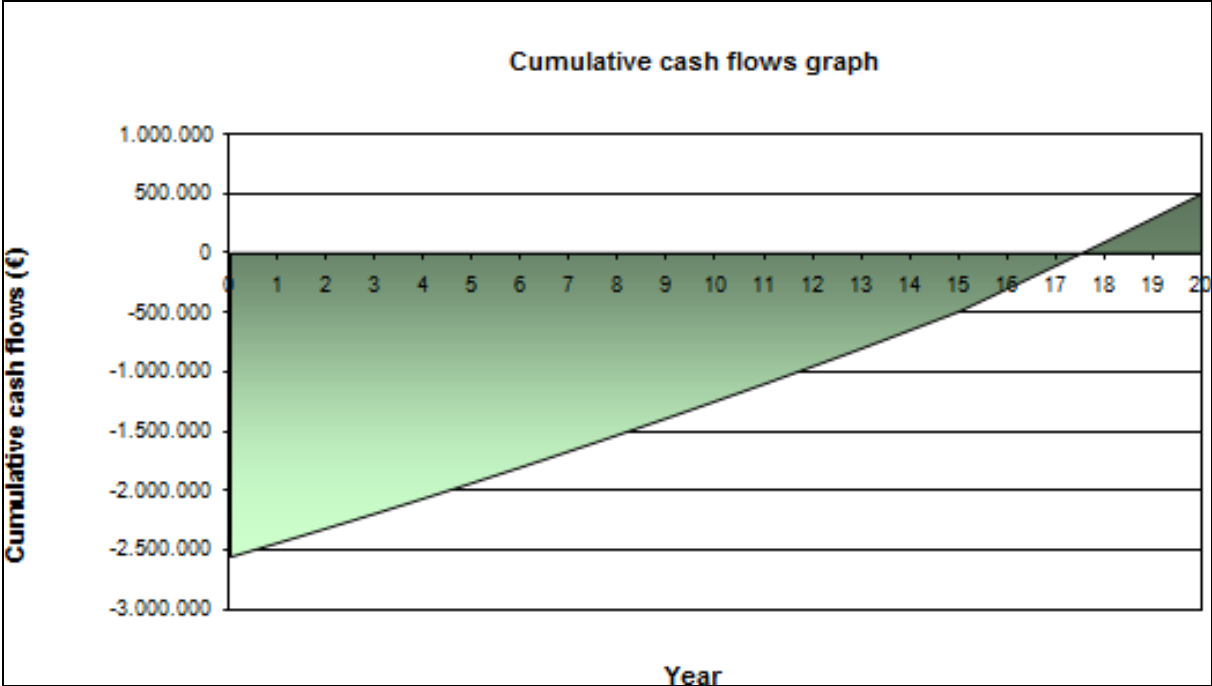


Figure 5-1: Cumulative cash flow graph for Maroua (wind assessment).

The model calculated the pre-tax internal rate of return (IRR) on equity (%) and the pre-tax internal rate of return (IRR) on assets (%), which represents the true interest yield provided by the project’s equity and assets respectively, over 20 years before income tax. For Maroua, this value was 1.6%, and 0.6% respectively. This was calculated using the pre-tax yearly cash flows and the project duration. This was obtained by finding the discount rate that causes the net present value of the equity/assets to be equal to zero. The IRR is calculated on a nominal basis, that is including inflation.

If the internal rate of return is equal to or greater than the required rate of return of the total costs, then the project will likely be considered financially acceptable (assuming equal risk). If it is less than the required rate of return, the project is typically rejected.

Based on the above financial analysis for Maroua, a wind energy project, similar to the one used in this research yielded a positive pre-tax IRR – equity/assets, which is an indication that such a project would be financially viable, although the debt incurred in the project is not capable of being paid back within the debt term, this payback is feasible within the project duration. A simple payback is guaranteed after 18.8 years, whereas an equity pay back can be realized 2.5 years after the debt term has elapsed.

Financial viability			
Pre-tax IRR - equity	%	1,6%	
Pre-tax IRR - assets	%	0,6%	
Simple payback	yr	18,8	
Equity payback	yr	17,5	

Garoua

The following cash flow graph for Maroua was obtained and the explanations given below.

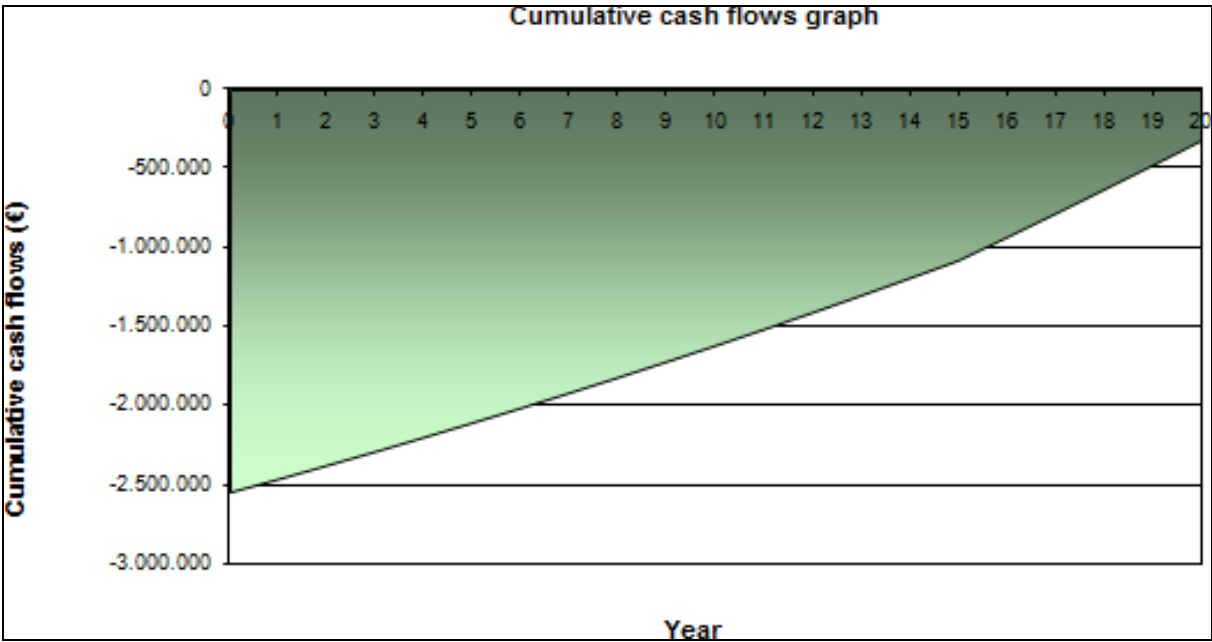


Figure 5-2: Cumulative cash flow graph for Garoua (wind assessment).

