Sudan University of Science and Technology

College of Graduate Studies

Evaluation of potentials for renewable energy in the power system in Sudan

تقييم إمكانيات الطاقة المتجددة للنظام الكهربائي في السودان

Thesis submitted for partial fulfillment required for MS.c. Degree in Engineering

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May 2018

Dedication

This thesis is dedicated to my father,who taught me that the best kind of knowledge to have is that which is learned for its own sake.it is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at atime.to my wife, who give me

the greatest support in my study and life.

Acknowledgement

I would like to express my gratitude to Allah for enabling the guidance to complete this work. I wish to express my gratitude to all those who assisted me in the course of preparing this work. To Sudan University of Science and Technology Faculty of engineering staff those who increased my knowledge to let this work appeared.

I would also like to extend my gratitude to Super visor **Dr. Abuelnuor Abdeen Ali** , for his intellectual insights, were very helpful in the development of this work.

Finally ,I must express my very profound gratitude to my parents and my partner for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. this accomplishment would not have been possible without them. Thank you.

Author

Adil Abdallah Mohammed

Abstract

Recently, one of the major and serious worldly concerns is the limitation of energy resources. Sudan, in specific, confronts a critical crises relating to fossil fuel resources, and mostly concerning the production of electricity energy from fired thermal power plants and hydropower. The primary energy supplies in the Sudan are 29% oil and gas, 71% hydropower. In this study, the potentials for renewable energy to generate electricity in the Sudan is analyzes. The results show that, they are many sours of renewable energy in Sudan. The solar energy and wind energy are generating electricity ا around 4.4% and 5.34% respectively.

Resulted values of renewable energy potentials are vastly spread all over the country with solar energy potential being the highest. Available lands for solar and wind energy production constitutes 4.4% and 5.34% of the total area of the country.

المستخلص

في الآونة الأخيرة أحد أكبر و أهم الإهتمامات العالمية هي محدودية موارد الطاقة. يواجه السودان علي وجه الخصوص تحديات وأزمات كبيرة تتعلق بالوقود الاحفوري . وتتعلق في الغالب بإنتاج الطاقة الكهربائية من محطات الطاقة الحرارية والطاقة الكهرمائية. إن إمدادات الطاقة الرئيسية في السودان تبلغ 29% من النفط والغاز و 71% من الطاقة الكهرومائية. في هذه الدراسة ، تم تحليل إمكانيات الطاقة المتجددة لتوليد الطاقةالكهربائية.

أظهرت النتائج أن هنالك عدد من مصادرالطاقة المتجددة في السودان، الطاقة الشمسية و طاقة الرياح تولد الكهرباء حوالي 4.4% و 5.34% علي التوالي.

إن القيم الناتجة من إمكانات الطاقة المتجددة تنتشر بشكل واسع في جميع أنحاء البلاد حيث تكون الطاقة الشمسية هي الأعلى . تمثل الأراضي المتاحة لإنتاج الطاقة الشمسية و طاقة الرياح 4.4% و 5.34% من إجمالي مساحة البلاد.

