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PROSPECT OF RENEWABLE ENERGY BASED POWER SYSTEMS IN AFRICA (CAMEROON-DJIBOUTI-SOMALIA)

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A Thesis Submitted to the Academic Faculty in Partial Fulfillment of the Requirements for the Degree of

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Declaration

We hereby declare that this thesis is the result of our original work carried out at the Islamic University of Technology Dhaka-Bangladesh under the supervision of Prof. Dr. Md. Ashraful Hoque (Head of the department of Electrical and Electronic Engineering Department) and Mr. Wahidur Rahman (lecturer, Electrical and Electronic Engineering Department). This thesis has never been submitted in part or in whole for a degree at any institution.

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List of Abbreviations and Acronyms

AES SONEL National Electricity Company, Cameroon

ALUCAM Aluminum Smelter Plant, Cameroon

ARSEL Electricity Sector Regulatory Agency, Cameroon**.**

CO2 Carbon Dioxide

FCFA Central African Franc

GHG Greenhouse Gases

GW Gigawatt

GWh Gigawatt Hour

IAEA International Atomic Energy Agency

IEA International Energy Agency

UNO United Nations Organization

KWh Kilowatt Hour

MWh Megawatt Hour

NASA National Aeronautics and Space Administration

NGO Non-Governmental Organization

RE Renewable Energy

PV Photovoltaic

IPP independent power provider

HOMER Hybrid Optimization Model for Electric Renewable

NREL National Renewable Energy Laboratory

COE Costs Of Energy

CO2 Carbon dioxide

KWh kilo Watt hour

GHG Greenhouse gas

RE Renewable energy

RAPS Remote area power supply

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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 was carried out to determine the wind and solar energy resource potentials for Cameroon using the Homer Pro software tool provided by CANMET Canada. This 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 was 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.

From the weather data recorded on the site of Dogba-Maroua over a period of 12 months (April 2015 to April 2016), a design engineering of a wind park of 30 KW in the region of the far-north of Cameroun was carried out. The analytical study of wind parameters (speeds, directions, turbulences intensities) was made with the Homer Pro software.

The study undertaken with the wind-generator of the Alstom ECO 100/3000 Class I, having a power of 3000 kW, 100 m diameter of rotor reveals an annual energy production of 22 699,5 MWh / year the directions where the wind blows are more recorded in sectors 30°NNE, 60°NE, 0°N and 90°E and are opposed to the directions where the flow winds are most turbulent (330° NNW, 0° N, 30° NNE, 60°).

Keywords: Homer Pro; turbulence intensity

PART1: CAMEROON

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 Chad, 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 CameroonSource: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 Sananga 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 constitute:

- 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 Gm
- 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).

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 them 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 were 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 4.9kWh/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 equipment, 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 11billion, 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).

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 is 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.

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 (Homer pro) used in this research to analyze the wind and solar potentials for Cameroon.

The fourth chapter provides the center 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 analyze the solar resource. The chapter ends with a general discussion for the solar resource.

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 Homer Pro 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

Software analysis

Prior to settling to the Homer, 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. The Homer software was selected because it helps rapidly evaluates whether a proposed clean energy project makes sense and is worth further consideration.

3.3 Homer Pro

The Homer Pro Clean Energy Project Analysis Software is an innovative energy awareness, decision support and capacity building tool. The HOMER Pro microgrid software by HOMER Energy is the global standard for optimizing microgrid design in all sectors, from village power and island utilities to grid connected campuses and military basest 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 Kaptouom 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. Furthermore, a fourth section reviewed what the government of Cameroon has done in a bid to improve the state of the energy sector.