Similarly to Maroua, the model calculated the pre-tax internal rate of return (IRR) on equity (%) and pre-tax internal rate of return (IRR) on assets (%), which represents the true interest yield provided by the project equity and assets respectively, over its life before income tax. For Garoua, the values obtained were -1.1%, and -2.0% respectively.

Financial viability			
Pre-tax IRR - equity	%	-1,1%	
Pre-tax IRR - assets	%	-2,0%	
Simple payback	yr	24,4	
Equity payback	yr	> project	

Based on the analysis for Garoua, the financial analysis yielded a negative pre-tax IRR – equity/assets for the given project period. This is an indication that such a project in Garoua would not be financially viable with the project timeframe of 20years. From the table above, it can be concluded that the simple payback time for the debt incurred would be 24,4 years whereas the equity payback would be greater than the project life. A wind energy project in Garoua would possibly be financially viable with an extrapolation of the project period to maybe 30 years. This would yield a positive pre-tax IRR – equity/assets well over 25 years of operation.

Hence for Garoua with respect to our proposed case and project life, a wind energy project of this category is not viable.

Adamawa - Ngaoundéré

The following cash flow graph for Ngaoundéré was obtained and the explanations given below.

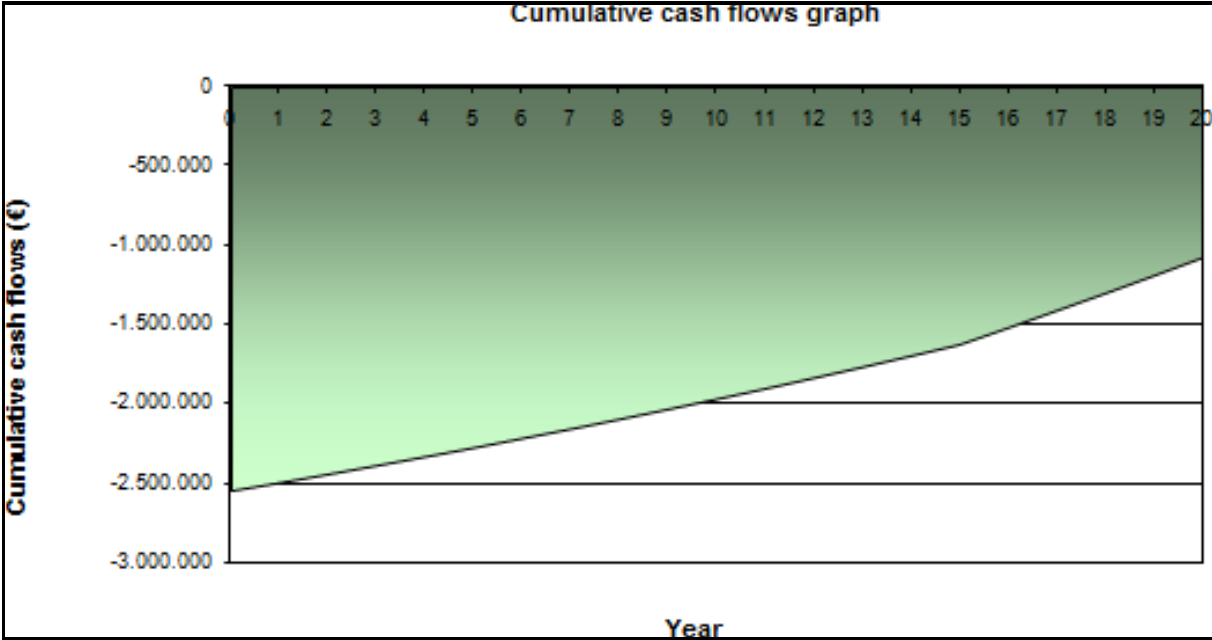


Figure 5-3: Cumulative cash flow graph for Ngaoundéré (wind assessment).

Similar to Maroua and Garoua, , the model calculated the pre-tax internal rate of return (IRR) on equity (%) and pre-tax internal rate of return (IRR) on assets (%), which

represents the true interest yield provided by the project equity and assets respectively, over its life before income tax. For Ngaoundéré, this values were very negative -4.2%, and -5.0% respectively.

Financial viability			
Pre-tax IRR - equity	%	-4,2%	
Pre-tax IRR - assets	%	-5,0%	
Simple payback	yr	33.7	
Equity payback	yr	> project	

With a strong negative pre-tax IRR – equity/assets Ngaoundéré is not a financially viable location for wind energy projects. Even an extrapolation of the project life of up to 10 years will not guarantee a debt payback.

5.4.2 Solar

The financial analyses for the solar resource were not very different from those of the wind resource. In fact, most of the financial parameters were the same except for the cost of equipments and operation and maintenance costs. The analysis for Garoua was assessed and the is given below, whereas analysis for the other locations were carried out and the results given in Table 5-4 below. The following financial parameters were used for the solar energy resource analysis.

Table 5-3: Financial paramters, solar analysis.

Financial parameters	Units	Value used	Description
Inflation rate	%	1.5%	Projected annual average rate of inflation over the life of the project.
Project life	yr	20	Duration over which the financial viability of the project is evaluated.
Debt ratio	%	10%	Reflects the financial levergae created for a project.
Debt interest rate	%	8.00%	Annual rate of interest paid to the debt holder at the end of each year of the term of the debt
Debt term	yr	15	Number of years over which the debt is repaid
Initial costs			
Power system (82.3%)	FCFA	2,320,500	Cost of the proposed power system
Other (17.7%)	FCFA	500,000	Other cost such as installation etc
Total initial costs(100.0%)	FCFA	2,820,500	Complete cost to purchase, transport and install equipment.

Incentives and grants	FCFA	0	Any contribution, grant, subsidy, etc. that is paid for the initial cost (excluding credits) of the project
Annual costs and debt payments			
OandM (savings) costs	FCFA	0	Annual operation and maintenance costs
Fuel cost - proposed case	FCFA	0	
Debt payments - 15 yrs	FCFA	32,952	Annual amount paid for debts
Total annual costs	FCFA	32,952	Total annual expenditures
Annual savings and income			
Fuel cost - base case	FCFA	0	
Electricity export income	FCFA	135,037	Annual income from sale of electricity (example for Garoua) .

North region – Garoua.

RETScreen used the above financial parameters alongside the energy generated per year to assess the financial viability for each location and the following results were obtained for Garoua.