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LIST OF ABBREVIATIONS

CSP ……Concentrated solar power

DEM……Digital Elevation Model

GADM…….Database of Global Administrative Areas

DLR…….German Aerospace Center

GDP……Gross Domestic Product

IEA……... International Energy Agency

IRENA…….. International Renewable Energy Agency

PV……. Photovoltaic solar panel

GHI……global horizontal irradiance

DNI……direct normal irradiance

SWERA…….Solar and Wind Energy Resource Assessment

NREL……. National Renewable Energy Laboratory

MSW…….. municipal solid waste

GHG…….. greenhouse gas

RE……..Renewable energy

Chapter One

Introduction

CHAPTER ONE

INTRODUCTION

1.1 Background

Today's energy mix is being driven by two primary factors, one the rising cost and diminishing reserves of fossil fuels, and growing concerns about the damage carbon emissions are causing to the environment [1]. These factors have motivated interest in renewable energy. Most of the energy from renewable energy is hydroelectric and biomass, although the contributions from solar and wind energy sources are growing. The production of electrical power from renewable energy sources does not emit as much pollution as power production from fossil fuels[2]. As for cost, most renewable energy will become less expensive over time as the infrastructure for harvesting and delivering energy matures. The most likely sources of renewable energy that are expected to contribute to the future energy mix are solar energy, wind energy, energy from water, and biofuels. Many of these are significant contributors to the global energy Supply today. For parts of the developing countries there is an additional and important motivation for the implementation of RE technologies , Renewable energy sources will play a crucial role in meeting increasing electricity demands by a rapidly growing urban population, as well as in providing sustainable energy access to rural areas. The recent launch of the United Nation's "Sustainable Energy for All" initiative reflects the substantial interest by the international community in this sector [1,3].Renewable energy in Sudan has a high potential due to the availability of solar, wind, hydro, and biomass resources. This high potential would lead to more sustainable development after integration of

Sudanese energy demand in the agricultural sector with the energy supply based on these clean technologies. Solar radiation intensity in Sudan is high and small scale thermal and photovoltaic applications were developed with limited studies conducted on the feasibility of the systems [14].

1.2 Problem statement

The problem of Sudan nowadays is the lack of energy and the reason for this is the rely heavily on fossil fuels, which has economic problems and environmental impacts. The economic problems are high cost of purchasing and decrease in the amount of fossil fuels. The environmental impacts are increase the greenhouse gas emission. I conducted a research title evaluation of potentials for renewable energy in the power system in Sudan to analyzes the effects of fossil fuel and the decrease in electrical power by using renewable energy resources. I will cover the renewable energy has great advantages compared to fossil fuels in Sudan.

1.3 Research Objectives

This research is focused on the following objectives:

1. To improve competitive financial power of renewable energy resources.
2. To maintain the growth of the renewable energy resources simultaneously.
3. To ease the administrative processes to integrate the renewable energy resources into national grid.
4. To remove the technical barriers in front of the electrical grid connections.
5. To investigate of renewable energy resources non spent.

1.4 Scope of Research

The scopes of this research in investigating the power flow within integration of renewable energy which had been decided as it is used to mean power that comes from sources that replenish themselves from the activity of the sun directly. renewable energy resource exploration evaluation, potential and related information system.

1.5 Scientific Study

In this research evaluation of potentials for renewable energy in the power system in Sudan to analyzes the effects of fossil fuel and has been to help the government in selecting priorities in development of energy sector as well as a datum for a venture in renewable energy fields. We argue that an increasing share of fossil fuel rents lessens the innovation of new energy technologies.

These characteristics resemble many renewable energy technologies such as solar or wind power. Due to their low capacity factors, large amounts of capacity are needed to generate sufficient amounts of electricity and this puts them at a clear cost.

Chapter Two

Literature Review

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The main purpose of this chapter is to describe the background of energy resource throughout the world and the development of current power grid system. The further studies in this chapter will go through to the definition of energy resource and review on some basis ideas by some researchers who are interested in this technology. The existing electrical power grid system is facing massive challenges in changing from centralized power generation into the decentralized generation. To point these issues, this chapter provides a fundamental understanding of energy resources or integration renewable energy and the impact smart grid technology to the power flow.

2.2 Energy Sources

Energy is the ability to do work. It can be classified as stored (potential) energy, and working (kinetic) energy. Potential energy is the ability to produce motion, and kinetic energy is the energy of motion. Sources of energy with some common examples include biomass (firewood), fossil fuels (coal, oil, natural gas), flowing water (hydroelectric dams), nuclear materials (uranium), sunlight, and geothermal heat (geysers). Energy sources may be classified as renewable or nonrenewable [1]. Energy is essential to economic and social development and improved quality of life in all countries. The energies that peoples have used today mostly are not sustainable if the technologies remain constant while the consumers will remain increase substantially, this world actually has consumed many kinds of energies for human benefits and some of them take over million years to form. In order to meet carbon reduction targets, it is

important to think a way in getting new energies with more sustainable and renewable. The traditional of used fossil-fuel such as coal, gas and oil for electric vehicles and machinery in industries must be replaced by the green sources which more sustainable[1,14].