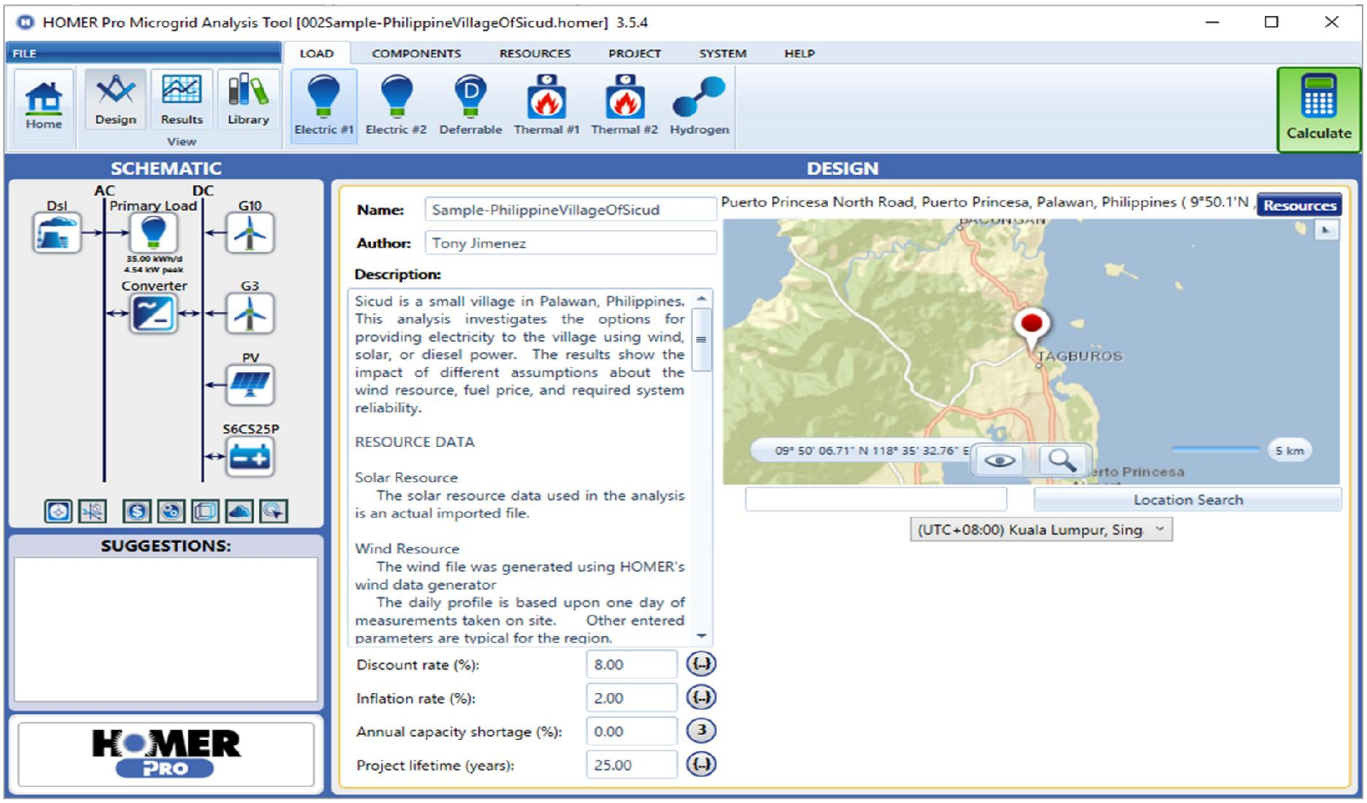


Fig 2.1: Homer Pro

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 was 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 location for this research was carefully selected.

4.1.1 Far North Region – Maroua: Location used

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 Gazetter, 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 Yaoundé **-** Capital of Cameroon**.**
The following step by step procedure was used for the analysis**.**

i. As part of the Homer Pro Clean Energy Project Analysis software, the Startworksheet 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).