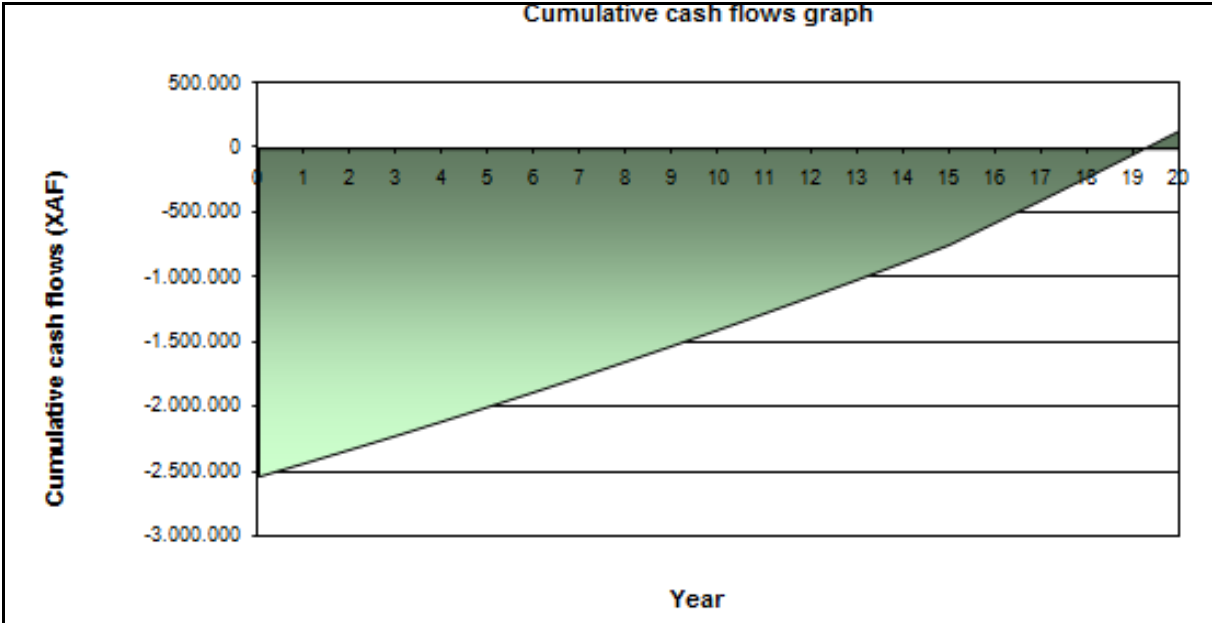


Figure 5-4: Cumulative cash flow graph for Garoua (Solar).

Similarly to the wind resource analysis, RETScreen calculated the pre-tax internal rate of return (IRR) on equity (%) and pre-tax internal rate of return (IRR) on assets (%), which represents the true interest yield provided by the project equity and assets

respectively, over its duration before income tax. For Garoua, these values were very positive for IRR on equity and negative IRR on assets. The values were 0.5%, and -0.5% respectively.

Financial viability			
Pre-tax IRR - equity	%	0.5%	
Pre-tax IRR - assets	%	-0.5%	
Simple payback	yr	20.9	
Equity payback	yr	19.2	

The analysis for Garoua yielded a weak positive pre-tax IRR on equity and a negative pre-tax IRR on assets. Such a result indicates that the project would not be economically viable for commercial purposes. A simple debt payback can only be guaranteed after the project life span, whereas an equity pay back can be completed just before the end of the project life cycle as shown above.

Results from the financial analysis for the other locations were developed and summarized in the table below.

Table 5-4: Financial analysis results and viability assessment - Solar resource.

Region (Location)	Electricity exported to grid (MWh)	Pre-tax IRR- equity (%)	Pre-tax IRR - assets (%)	Simple payback (yrs)	Equity payback (yrs)	Viability of project
Maroua	3.342	0.4	-0.6	21.1	19.4	Risky
Garoua	3.376	0.5	-0.5	20.9	19.2	Risky
Ngaoundéré	3.340	0.3	-0.6	21.1	19.4	Risky
Bamenda	2.953	-0.9	-1.8	23.9	> project	Not viable
Bafia*	2.927	-1.0	-1.9	24.1	> project	Not viable
Yaoundé	2.730	-1.7	-2.5	25.8	> project	Not viable
Douala	2.521	-2.5	-3.3	28.0	> project	Not viable
Bertoua	2.936	-1.0	-1.8	24.0	> project	Not viable
Ebolowa	2.689	-1.8	-2.7	26.2	> project	Not viable
Fontem	2.819	-1.4	-2.2	25.0	> project	Not viable

From the results in the table above, it can be seen that all the locations yielded a negative pre-tax IRR on assets, whereas only three locations, Maroua, Garoua and

Ngaoundéré could yield a positive pre-tax IRR on equity. Although these regions gave positive results, a commercial solar projects on the scale analysed in this research, in those locations were designated as risky. This is because the positive pre-tax IRR values on equity were very weak, with the maximum value being that of Garoua, which is just 0.5%.

Chapter 6 : Environmental Analysis

6.1 Introduction

The environmental analysis seeks to assess the emission offsets in the environment that can be achieved through the use of renewable energy instead of conventional fossil fuel. This section looks at the most current documented rates of emissions for electricity generation and other sources for Cameroon, mainly the emission of GHG. Furthermore it brings out the best use of renewable energy in terms of minimizing CO₂ and other pollutants.

GHG include water vapour, carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), ozone (O₃) and several classes of halo carbons (that is, chemicals that contain carbon together with fluorine, chlorine and bromine). GHG allow solar radiation to enter the Earth's atmosphere, but prevent some of the infrared radiation reflected by the Earth's surface from escaping. Instead, this outgoing radiation is absorbed by the GHG and then partially re-emitted as thermal radiation back to Earth, warming the surface. GHG that are most relevant to energy project analysis are carbon dioxide, methane and nitrous oxide. These gases are considered in the RETScreen emission reduction analysis. RETScreen also considers the direct chemical contribution of refrigerants (fluorocarbons) to greenhouse gas emissions resulting from the operation of the base case and proposed case systems. Fluorocarbons include chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs). They are used in a variety of applications including refrigeration and air-conditioning systems. For many years, CFCs, such as CFC-11 and CFC-12, have been used widely, but due to the Montreal Protocol they are now being replaced by HCFCs, such as HCFC-22 and HCFC-123 and HFCs, such as HFC-23 and HFC-134a, because they exist for a shorter time in the atmosphere, addressing the concern about ozone depletion. They can also have a significant impact on global warming.

6.2 Greenhouse Gas Emissions in Cameroon

According to information obtained from WRI, 2009, Cameroon, by 2000 had a 7,434.8 thousand metric tons of Carbon monoxide, 351.8 metric tons of nitrogen oxides, and 6,797 thousand metric tons of carbon dioxide emissions by 2005 from various sources. Other emissions from various sources for Cameroon have been summarized and presented below (Table 6-1).