2.2.1 Conventional energy

Conventional energy sources, such as coal, natural gas, petroleum, and hydropower, have been the primary sources of energy generation. Fossil fuels are the dominant energy source in the modern global economy. they include coal, oil, and natural gas .Coal is a combustible rock that is composed primarily of carbon-rich organic (carbonaceous) material [1].

2.2.1.1 Coal

Coals are classified by rank. Rank is a measure of the degree of coalification or maturation of carbonaceous material. The lowest rank coal is lignite, followed in order by sub-bituminous coal, bituminous coal, anthracite and graphite. The moisture content of lignite is high compared to the moisture content of anthracite. High moisture content is associated with low heating value, while low moisture content is associated with high heating value.

Coal rank is correlated to the maturity, or age, of the coal. As a coal matures, the ratio of hydrogen to carbon atoms and the ratio of oxygen to carbon atoms decrease. The composition of the highest rank coal, graphite, approaches 100% carbon. Coal becomes darker and denser with increasing rank [1].

2.2.1.2 Gas

Environmental concerns are motivating a change from fossil fuels to an energy supply that is clean. Clean energy refers to energy that has little or no detrimental impact on the environment. Natural gas is a source of relatively clean energy that can be obtained from such sources as

conventional oil and gas fields, unconventional gas resources, landfill gas, and municipal solid waste gas (MSW gas). Unconventional gas resources include gas hydrates, tight gas sands, coal gas, and shale gas . Gas hydrates, tight gas sands and shale gas are discussed below. Gas from landfills and municipal solid waste (MSW) gas are obtained from the decay of organic waste [1]. Landfill gas and MSW gas are not fossil fuels; they are renewable energy sources.

2.2.1.3 OIL

Crude oil is "a mixture of hydrocarbons that exists in liquid phase in natural underground reservoirs and remains liquid at atmospheric pressure" after passing through facilities on the surface that separate gas and liquid [US EIA Glossary, 2012]. The SPE defines petroleum in terms of liquids and gases, while EIA defines petroleum in terms of liquids and keeps gas separate. It is important to recognize context to understand the meaning of the term petroleum [1].

2.2.2 Nuclear energy

Nuclear energy can be provided when large nuclei split into smaller fragments in the nuclear fission process. Energy can also be provided by combining, or fusing, two small nuclei into a single larger nucleus in the nuclear fusion process. Nuclear fusion reactions are the source of energy supplied by the sun. Energy from nuclear fission generates heat, which is typically used to generate electric power. Energy consumed by the United States included over 8% nuclear fission energy in 2010 and world energy consumption was approximately 5% nuclear fission energy in 2010. Nuclear materials also have a finite supply [1].Uranium, used to generate nuclear electricity, is non-renewable as it is a finite element in nature. A recent policy brief by the Nuclear Energy Institute states that "uranium resources are adequate to meet nuclear energy needs for at least the next

100 years at present consumption levels" (Nuclear Energy Institute 2009). This time frame does not represent a long-term solution however, and issues around nuclear energy are compounded by concerns around nuclear waste and the risk of nuclear weapons development.

2.2.3 Renewable and sustainable energy

Renewable energy is energy generated from natural resources such as sunlight, wind, rain , tides and geothermal heat which are renewable (naturally replenished). Renewable energy technologies range from solar power, wind power, hydro power, biomass and biofuels for transportation[9].

2.2.3.1 Wind

Kinetic energy present in wind motion that can be converted to mechanical energy for driving pumps, mills, and electric power Generators. The wind is a free, clean, and inexhaustible energy source. It has served mankind well for many centuries by propelling ships and driving wind turbines to grind grain and pump water. Interest in wind power lagged, however, when cheap and plentiful petroleum products became available after World War. The high capital costs and the uncertainty of the wind placed wind power at an economic disadvantage[8].

2.2.3.2 Hydropower

Hydroelectricity is an example of an energy conversion technology that is not based on heat generated by fossil or nuclear fuels. The potential energy of rain falling in mountainous areas or elevated plateaus is converted into electrical energy via a water turbine. With tidal pools the potential energy stored in the tides can also be converted to mechanical energy and subsequently electricity .The kinetic energy of wind can be converted into mechanical energy using wind mills.[7]

2.2.3.3 Biomass

Organic non-fossil material of biological origin, over the many thousands of years of human history, until the industrial revolution when fossil fuels began to be used, the direct use of biomass was the main source of energy. Wood, straw, and animal waste were used for space heating and cooking. Candle (made of whale fat) and vegetable oil were used for light. The mechanical power of the horse was energized by feeding biomass. In less developed countries of the world, this situation remains the norm. Even in well-developed countries, direct use of biomass is still very common: for example, firewood for fireplaces and wood-burning stoves [30].