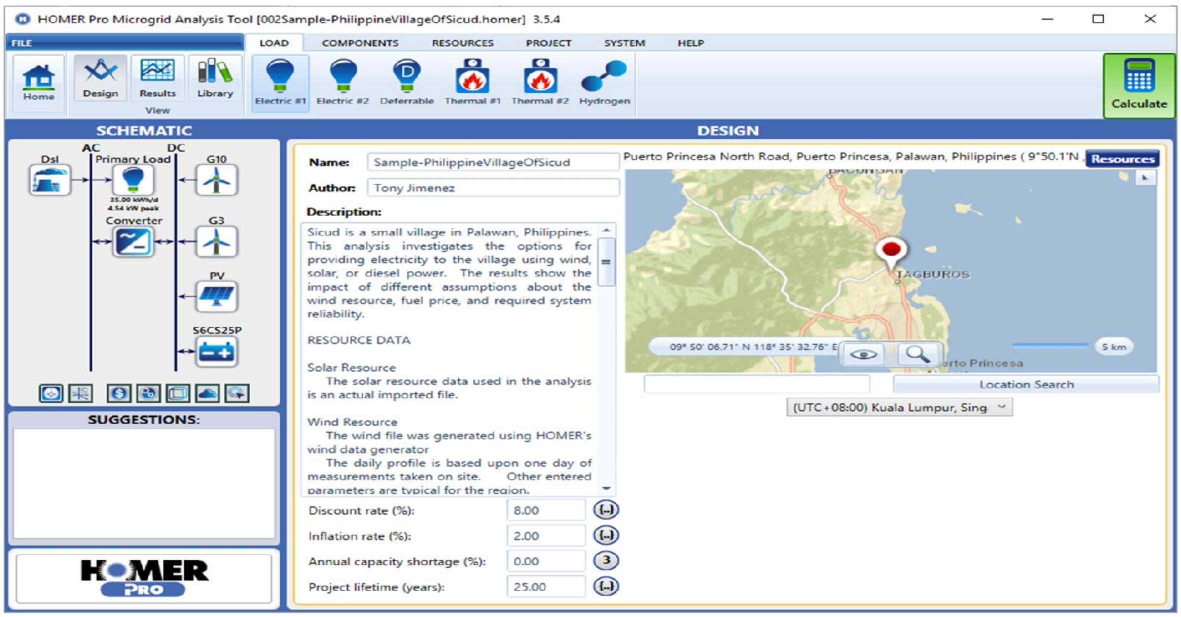


Fig 4.2 : Homer start worksheet

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.

Results and Discussions.

Table 4-13: Wind analysis results.

Region	location	Annual electricity exported to grid [MWh]	No of plants to generate 3,490GWh
Far north	Maroua	1,732	2,016

Table 4-14: Monthly assessment results – Maroua

Month	Maroua wind speed (m/s)
January	4.1
February	4.0
March	4.4
April	4.6
May	4.2
June	3.5
August	3.1
September	2.8
October	3.2
November	3.8
December	4.3
Annual	**3.8**

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.