Table 6-1: GHG emission rates in Cameroon

Emission	Amount (thousand metric tons of CO ₂ equivalent)		
	1990	2000	2005
Carbon monoxide (CO)	3,803.6	7,434.8	-
Carbon dioxide (CO ₂)	2,982	6,774.0	6,797
Nitrogen oxides (NO _x)	180.2	351.8	-
Non-methane VOC	449.9	725.4	-
Sulfur dioxide	46.4	174.4	-
Non- CO ₂ greenhouse gas emissions: Fluorinated gases	656.4	2,274.0	-
Non- CO ₂ greenhouse gas emissions: Methane	10,505.1	14,968.9	-
Non- CO ₂ greenhouse gas emissions: Nitrous oxide	8,285.5	11,819.3	-

Source: WRI, 2005

Cameroon by 2006, had an annual average CO₂ emission of 3,645 thousand metric tons of CO₂ equivalent (WRI, 2005). This value is less than 1% of the global total, and have been observed to increase over the years. If measures are not taken, given the increase energy demand and growing population, this value might double within the next 10 to 20 years leading to an increased rate of environmental problems.

RETScreen makes it easy for the user to evaluate proposed projects in both domestic and international markets, including projects that fall under the Kyoto Protocol's Clean Development Mechanism (CDM) and Joint Implementation (JI). The model calculates the net annual reduction in GHG emissions estimated to occur if the proposed project is implemented. The calculation is based on the gross annual GHG emission reduction and the GHG credits transaction fee. Units are given in equivalent tons of CO₂ emissions per year (tCO₂e/yr). The model allows the user to compare the net annual GHG emission reduction with units that are easier to conceptualize (e.g. cars and light

trucks not used, barrels of oil not consumed, acres of forest land absorbing carbon etc). The calculation is based on a GHG emission factor with (0.045) or without (0.039) T&D (transmission and distribution) losses per MWh of electricity generated. Based on these analysis RETScreen calculated the amount of GHG that could be offset for the cases of this research. These results were divided based on the resource type and are given below.

6.3 Offsetting Greenhouse Gases by Wind

Calculations for reducing GHG for wind was done only for Maroua, Garoua, and Ngaoundéré. Other locations were not taken into consideration because the wind resource in these areas was assessed not strong enough to be capable of generating electrical energy on a commercial scale. Although a wind project in Ngaoundéré was analysed to be commercially not profitable, the analysis considered the location as capable of offsetting GHG.

According to the analysis, a single ENERCON E-82 wind turbine installed in Maroua generating an average 1,732MWh electricity a year, would be capable of reducing 78.6t CO₂e/yr. Taking into consideration transmission and distribution (T&D) losses of electricity (15% used in this case) a net annual GHG emission reduction for Maroua would be 66.8t CO₂e/yr. This value can be conceptualized as follows:

Equivalent to

- 12.2 cars and light trucks not used
- 28,718 liters of gasoline not consumed
- 155 barrels of crude oil not consumed
- 66.8 people reducing energy consumption by 20%
- 15.2 acres of forest land absorbing carbon
- 6.1 hectares of forest absorbing carbon and
- 23.0 tons of waste recycled.

The analysis for Garoua and Ngaoundéré were tabulated and are given below (Table 6-2).

Table 6-2: GHG offsets by wind for Garoua and Ngaoundéré.

Value	Location	
	Garoua	Ngaoundéré
Annual electricity exported to grid MWh	1,368	876
GHG emission reduction (t CO ₂ e/yr)	57.4	36.7
Net annual GHG emission reduction (t CO ₂ e/yr)	52.8	33.8
Cars and light trucks not used	9.7	6.2
Litres of gasoline not consumed	22,693	14,524
Barrels of crude oil not consumed	123	78.6
People reducing energy consumption by 20%	52.8	33.8
Acres of forest land absorbing carbon dioxide	12.0	7.7
Hectares of forest absorbing carbon	4.9	3.1
Tons of waste recycled	18.2	11.7

6.4 Offsetting Greenhouse Gases by Solar

Similar analyses were done for the solar resource. They showed that the potential for environmental protection by offsetting GHG emissions by solar energy projects assessed in this research was very small relative to wind. The reason for this is that RETScreen’s calculation is based on a GHG emission factor with (0.045) or without (0.039) TandD losses per MWh of electricity generated. Garoua for example, is capable of generating just about 3,376kWh (approximately 3.5MWh) solar electricity per year.

Emission analysis for solar energy across the entire nation was not convincing with most of the areas giving an approximate value of 0.1t CO₂/yr. Because the results were similar and only differed slightly in terms of amount of gasoline not consumed, certain results were summarized and presented below (Table 6-3).

Table 6-3: GHG offsets by solar for selected locations.

Value	Location			
	Maroua	Garoua	Ngaound éré	Bertoua
Electricity exported to grid kWh/yr	3,342	3,376	3,340	2,936

GHG emission reduction (t CO ₂ /yr)	0.1	0.1	0.1	0.1
Net GHG emission reduction (t CO ₂ /yr)	0.1	0.1	0.1	0.1
Cars and light trucks not used	0.0	0.0	0.0	0.0
Litres of gasoline not consumed	55.4	56.0	55.4	48.7
Barrels of crude oil not consumed	0.3	0.3	0.3	0.3
People reducing energy consumption by 20%	0.1	0.1	0.1	0.1
Acres of forest land absorbing carbon dioxide	0.0	0.0	0.0	0.0
Hectares of forest absorbing carbon dioxide	0.0	0.0	0.0	0.0
Tons of waste recycled	0.0	0.0	0.0	0.0

Chapter 7 : Political and Regulatory Framework

Introduction

In this section, a review of political and regulatory frameworks and laws put forward by the Cameroonian government in the energy sector was carried out with emphasis on renewable energy.

Since 1996, Cameroon has made major advances in the development of regulations for its energy sector. In 1998, the Government of Cameroon (GOC) initiated a series of policy and structural reforms to promote the efficient operations of the energy sector and increase the role of the private sector in its future development. An Electricity Law was adopted in 1998. The passage of a complementary Electricity Decree followed in 2000 as well as the establishment of a sector regulator (ARSEL) and a rural electrification agency (AER). The vertically integrated, formerly state owned electricity company was privatized through a 20year concession in 2001. While electricity access rates have improved since privatization, AES SONEL fell significantly short of meeting its initial connection targets. Despite the GOC's commitment to privatization, a number of structural issues need to be addressed to secure sustainable and affordable electricity development in the long run (SME, 2004). There are no regulations in Cameroon dealing specifically with renewable energy. The following are laws enacted by the Cameroonian government dealing with energy of which renewable energy is a subset.

Decree N° 96/36/PM to set up a National Committee of The World Energy Council

This law was published on February 21st 1996 by the Prime Ministry of the Republic of Cameroon, to set up in the Ministry in charge of energy A National Committee of the World Energy Council. Article II of the decree stipulates the duties of the committee, to prepare and ensure Cameroon's participation in the meetings of the World Energy Council, and monitor the enforcement of the recommendations of the

Council in Cameroon. Article III of the decree provides for the organization and functioning of the committee.

Law N° 98/022 governing the electricity sector

Passed into law on the 24th of December 1998, this law governs the production from any primary or secondary energy source, the conveyance distribution, the supply, the import, export and sale of electricity by any company in Cameroon.