2.2.3.4 Solar

Solar energy is provided by the sun as the result of nuclear fusion reactions. The nuclear fusion process in the sun consumes isotopes of hydrogen to form helium and release energy. Eventually, the fuel for the nuclear fusion process will be exhausted. Since the remaining lifetime of the sun is expected to be a few billion years, many people consider solar energy an inexhaustible supply of energy [1]. In fact, solar energy from the sun is finite, but should be available for use by many generations of people. Solar energy is therefore considered renewable. Energy sources that are associated with solar energy, such as wind and biomass, are also considered renewable [2].

2.2.3.5 Geothermal Energy

The heat that is extracted from hot water or steam that is mined from geothermal reservoirs in the Earth’s crust. Water or steam can be used as a working fluid for geothermal heat pumps, water heating, or electricity generation, and then is injected back into the Earth.[32]

2.3 Solar energy

2.3.1 Solar photovoltaic (PV)

PV cells convert incident light directly into electricity (direct current). An electronic device consisting of layers of semiconductor materials fabricated to form a junction (adjacent layers of materials with different electronic characteristics) and electrical contacts. Solar energy, including solar photovoltaic (PV), has a vast sustainable energy potential in comparison to global energy demand .solar electricity contributes about 20% of the world's energy supply by 2050 and over 60% by 2100 [2]. This suggests PV could play an important role in the transition to a sustainable energy economy. However, the further development of PV science and technology is essential for PV to become a major source of electricity and energy.

Figure (2.1): photovoltaic (PV) solar cells with single-axis tracking [5].

2.3.2 Concentrating Solar Power (CSP)

a solar energy conversion system characterized by the optical concentration of solar rays through an arrangement of mirrors to heat working fluid to a high temperature. Concentrating solar power (but not solar thermal power) may also refer to a system that focuses solar rays on a photovoltaic cell to increase conversion efficiency [2]. The CSP technology is especially interesting for desert regions, where almost all the solar radiation is incident as direct radiation.one problem of CSP systems is that the efficiency of the collector diminishes as its operating temperature rises, while the efficiency of the engine increases with temperature.[7]