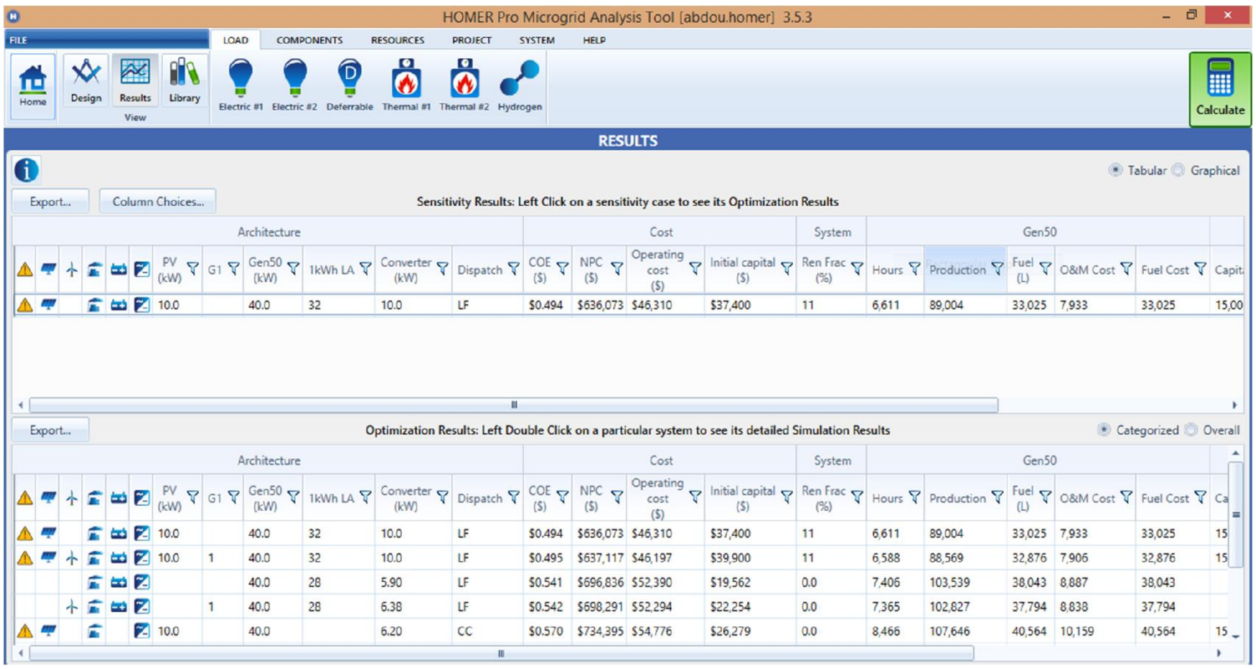
Extreme North region – Maroua

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

Month	**Daily solar radiation -horizontal kWh/m²/d**
January	5.61
February	6.24
March	6.56
April	6.31
May	5.96
June	5.50

July	5.03
August	4.85
September	5.34
October	5.70
November	5.85
December	5.56
Annual	**5.70**

4.2 Simulation Results



Our goal was to keep the Cost of Energy as low as possible (Less than 1).
In this project our COE= 0.494 which is very good because <<1, and the Net Present Cost NPC is $636,073,So the project is feasible.
The COE is simply the average cost per kWh of electricity.
NPC: Represent the life-cycle cost of the system
This single value includes all costs and revenues that occur within the project lifetime.

CONCLUSION AND PERSPECTIVES

The present work is to make a design study of a wind farm in the region of the extreme north of Cameroon on the site Dogba-Maroua. For this, a study of the site said energy potential was performed with the software Homer Pro.

The study of the deliverability of the site, the installation of wind turbines on the site and study the noise impact has been made with the Homer Pro software. This study allowed us to give the following conclusions:

- The annual average rate increased to 50 m height is 3.71 m / s. it is3, 89 m / s to 70 m high, 4.09 m / s to 100 m high, 4.28 m / s to 139 m high and 4.32 m / s to 150 m high.
- The directions where the winds are most dominant is recorded in sectors 30 ° NE, NE 60 °, 0 ° N and 330 ° NNW.

To refine this work, there should be a comprehensive environmental study showing clearly:

- The study of the visually impacted area (ZVI)
- The study of the impact on birds
- The study of SHADOW (duration flicker shadows)

It would also make a soil survey to facilitate the achievement of Foundations different wind turbines to be installed at the site, a study of injection to the existing network and make a detailed economic study.

Part 2: Somalia

Abstract

In this part of the study we will discuss how we designed a hybrid micro grid system for 50 homes in the off grid town of Taleex in Somalia. This system incorporates a combination of solar PV, wind turbine, battery and diesel generator. HOMER software is used to analyze and find out the optimum configuration among a set of systems for the electricity requirements of the towns essential electricity needs.

Taleex is located in the northen Region of Somalia and has a total population of 25,354 residents. [1] The monthly average daily solar global radiation for Taleex ranges from 5.5 to 7.03 kWh/m2/day and monthly average wind speed varies from 4.2 to 8.2 m/s. The cost of generating energy from the above hybrid system was (COE, 0.477US$/kWh). But for the diesel-only option in the existing arrangement, levelized cost of energy for Taleex $0.564/kWh and if diesel remains at $1.0/liter. The costs of energy (COEs) of hybrid system would be lower than the COE of a diesel-only system. Though the optimum system configuration changes under different diesel price assumptions, the hybrid system remains most economically feasible solution than the existing arrangements (diesel-only).