Part I of the law;

- lays down the conditions for producing, conveying, distributing, importing, exporting and selling electricity;
- establishes the basis for fair competition in the electricity sector so as to enhance its economic efficiency;
- determines the manner of checking the implementation of the specific obligations by persons involved in non-competitive activities;
- determines the rules governing environmental and consumer protection in terms of prices, the conditions of supply and the safety of the services;
- guarantees the continuity and quality of services.

By so doing, the law defines primary sources of energy as resources which exist in their natural state on the territory of the Republic of Cameroon or are imported, and which can either be used directly as fuel, such as organic matter (petroleum, crude oil, schist, coal, peat, biomass, fuel gas); converted into other forms of energy; used as nuclear energy; or be obtained from renewable sources of energy (water, solar energy, wind and geothermal energy).

Renewable energy resources are: sources of energy that exist naturally and are permanently renewed by nature.

Part III of the law stipulates the activities in the electricity sector and placed them under one of the following legal schedules: concession; licensing, authorization; declaration and the free scheme.

Decree N° 99/125 to set up the organization and functioning of The Electricity Sector Regulatory Agency.

This decree published in June 1999 by the Presidency of the Republic of Cameroon, organized and laid down the conditions for the functioning of the Electricity Sector Regulatory Agency, hereinafter referred to as the “Agency”, set up by Law N° 98/22 of 24th December 1998 governing the electricity sector. The Agency’s mission was to regulate, control and monitor the activities of operators in the electricity sector and to arbitrate disputes between electricity sector operators, upon referral by the parties.

Decree N° 99/193 relating to the organization and functioning of the rural electrification agency.

From a regulatory perspective, this decree published in September 1999 by the Presidency of the Republic of Cameroon is responsible for promoting rural electrification. In this capacity, it provides operators and consumers the technical and, if necessary, financial assistance required for development of rural electrification. Article II of the decree places the agency under the supervisory authority of the government service in charge of electricity which, in this capacity, defines state policy in the rural electrification sector.

Decree n° 2001/21/pm 29 January 2001, to fix the rates and the conditions of calculating, collecting and distributing royalties on activities in the electricity sector.

This decree clearly divides and fixes;

- The rates and the conditions of calculating, collecting and distributing royalties in the electricity sector;
- The royalty paid on any activity falling under one of the schedules provided for below, shall be based on the annual turnover exclusive of tax of the activity carried out by the operator for the financial year ending during the previous year;
- Exempts private production installations other than hydroelectric power plants, of a capacity lower than or equal to 100 kW from the royalties that are the subject of this decree.

Decision N°. 17/DG/ARSEL of 25 January 2002 to fix prices exclusive of tax of electricity sold by AES-SONEL

Published by the Electricity Sector Regulatory Agency (ARSEL), this decision clearly divides subscribers into the level of consumption and set prices applicable for each group as follows.

1. Low Voltage Subscribers

Lighting for home and business use

- **Social Range.** Consumption lower than or equal to 110 kWh within the month: 50 CFAF/kWh.
- **Normal Range.** For all kWh consumed over 110 kWh: 64 CFAF/kWh.
- **Public Lighting.** Price applicable provided consumption takes place from 6.30 p.m. to 6 a .m: 33.6 CFAF per kWh.

2. Medium Voltage Subscribers

General schedule. The rate shall comprise two complementary elements:

- Annual fixed bonus per kW of subscribed power: 9.125 FCFA.
- Proportional rate per kWh consumed.

It shall depend on the number of hours of monthly consumption of the subscribed power, and shall be calculated in accordance with the following table.

- Number of hours proportional rate

From 0 to 200 hours 40.5 FCFA/kWh

From 201 to 325 hours 37 FCFA/kWh

From 326 to 450 hours 33.5 FCFA/kWh

Over 450 hours 31.2 FCFA/kWh

Industrial Free Zones And Special Industrial Free Zones

The price shall comprise two complementary elements:

1. Annual fixed bonus per kW of subscribed power. It shall depend on the number of hours of the annual consumption of the subscribed power, and shall be calculated in accordance with the following table.

Number of hours fixed bonus

From 0 to 3, 900 hours 15, 612 CFAF/kW

From 3, 901 to 5, 400 10, 870 CFAF/kW

From 5, 401 hours to 6, 600 5, 437 CFAF/kW

Over 6, 600 NIL

2. Proportional price per kWh consumed. It shall depend on the number of hours of monthly consumption of the subscribed power and shall be calculated in accordance with the following table.

Number of hours proportional rate

From 0 to 200 hours 23.10 CFAF/kWh

From 201 to 325 hours 20.79 CFAF/kWh

From 326 to 450 hours 16.17 CFAF/kWh

Over 450 hours 11.55 CFAF/kWh

Enterprises set up in an Industrial Free Zone or in a Special Industrial Free Zone shall be exempt from payment of advance on consumption. AES-SONEL shall keep any advances on consumption collected before the signing of this decision. An increase of 10% of proportional prices shall be collected as guarantee in respect of the minimum export rate of 80% of the production of the said enterprise set up in the Industrial Free Zone or in the Special Industrial Free Zone. This deduction shall be retroceded at the end of every financial year as credit upon justification of compliance with the export to AES-SONEL of 80% of production.

3. High voltage subscribers

Sale prices of high voltage electricity to subscribers existing at the date of signature of the concession and licence agreements of AES SONEL shall remain in force, and shall be revised in accordance with the specifications of the framework concession and licence agreement of the company.

Sale prices of high voltage electricity to new subscribers shall be fixed within the framework of agreements signed with AES SONEL, upon approval by the Electricity Sector Regulatory Board in accordance with the specifications of the framework concession and license agreement of the company.

Decree N° 2003/243 of 12 December 2003 to set up an Energy Steering Committee

In an effort to support and supervise strategies for the management of energy crises and for the finalization of the national energy plan, an energy steering committee was set up in the Presidency of the Republic of Cameroon in 2003. The committee is responsible for;

- developing and facilitating necessary synergies between different administrations in determining the most appropriate strategies for short term situations of energy crises;
- promoting and boosting consultations in view of finalizing the national energy plan;
- suggesting any measure likely to favor the implementation of programs and projects coming within the framework of strategies of energy crises situations.

Decree N°2006/406 to set up the Electricity Development Corporation

In order to ensure the conservation of public patrimony in the electricity sector, a public corporation – The Electricity Development Corporation (EDC) was set up on November 29th 2006 by the President of the Republic of Cameroon. Under this decree, the EDC is responsible for;

- managing for the account of the State, public patrimony in the electricity sector;
- studying, preparing or realizing in the electricity sector, any infrastructural project that the state shall confide to it;
- participating in promoting private and public investments in the electricity sector.

The GOC has so far indicated strong signals of its interest for the development of the country's energy services. With clarity of the roles as laid down by the laws and decrees passed, as well as responsibilities of actors in the sector, a key milestone would be an increase in the public budgetary fund. However, a continuing support of the World Bank to the country through 20 active projects with a commitment value of US\$ 659.5 million as of September 2009 in various sectors would further leverage GOC resources that could be directed to the energy sector (World Bank, 2009).