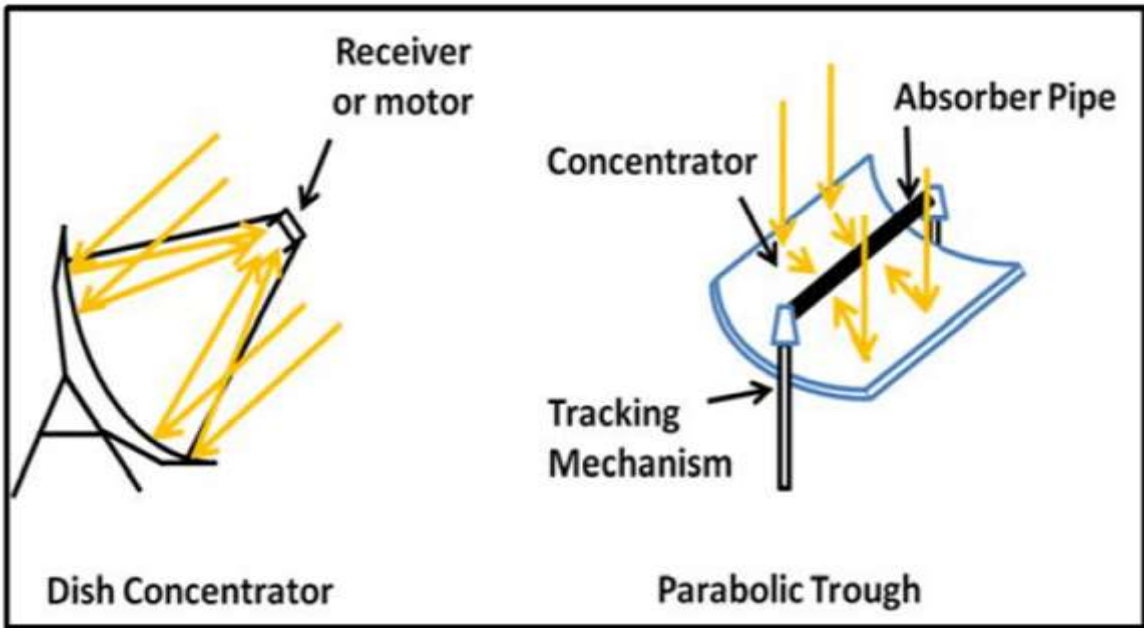

Figure (2.2): Concentrating Solar Power Systems [1].

2.3.3 Solar Thermal Collector

A device designed to receive solar radiation and convert it to thermal energy. Normally, a solar thermal collector includes a frame, glazing, and an absorber, together with appropriate insulation. The heat collected by the solar collector may be used immediately or stored for later use. Solar collectors are used for space heating; domestic hot water heating; and heating swimming pools, hot tubs, or spas [2].

Figure (2.3): Solar collector assembly of a trough system [5].

2.4 Wind energy

Wind energy is derived fundamentally from solar energy via a thermodynamic process. Sunlight warms the ground causing air above it to rise. The ensuing pressure differential causes air from elsewhere to move in, resulting in air motion (wind). Different regions on earth are heated differently than others primarily a function of latitude. Air motion is also affected by the earth's rotation. The net effect is that certain parts of the world experience higher average winds than others. The regions of highest winds are the most attractive for extracting its energy: Theoretically, the power which can be extracted from the wind is proportional to the cube of the velocity, so a good wind regime is particularly important. The power that can be extracted in practice, however, is somewhat less than proportionally related to the cube of velocity [2].

The kinetic energy in a volume of air with mass m and velocity v is

$$\text{Kinetic energy} = 0.5mv^2. \quad (2.1)$$

$$m = \rho vA. \quad (2.2)$$

If the

m: mass of air(kg).

ρ: density of air (kg/m^3).

A: surface of area(m^2).

v: velocity of wind(m/sec).

P_o: wind power(W/m^2).

the mass of air passing through a surface of area A perpendicular to the velocity of wind per unit time is

$$P_o = \rho vA \times \tfrac{1}{2}v^2 = \tfrac{1}{2}\rho v3A. \quad (2.3)$$

The wind power P_o, or the kinetic energy of air moving through an area A per unit time.

Under standard conditions (1 atm pressure and 18ºC), the density of air is 1.225 kg/m³.

If the wind speed is 10 m/s, the wind power density is

$$P_o \approx 610 \text{ W/m}^2. \quad (2.4)$$

It is of the same order of magnitude as the solar power density.

However, the efficiency of a wind turbine is not as high as that of hydropower [5].

Figure (2.4): Typical Wind Turbine.

2.5 Hydro-power

Hydroelectric power or hydro-power is the most widely used renewable energy source in the world, 20% of electricity is produced by hydro-power. Hydroelectric power is a well-established technology. Since the late nineteenth century, it has been producing substantial amounts of energy at competitive prices. Currently, it produces about one sixth of the world's electric output, which is over 90% of all renewable energy Hydro-power has the highest electricity converted efficiency nearly 80% compare with the second highest bio-energy 35% (the same as the fossil fuel) [4].during construction of the hydro-power station it will release large amount of CO2 and other greenhouse gases, the dam and reservoir has large influence to the local environment and ecology. the physics of hydropower is straightforward. [5]. the power carried by the water mass is given as

$$P = \rho g Q H. \quad (2.5)$$

Where

g: is the gravitational acceleration(9.81m/sec^2).

P: power (kW).

ρ: density of water (kg/m^3).

Q: flow rate of water (m^3/sec^2).

H: head of water (m).

Water is the only non-conventional energy source that has been exploited by man on a large scale. The technology is well established and simple. The industrial infrastructure for the manufacture of water turbines, valves, gates, generators and associated electrical equipment are well established in many countries.