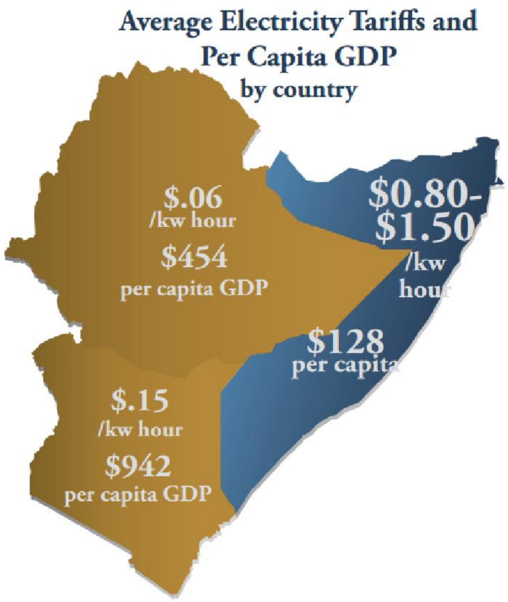
Chap1: Introduction

The majority of people living in rural and peri-urban areas have no access to electricity. Those with access in urban areas are paying some of the highest tariffs in the world for limited and sometimes unreliable services. The burden of such high costs is borne by businesses, which must curtail their productivity due to electricity costs and in some cases consider moving operations to other countries with more affordable electricity services. The strain of limited and expensive electricity is also felt by households, health facilities, and schools. A major casualty of the problem is continued deforestation as people continue to use charcoal from Somalia forests for cooking needs. Somalia is particularly well endowed in wind and solar energy resources: the country has the highest potential of any African country for onshore wind power and one of the highest rates of daily total solar radiation in the world.

1.1: current Energy status

Somalia suffers from three major problems related to broad-based electrification: lack of access, extremely high costs, and low reliability. Only a small minority of households and businesses in the country have access to electricity. Reliable statistical information about the energy situation throughout Somalia is unavailable as very few surveys have been conducted in the country in the last few years. While the World Bank estimates that 29.1 percent of the population of Somalia has access to electricity, the more recent evaluation from the 2014 African Energy Outlook estimates that less than a quarter of the population has the privilege of electricity. [2]

These estimates obscure a major rural-urban divide. Electricity in rural areas is nearly nonexistent. In urban areas, it varies significantly across the country. Recent estimates for Mogadishu and Hargeisa are 60 percent and 68 percent of the population, respectively, while smaller cities, like Merka, have only 23 percent connected to electrical services. In areas with higher numbers of internally displaced people who are harder to track, the estimates of the proportion with access to electricity are probably overstated. While these percentages, particularly in Mogadishu and Hargeisa (major cities), are actually higher than comparable cities in sub-Saharan Africa, the electricity to which businesses and households have "access" is problematic. The primary issue is that electricity tariffs are among the highest in the world, varying from $0.80 to $1.50 per kilowatt hour. [3]



Comparatively, the neighboring countries of Kenya and Ethiopia enjoy average rates of $0.15 and $0.06, respectively. [4] Not only are Somalis paying substantially higher tariffs for electricity, but they are also earning substantially less. The GDP per capita estimate for Somalia is $128, a fraction of the GDP per capita of $454 in Ethiopia and $942 in Kenya. [5] Somali citizens live in one of the poorest countries in the world and pay one of the highest tariffs for electricity of any country.

The variation in electricity tariffs within Somalia is explained by location and differential pricing by energy providers. People in locations that are far from urban centers typically pay the most in energy costs. [6] Within cities, tariffs fluctuate across different providers and providers do not necessarily use a uniform rate among their own customers. The lack of transparency and predictability creates problems for users as well as suppliers who compete in the sector. The other issue with electrical supply is its extreme unreliability. Shortages and outages plague the networks due to the limitations of the existing infrastructure.

Solutions for electricity transmission and distribution have been improvised without regulation or standards, often without professional technical training. These ad hoc systems lead to inefficiencies, which contribute to substantial losses—as high as 40 percent—during energy production and delivery to end-users. [7]

The problems of pricing, unreliability, and limited access explain why the consumption of electricity in Somalia is among the lowest in the world. The estimate of net consumption of electricity from 2012 was 288.3 million kilowatt hours, placing Somalia in the bottom quintile in the world [8]. Considering consumption per capita paints a direr picture. Somalia's 28.7 kW hour use per capita is a mere 1 percent of the world average (2,798 kWh), half that of Ethiopia's usage (57 kWh) and only 19 percent of Kenya's usage (153 kWh). [9]

1.2: The Weight of Energy Deficiencies in Somalia

The energy deficit burden in Somalia that stems from high cost and limited access weighs heavily on the economy, the environment, and the provision of basic services. While electricity has the potential to transform Somalia, without prompt and substantial change or investment in the sector, it will continue to be a constraining factor for further development and impede opportunities for growth.