Chapter 8 : Conclusion

In this research, a few goals discussed in section 2.2 could be achieved. The contributions of this thesis are discussed in the following.

Technology and Infrastructure. As explained in section 1.3 and 2.1 Cameroons inability to generate the full facet of its installed electricity capacity is largely due to its poor infrastructure, and reliance on aging equipments. With an installed electricity production capacity of 935MW, the energy sector is capable of producing just about 50% of this installed capacity. Also, its poor infrastructures accounts for the poor coverage of the country and low access rates especially in rural areas. Technology wise, Cameroon depends solely on hydro and thermal technologies for its electricity production. Wind and solar have not been developed and fully integrated.

Resource Potentials with its estimated 55,200MW hydropower potential, Cameroon is second only to the Democratic Republic of Congo in Africa in the domain of hydro. Cameroon has huge potentials for biomass fuels which account for 78% of its primary energy source. From the technical analysis presented in section 4, the northern regions of Cameroon especially Maroua has promising potentials for wind energy. With a single wind turbine installed in this location capable of generating an annual 1,732MWh electrical energy, the wind resource can be developed on a commercial scale. The solar potential though very low compared to the wind resource is still promising for commercial purposes in the northern regions of Cameroon. Apart from the northern regions of the country, the wind and solar potentials are not good enough to be developed for commercial purposes, but can still be exploited for small scale micro projects, for instance, to enhance sustainable water supply pumps, food processing and conservation, agriculture and low-cost building techniques for local communities with little or no access to the national electricity grid.

Sustainability: sustainability is a term, or even a concept, that has been widely used in recent years, especially regarding international development. Brundtland (1987), for the World Commission on Environment and Development, has defined *Sustainable development* as: “development that meet the needs of the present without compromising the ability of future generations from meeting their own needs”. With

mean annual hours of sunshine per year of over 3,000 hours and annual mean wind speeds that are equal to or exceed 2m/s for over 80% of the time, these prospective technologies can guarantee a long term supply of Cameroon's economy with energy on a sustainable basis if fully developed.

Policy setbacks: Most legislations governing the energy sector in Cameroon reviewed in section 7 of this research have shown that there are no direct laws or decrees governing renewable energy in Cameroon. Most of these are regulatory texts governing the energy sector as a whole. These policies have failed to promote and encourage the incorporation and use of other sources of energy such as wind and solar, by providing incentives and grants. Also these legislations and policies have fallen short of strict guides and practices geared towards the conservation and protection of these resources so as to guarantee a long term supply. This has been reflected in the increasingly drying up of streams and rivers causing below capacity productions of electricity in the sector.

Energy and the environment: The energy sector in Cameroon has suffered a lot of effects from climatic changes, from the Sahara desert encroachment to the north, to some major streams and rivers drying up during the dry seasons. This has been a major blow to the electricity sector due to the fact that, it depends solely on hydro and thermal power for the generation of electrical energy, leading to constant generations below capacity during these periods.

Conclusively, the economy of Cameroon is not in a very good shape. Attempts made by the Government of Cameroon to rehabilitate the economy would go in vain if there is no boost in the energy sector. Cameroon has a plethora of unexploited renewable resources, with a hydropower potential second only to Congo in Africa. These potentials are there untapped, from hydropower, through biomass to wind and solar, but the country still goes through insufficient supply of electricity.

The northern regions of Cameroon are highly endowed with vast wind and solar potentials that can be exploited on a commercial scale and help improve energy and electricity problems in Cameroon. Despite their low potentials for wind and solar, other locations in Cameroon still possess some small but seasonal potentials. The findings in this research could not be different, as some researches have already been

undertaken in an attempt to estimate the wind potentials in the northern regions of Cameroon . But normally, there are a number of conflicting options as to where, how and what can be done in revitalizing the energy sector in Cameroon, which demand funding and the purpose of this research is to ascertain which of such projects will give the best returns.

Looking at the fundamentals of the Cameroonian economy, there is a huge energy gap that is acting as a key constraint to its development. Also, the gap between the demand and supply of energy is not diminishing, instead it is constantly increasing with an estimated 8%. For Cameroon to narrow or close this gap, it has to move on board by developing its full potentials. The main question is, with the kind of institutional setup and the regulations that are available now in the sector, is it possible for these highlighted potentials to be moved into action? What can be changed, what can be done in the institutions, what do we need to change in the technology, what do we need to change in the infrastructure, what do we need to change even at the level of the policies to ensure that these potentials are fully taken up?

Cameroon, like most other countries has been at the realm of corruption. But even in the face of corruption, we cannot only advocate stopping the corruption, but also we have to see what we can do to survive in the midst of those corruptions. There are good projects and creative business opportunities that can be used to work a way out and to immunize the threats of corruption. Corruption normally is not only at the top, but from top to bottom and is driven by different incentives and motivations of the people. For the man at the bottom, corruption means survival, and for the man at the top, corruption is to plunder those resources directed towards development.

Corruption normally is a constraint in every domain, but we have to ensure not only how we can eliminate corruption completely but also, how to reduce the ability of corruption such that it is not a binding constraint in rolling out a project and the development of our objectives.

Chapter 9 : Recommendations

Finally, the recommendations that could be drawn from this research work are that the Government of Cameroon should develop a renewable energy plan, that will guarantee a future energy supply that will be adequate, reliable, and affordable both to industries to enable them to provide continuous employment and low-cost goods and services; and to the ordinary citizens, to enable them to achieve a decent lifestyle. This plan should also ensure that energy will be produced and used in a manner that promotes sustainable development in the utilization of the country's natural resources but at the same time maintain the country's overall economic competitiveness.

In order to attain this goal, there is a need to recognize the factors that hinder the development of the full potential of renewable energy in Cameroon. This would include those core issues that act as constraints to the development of renewable energy resources. Mostly, those constraints that are amendable such as institutional set up, technology, policy, regulations, and not geographical constraints. In order to look in the direction that the Government of Cameroon can translate the potentials highlighted above into action, the following recommendations have been set forth.

1. Diversify sources of energy

The over-dependence on hydropower as the main source of electricity has greatly contributed to the growing energy problems in Cameroon. Cameroon certainly has the second largest hydropower in Africa, but with the increasing global warming concerns and desert encroachment to the north, the energy sector will still be at great risks if other sources are not employed. A combination of hydro, wind, solar and thermal technologies will not only eliminate below capacity productions, but will also guarantee a continuous supply of energy. For example, during the heart of the dry seasons between December and March, when streams are drying up and the water power is not strong enough to supply the required capacity, the solar irradiance and wind speeds for Cameroon are at their peaks and vice versa. With these technologies in use, there will always be supplements to make up for the drawbacks of one source by another.