Based on the capacity, it could be a micro, mini, small and big power plant. Based on the head, it is called a low head (<15 m), medium head (15-50 m) or high head (>50 m). Based on the type of load it may be base

load or peak load. Based on the hydraulic features, it may be conventional, pumped storage or tidal type. Based on construction, it may be run of river, valley dam type, a diversion canal type or a high head diversion plant [33].

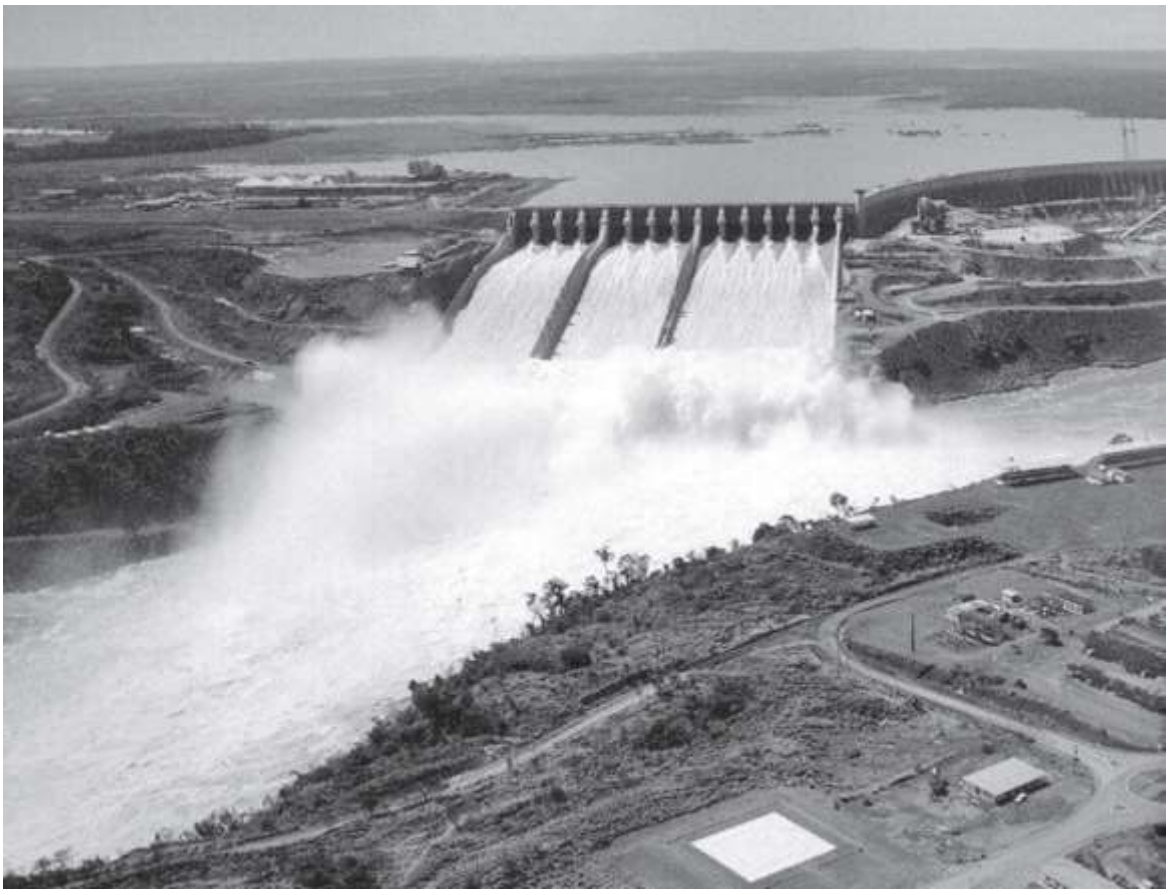

Figure (2.5): Percentage of electricity generation from hydropower in various countries [5].