1.2.1 Constraints to the Economy

The high cost of and limited access to electricity have serious economic implications. Across developing countries, the penalty of electrical outages and unreliable service on productivity leads to a substantial aggregate effect on economies [10].
The unreliable electrical supply in Africa can cost an average of 1 to 2 percent of GDP per year, as businesses are forced to shut down operations when the power goes out. [11] As with many fragile and conflict-affected states, in Somalia, electricity is provided by private entrepreneurs who use diesel-powered generation systems that are commonly used or refurbished—a reflection of what is available rather than technically optimal. Ultimately, dependence on such diesel-run systems increases the economic toll of unreliable services to as much as 4 percent of GDP.[12]

The tariffs that Somali businesses pay are among the highest in the world, which makes the high costs of electricity in Somalia perhaps more serious than problems stemming from reliability. This fact impedes the development of new businesses and threatens the thriving business development that has already occurred. The high cost of electricity devours Somali business margins at such a high rate that to remain competitive, production costs must be offset in disproportionately lower raw material or labor costs. Imports are produced more cheaply simply because overhead costs are lower abroad.

1.2.2 Damage to the Environment

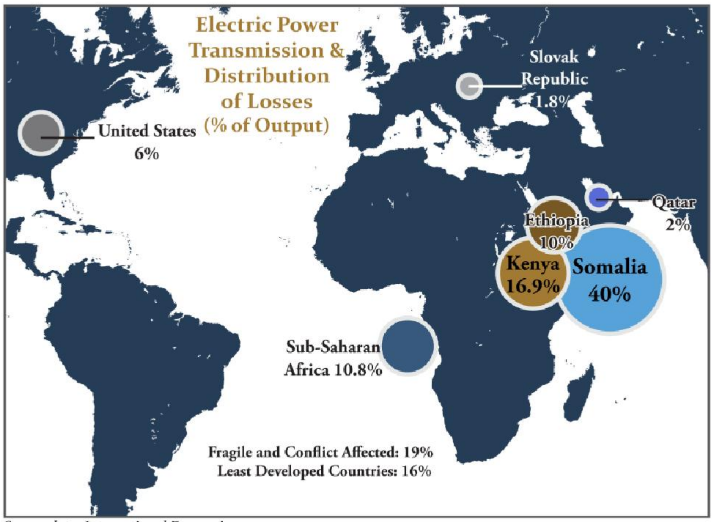
Without affordable or reliable access to electricity, Somalis continue to rely on biomass for basic needs, which has serious environmental ramifications for the country. Biomass, the primary source of cooking fuel even for those with access to electricity, accounts for 96 percent of energy sources in the country. [23]
Biomass comprises an array of organic fuels including wood, charcoal, and agricultural and animal waste. In Somalia, charcoal remains the primary fuel as electricity or alternative fuels remain uncompetitive, which has led to compounding environmental, economic, and public health problems.[24] An estimated 2 million bags of charcoal are consumed in Somalia each year, contributing to the devastation of local forests.[25] Overexploitation from domestic charcoal use

and illegal exports has reduced forest cover in Somalia from an estimated 60 percent in 1985 to 10 percent in 2001, a stunning reduction that continues at an increasing rate.[26] This deforestation is causing desertification, a process that cuts deeply into the economic prospects for agriculture and ranching industries in the country and is already related to the occurrence of recent famines.[27] At the same time, costs for charcoal have more than quadrupled since 2007, cutting into the incomes of Somalis, sometimes eating up more than half of households' monthly income.[28] Moreover, the use of charcoal poses significant health risks for families as it is related to child pneumonia, pulmonary disease, and lung cancer.[29] The World Health Organization estimates that indoor pollution–related deaths in Somalia exceed 11,000 per year.[30]