2. Implement clear and direct policies

There is a need to improve the implementing rules and regulations to remove the barriers in the expansion of renewable energy. Traditional policy of the government must be further improved also to facilitate the energy sector's transition to a sustainable system with renewable energy as an increasingly prominent, viable and competitive option.

3. Support development of expertise in RETs

In order to achieve a higher level of RET development and utilization in the country, there is a need to build expertise in RET development and management through enhanced training of Cameroonian professionals locally and abroad and the government must endeavor to solicit funding possibilities to make this possible.

4. Enhance investment in non-power applications

Due to the lack of financing and lack of awareness, the country has not yet been ready in terms of development of non-power applications, for example in geothermal fields. People are yet to realize the benefits of using these technologies, especially geothermal heat in terms of time saved in drying, owing to its higher temperature and non-seasonality compared to sunlight.

5. Take advantage of international financing opportunities

The Government of Cameroon should support all private sector initiatives that can draw on the financing instruments of the World Bank's Prototype Carbon Fund (PCF), the Global Environmental Facility (GEF) and the United Nations Framework Convention on Climate Change (UNFCCC): Clean Development Mechanism/Joint Implementation [CDM/JI], all of which are funding sources for clean energy projects. The Ministries of Energy and Water, Finance, Environment and Nature Protection, Industry, Mining and Technology Development as well as the Ministry of Scientific Research and Innovation should provide more information and technical support to organizations that intend to seek funding support from these international financing schemes.

6. Improve awareness and interest in investment opportunities

To this fact, the utilization of wind and solar energy in the country serves as an example. There has been limited private sector investment in wind energy

development. Another issue is the commercialization of hydropower technology. There is a need to further develop and commercialize suitable micro hydro technology in the country, even as hydropower technology for large and small projects is proven and mature. The effect of this problem causes the country to remain dependent on imported electro-mechanical equipment for micro hydro projects.

7. Learning, experimentation and accountability

Rather than prematurely trying to identify the most efficient technology to move towards a sustainable energy system, there is an ongoing need for flexibility, experimentation and learning. Instead of settling on solutions on the basis of costs (or cost projections), more effort should be expended on R&D and commercialization of promising technologies, so as to drive down their costs (Ivan and Gordon, 2009).

8. Implement an energy pricing policy

Adopt an energy pricing policy that will be able to satisfy the energy needs of consumers of different income levels with consideration given to economic growth promoting economically efficient allocation of resources in all economic sectors including the renewable energy sector. Such a policy should be able to guarantee a rate of return to enable self-financing as an acceptable contribution to the required investments. Energy conservation should be a main objective of such a pricing policy. In developing such a policy, constraints such as price stability, the prevention of shocks on prices, avoidance of large price fluctuations, simplicity in the pricing structure, simple metering and billing strategies and certain environmental aspects through taxation should be carefully dealt with.

If the GOC weigh the renewable energy potentials on the basis of the constraints that are inhibiting the development of its full potential and see how these can be overcome to help its economy, they will be a long way ahead in revitalizing the country's energy sector and the already crippled economy of Cameroon.

9. Further research in the northern regions of Cameroon

Finally, there are almost always ways that a study could be improved or refined. The Government of Cameroon should promote and sponsor researches in the northern regions of Cameroon, to further and completely evaluate the full potential of wind and solar in these northern regions.

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Appendix



RETScreen® International

www.retscreen.net

Clean Energy Project Analysis Software

Project information

[See project database](#)

Project name	2000KW
Project location	Cameroon
Prepared for	Master Thesis
Prepared by	Bobbo Nfor Tansi
Project type	Power
Technology	Wind turbine
Grid type	Central-grid
Analysis type	Method 1
Heating value reference	Higher heating value (HHV)
Show settings	<input checked="" type="checkbox"/>
Language - Langue	English - Anglais
User manual	English - Anglais
Currency	Euro
Units	Metric units

Site reference conditions

[Select climate data location](#)

Climate data location	Maroua
Show data	<input checked="" type="checkbox"/>



Climate data

	Unit	location	Project location
Latitude	'N	10,6	10,6
Longitude	'E	14,3	14,3
Elevation	m	387	387
Heating design temperature	°C	19,7	
Cooling design temperature	°C	37,0	
Earth temperature amplitude	°C	16,7	

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	26,3	17,2%	5,61	96,8	4,1	28,8	0	504
February	28,3	14,3%	6,24	96,7	4,0	31,4	0	511
March	31,3	22,5%	6,56	96,4	4,4	34,9	0	661
April	30,9	44,3%	6,31	96,3	4,6	34,1	0	628
May	29,1	59,3%	5,96	96,5	4,2	31,3	0	591
June	26,9	70,2%	5,50	96,7	3,5	28,2	0	506
July	25,1	78,0%	5,03	96,8	3,2	25,9	0	469
August	24,9	78,3%	4,85	96,8	3,1	25,7	0	462
September	25,8	72,4%	5,34	96,7	2,8	26,7	0	473
October	28,1	48,6%	5,70	96,6	3,2	29,7	0	560
November	29,0	23,2%	5,85	96,6	3,8	30,9	0	570
December	27,0	19,4%	5,56	96,8	4,3	29,0	0	527
Annual	27,7	45,8%	5,70	96,6	3,8	29,7	0	6.462
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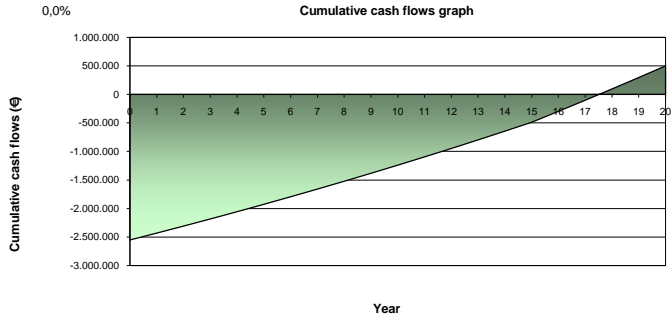


[Complete Energy Model sheet](#)

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<div style="border: 1px solid black; padding: 2px; display: inline-block;">€ 2.736.000</div>																																																																																																																			

Emission Analysis				
Base case electricity system (Baseline)				
Country - region	Fuel type	GHG emission factor (excl. T&D) tCO2/MWh	T&D losses %	GHG emission factor tCO2/MWh
Cameroon	All types	0,039	8,0%	0,042
Electricity exported to grid	MWh	1.732	T&D losses	8,0%
GHG emission				
Base case	tCO2	72,6		
Proposed case	tCO2	5,8		
Gross annual GHG emission reduction	tCO2	66,8		
GHG credits transaction fee	%	0,0%		
Net annual GHG emission reduction	tCO2	66,8	is equivalent to	28.718 Litres of gasoline not consumed
GHG reduction income				
GHG reduction credit rate	€/tCO2	0,00		