2.6 Biomass and Bio-energy

Bio-energy is a very clean energy resource, though it will release CO2 during burning, but the amount is very little, and will be absorb during photosynthesis by plants. And the bio-energy can be used for CHP plant just like fossil fuels, and make the efficiency very high, for electricity is nearly 35% and the rest heat will be used for district heating .The only disadvantage of bio-energy is that the growth of plants is relatively slow,

if the human use more bio-energy than its growth the local economy would be destroyed, so use the bio-energy should have a long-term perspective [5]. Over the many thousands of years of human history, until the industrial revolution when fossil fuels began to be used, the direct use of biomass was the main source of energy. Wood, straw, and animal waste were used for space heating and cooking. for example, firewood for fireplaces and wood-burning stoves.

Biomass is created by photosynthesis from sunlight. Although the efficiency of photosynthesis is only about 5% and land coverage by leaves is only a few percent, the total energy currently stored in terrestrial biomass is estimated to be 25,000 EJ, roughly equal to the energy content of the known fossil fuel reserve of the world. Currently there is a well-established industry to generate liquid fuel using biomass for transportation. Two approaches are widely used: produce ethanol from sugar and produce biodiesel from vegetable oil or animal oil [4,5].

2.7 Geothermal energy

Geothermal energy is a renewable resource.one of its biggest advantages is that it is constantly available. The constant flow of heat From the Earth ensures an inexhaustible and essentially limitless supply of energy for billions of years to come. its power output can remain consistent nearly 24 hours a day, giving geothermal energy a higher capacity factor than solar or wind power, which must wait for the sun to shine or the wind to blow, respectively. This means a geothermal plant with a smaller capacity than a solar or wind plant can provide more actual, delivered electricity.[33]

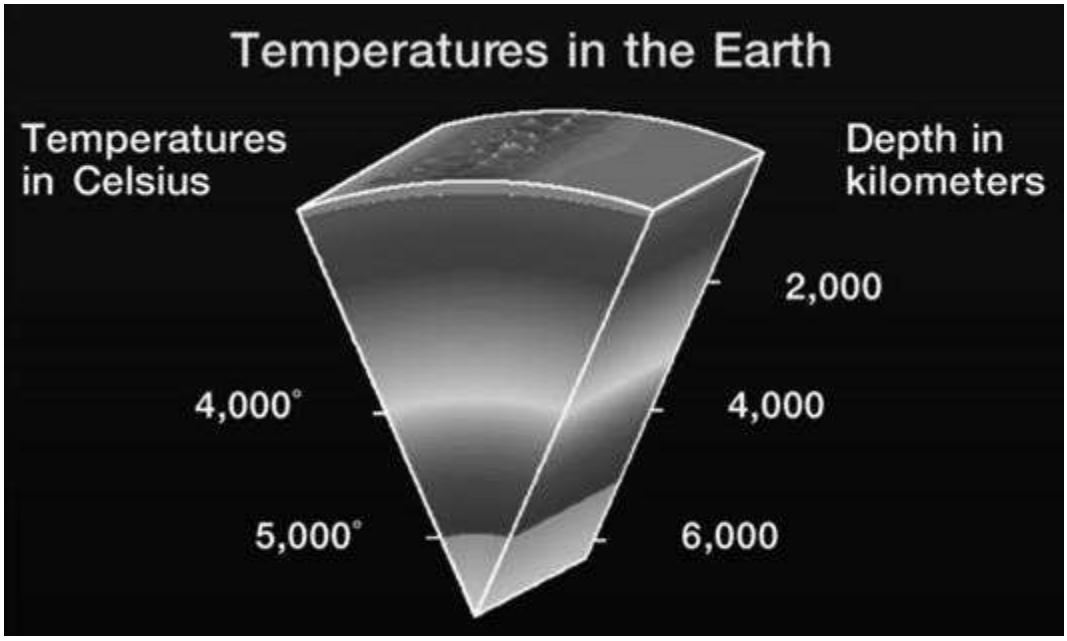

Figure (2.6): Temperatures in the Earth.