1.3: The Landscape of Electricity Provision in Somalia

The energy sector in Somalia has many features common to countries in or emerging from conflict. The most common supply of electricity in such contexts is a decentralized, private supply of energy using relatively small generators. [31]As in Somalia, small, private energy providers have thrived in Lebanon, Cambodia, and Sri Lanka. Larger energy utilities that are the norm in more stable countries are vulnerable in conflicts for two reasons. First, large generators and unified grids are usually public and suffer during conflicts from the diversion of public funds to military spending. Second, consolidated energy markets usually have fewer generators that are located farther from consumers. These are easy targets for groups engaged in the fighting, which can make the entire electrical system vulnerable to disruption. In the absence of government-provided electricity services, several small independent power providers (IPPs) stepped in to address the dearth of electricity by creating small power generation companies. Many of these IPPs entered the sector because they needed access to electricity to run their own businesses, such as telecom companies. [32]

Once generators were installed, they began to provide electricity as a business for surrounding households. The ad hoc nature of private energy services has led to a highly fragmented, nearly fully private electricity sector throughout the country. The sector is essentially unregulated by government, which has to this point lacked the technical capacity and resources to regulate energy service providers. Moreover, sufficient energy laws and electricity service provision regulations are lacking.



Source data: International Energy Agency

The size of IPPs varies, with some having grown to the scale of medium-sized utilities generating 5 megawatts, while others generate small amounts of electricity and service a limited set of households or businesses. Interconnection between IPP networks is rare. Instead, in many cities of Somalia, multiple distribution lines for various providers hang from electrical poles throughout the city. Because there is no standard or regulation by government, these transmission lines are often unsafe and have electrocuted energy company personnel and bystanders. [33]

Chap 2: Case study "Taleex Town"

Taleex is a town located in northern region of Somalia (9.1491° N, 48.4200° E) with population of 25,354 residents. The people of Taleex live a nomadic life style and relay completely on livestock such as camels and sheep. Only few diesel generators are available to power the privileged and the rest meet their energy demand through charcoal and other biomass. Famines are known to that part of Somalia due to the complete reliance on the seasonal raining season. Taleex have been chosen for this case study as a humanitarian preventive plan for the crisis that might occur in case of another droughts as it have been registered.

Taleex has a substantially good potential for the implementation of solar PV The monthly average daily solar global radiation ranges from 5.5 to 7.03 kWh/m2/day and monthly average wind speed varies from 4.2 to 8.2 m/s. Homer software has been used to find out the best energy efficient renewable based hybrid system options to power a unit of 50 homes and supply water via a water pump.

Input information to be provided to HOMER includes: electrical load (primary energy demand), renewable resources (solar radiation, wind speed data), component technical details, cost, constraints, controls etc. The software designs an optimal configuration to serve the desired electric loads. To design the optimum system HOMER performs thousands of hourly simulations. HOMER also performs sensitivity analysis tosee the impact of solar insolation, PV investment cost, wind speed and diesel fuel price on the COE.[34]

Homer can't Module transient changes which are smaller than 1 hour. Economic analysis is very important before installing the system to generate power. HOMER makes this economic analysis and ranks the systems according to their net present cost.

2.1 Load

In this study, a unit of 50 households and a water pump has been considered. This load isbased on 3 energy efficient lamps (compact fluorescent bulb, 15 W each), 1 fan (ceiling fan, 40 W), and 1 television (TV, 40 W) for each family and 2 energy efficient lamps (15 W each), 1 fan (40 W) and a ¾ HP water pump (850 watt).