Financial Analysis				
Financial parameters				
Inflation rate	%	1,5%		
Project life	yr	20		
Debt ratio	%	10%		
Debt interest rate	%	8,00%		
Debt term	yr	15		
Initial costs				
Power system	€	2.736.000	96,5%	
Other	€	100.000	3,5%	
Total initial costs	€	2.836.000	100,0%	
Incentives and grants	€	0	0,0%	
Annual costs and debt payments				
O&M (savings) costs	€	15.000		
Fuel cost - proposed case	€	0		
Debt payments - 15 yrs	€	33.133		
Total annual costs	€	48.133		
Annual savings and income				
Fuel cost - base case	€	0		
Electricity export income	€	166.228		
Total annual savings and income	€	166.228		
Financial viability				
Pre-tax IRR - equity	%	1,6%		
Pre-tax IRR - assets	%	0,6%		
Simple payback	yr	18,8		
Equity payback	yr	17,5		





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Clean Energy Project Analysis Software

Project information

[See project database](#)

Project name	2000W
Project location	Cameroon
Prepared for	Master Thesis
Prepared by	Bobbo Nfor Tansi
Project type	Power
Technology	Photovoltaic
Grid type	Isolated-grid
Analysis type	Method 1
Heating value reference	Higher heating value (HHV)
Show settings	<input checked="" type="checkbox"/>
Language - Langue	English - Anglais
User manual	English - Anglais
Currency	Cameroon
Units	Metric units

Site reference conditions

[Select climate data location](#)

Climate data location	Garoua
Show data	<input checked="" type="checkbox"/>



Climate data

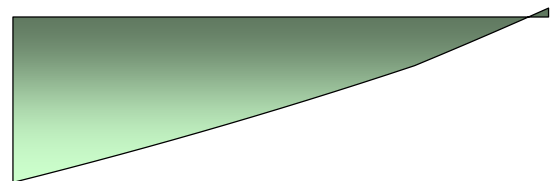
	Unit	location	Project location
Latitude	'N	9,3	9,3
Longitude	'E	13,4	13,4
Elevation	m	424	424
Heating design temperature	°C	19,4	
Cooling design temperature	°C	35,6	
Earth temperature amplitude	°C	15,8	

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	26,4	17,8%	6,07	96,3	3,8	28,8	0	507
February	28,2	16,1%	6,36	96,2	3,8	31,1	0	509
March	30,1	31,1%	6,50	96,0	4,1	33,2	0	623
April	28,9	56,7%	6,24	96,0	4,3	31,0	0	566
May	27,1	69,6%	5,78	96,2	3,9	28,3	0	530
June	25,5	76,7%	5,37	96,3	3,3	26,2	0	464
July	24,4	80,2%	4,94	96,4	3,1	25,0	0	445
August	24,2	80,3%	4,83	96,4	2,9	24,9	0	441
September	24,8	77,0%	5,16	96,4	2,7	25,5	0	445
October	26,1	61,5%	5,70	96,3	3,0	27,1	0	500
November	28,0	29,0%	6,17	96,2	3,5	29,6	0	539
December	26,9	20,4%	5,93	96,3	4,0	28,8	0	525
Annual	26,7	51,6%	5,75	96,3	3,5	28,3	0	6,094
Measured at	m				10,0	0,0		



[Complete Energy Model sheet](#)

Proposed case power system		Incremental initial costs			
Technology	Photovoltaic				
Analysis type	<input type="checkbox"/> Method 1 <input checked="" type="checkbox"/> Method 2				
Resource assessment					
Solar tracking mode	Fixed				
Slope	35,0				
Azimuth	45,0				
<input checked="" type="checkbox"/> Show data					
	Month	Daily solar radiation - horizontal kWh/m ² /d	Daily solar radiation - tilted kWh/m ² /d	Electricity export rate XAF/MWh	Electricity exported to grid MWh
	January	6,07	6,70	40.000,0	0,347
	February	6,36	6,53	40.000,0	0,304
	March	6,50	6,15	40.000,0	0,317
	April	6,24	5,44	40.000,0	0,276
	May	5,78	4,74	40.000,0	0,250
	June	5,37	4,31	40.000,0	0,221
	July	4,94	4,05	40.000,0	0,217
	August	4,83	4,16	40.000,0	0,225
	September	5,16	4,72	40.000,0	0,245
	October	5,70	5,65	40.000,0	0,297
	November	6,17	6,69	40.000,0	0,333
	December	5,93	6,68	40.000,0	0,345
	Ann	5,75	5,48	40000,00	3,376
Annual solar radiation - horizontal	MWh/m ²	2,10			
Annual solar radiation - tilted	MWh/m ²	2,00			
Photovoltaic					
Type	poly-Si				
Power capacity	kW	2,00		XAF 2.320.500	See product database
Manufacturer	BP Solar				
Model	poly-Si - BP SX3200 10 unit(s)				
Efficiency	%	9,0%			
Nominal operating cell temperature	°C	45			
Temperature coefficient	% / °C	0,40%			
Solar collector area	m ²	22			
Miscellaneous losses	%	2,0%			
Inverter					
Efficiency	%	95,0%			
Capacity	kW				
Miscellaneous losses	%	0,0%			
Summary					
Capacity factor	%	19,3%			
Electricity exported to grid	MWh	3,376			



Emission Analysis

Base case electricity system (Baseline)		GHG emission factor (excl. T&D)	T&D losses	GHG emission factor
Country - region	Fuel type	tCO2/MWh	%	tCO2/MWh
Cameroon	All types	0,039	8,0%	0,042
Electricity exported to grid	MWh	3	T&D losses	8,0%
GHG emission				
Base case	tCO2	0,1		
Proposed case	tCO2	0,0		
Gross annual GHG emission reduction	tCO2	0,1		
GHG credits transaction fee	%			
Net annual GHG emission reduction	tCO2	0,1	is equivalent to	56,0 Litres of gasoline not consumed
GHG reduction income				
GHG reduction credit rate	XAF/tCO2			

Financial Analysis

Financial parameters				
Inflation rate	%		1,5%	
Project life	yr		20	
Debt ratio	%		10%	
Debt interest rate	%		8,00%	
Debt term	yr		15	
Initial costs				
Power system	XAF	2.320.500	82,3%	
Other	XAF	500.000	17,7%	
Total initial costs	XAF	2.820.500	100,0%	
Incentives and grants	XAF	0	0,0%	
Annual costs and debt payments				
O&M (savings) costs	XAF	0		
Fuel cost - proposed case	XAF	0		
Debt payments - 15 yrs	XAF	32.952		
Total annual costs	XAF	32.952		
Annual savings and income				
Fuel cost - base case	XAF	0		
Electricity export income	XAF	135.037		
Total annual savings and income	XAF	135.037		
Financial viability				
Pre-tax IRR - equity	%		0,5%	
Pre-tax IRR - assets	%		-0,5%	
Simple payback	yr		20,9	
Equity payback	yr		19,2	