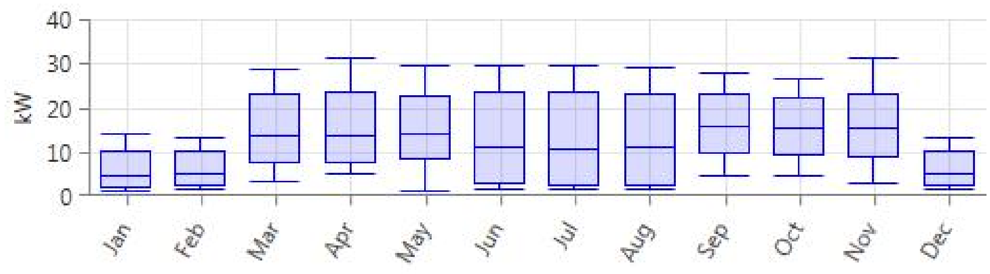


Figure.1 shows the yearly load profile in Taleex.

2.2 Solar Energy

As hourly data is not available therefore monthly averaged global radiation data has been taken from NASA (National Aeronautics and Space Administration). [35] HOMER introduces

Fig 2. Annual Solar radiation

clearness index from the latitude and longitude information of the selected site. HOMER creates the synthesized 8760 hourly values for a year using the Graham algorithm. Figure 2 illustrates that the solar radiation is high between February to April.

2.3 Wind Energy

When hourly data is not available, hourly data can be generated synthetically from the monthly averages. HOMER's synthetic wind speed data generator is a little more different to use than the solar data because it requires four parameters [36].
The Weibull value: k value is a measure of distribution of wind speed over the year. In this study the value of k is taken as 2. The autocorrelation factor: This factor measures the randomnessof the wind. Higher values indicate that the wind speed in 1 h tends to depend strongly on the wind speed in the previous hour. Lower values mean that the wind speed tends to fluctuate in a more random fashion from hour to hour. The autocorrelation factor value is taken as 0.78. The diurnal pattern strength: It is the measure of how strongly the wind speed depends on the time of the day. In this study, 0.30 is used. The hour of peak wind speed: It is simply the time of day tends to be windiest on a average throughout the year. In this study, 14 is used as the hour of peak wind speed [37].

Fig. 3 Average wind speed

2.4 Emission analysis

Power generation with renewable energy sources reduces the emission of CO2, SO2, NOX to the atmosphere. A PVwind-diesel hybrid energy system emits 20,506 kg/yr of CO2and 50.6 kg/yr of CO while only diesel generator emits 34,206 kg/yr of CO2. Fig. 11 show the emissions of carbon dioxide for two different systems such as PV-diesel-battery and windPV-diesel-battery.

2.5 Results and discussion

In this software the optimized results are presented categorically for a particular set of sensitivity parameters likesolar radiation, wind speed,diesel price, maximum annual capacity shortage and renewable fraction. HOMER performs thousands of hourly simulations over and over in order to design the optimum hybrid system.

Simulations have been conducted considering different values for solar radiation, wind speed, minimum renewable fraction, and diesel price providing more flexibility in the experiment. The optimization results for specific wind speed 4.71m/s, solar irradiation 4.5486kWh/m.sq.

It is seen that a PV, wind turbine, diesel generator and battery hybrid system is economically more feasible with a minimum COE $0.477 KWh and a NPC $613,935

Conclusion

Data of most kinds are scarce for Somalia where even reliable GDP estimates have been difficult to ascertain. This study includes several statistical facts that we cite with as much diligence about their validity as possible given the lack of data about the country. All statistics cited should therefore be used cautiously.

Improving electricity access and affordability will help the country address poverty through increasing household incomes. Although it is difficult to know the size of the effect of electricity on development, a growing number of studies in developing countries uphold the axiom that electricity increases household incomes. For example, a 2002 World Bank study in the Philippines calculated that electricity access increased household income by $81–$150 per month dependent on the number of household wage earners and the level of economic activity in the home.[19] Similarly, a 2009 study in Bangladesh found that electricity access caused a 12.2 percent increase in household income.[20] In 2005, the UNDP (United Nations Development Programme) found that across villages in Mali electrification led to a $0.32 increase in daily income and raised the annual average income of women by $68.20The improvement in household income in turn affects poverty, as has been shown in Tanzania where electricity access reduced household poverty between 4 and 13%.[22]

As the results shown of the case study of Taleex town the feasible implementation of a hybrid system, we can duplicate the concept to the rural regions which represent the majority of the Somali landscape and avoid other humanitarian crises also it would refresh the overall economy.

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