Show in Figure (2.6). Heat has been radiating from the center of the Earth for some 4.5 billion years. At 6437.4 km (4,000 miles) deep, the center of the Earth hovers around the same temperatures as the sun's surface, 9932°F (5,500°C) Scientists estimate that 42 million megawatts (MW) of power flow from the Earth's interior, primarily by conduction Geothermal energy is a renewable resource.[33]

2.8 Existing energy system in Sudan

Sudan is an agricultural country with vast arable land and abundant water resources. Water is allocated to Sudan from the Nile the longest river in the world, Sudan is the largest second country in the African continent with a tropical climate and an area of approximately 1.87 million km². it lies between latitudes 8.4ºN and 23ºN and longitudes 21º45E and 39ºE , geographic coordinate 15.85ºN, 30.25ºE .at an annual rate 18.5 billion m3, and the current actual water demand for the country was estimated at 87% of this total allocation . In 2016, agriculture had contributed by 48% to the GDP, and more than 80% of the total

population in Sudan depend mainly on this sector to generate their income. the total population according to 2015 census was 40 million inhabitants and population density is 16.4 persons per km².

Renewable energy in Sudan has a high potential due to the availability of solar, wind, hydro, and biomass resources. This high potential would lead to more sustainable development after integration of Sudanese energy demand in the agricultural sector with the energy supply based on these clean technologies. Solar radiation intensity in Sudan is high Solar irradiance 649 Wh/m² and small scale thermal and photovoltaic (PV) applications were developed with limited studies conducted on the feasibility of the systems. Concentrated solar power (CSP) plants use mirrors to concentrate the direct solar irradiation. This energy heats the air or fluids and then converts the steam to electricity, like in traditional steam engines. Sudan is rich in wind ,mean wind speeds of 4.5m/s are available over 50% of Sudan , It gives 680 MWh of electricity per year.[14]

Final Energy Consumption:

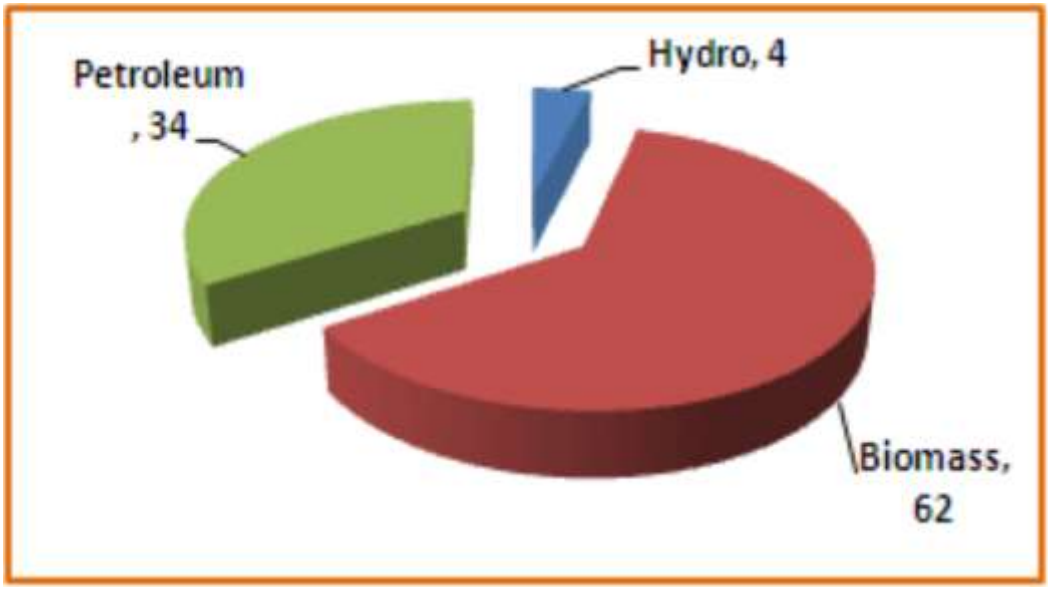

Figure (2.7): Energy Consumption in Sudan, biomass accounts for around 62% of total consumption of energy resource petroleum 34%, hydro 4%.

Chapter Three

Methodology

CHAPTER THREE

METHODOLOGY

3.0 Overview

As has been noted the top-down approach was used to evaluate technical potentials of solar, wind and biomass energy. Below is the list of steps conducted in this work:

1. An overview of Sudan's situation regarding renewable energy development.
2. Identification of physically available renewable energy resources in the Sudan.
3. Estimating technical potential energy with existing energy system.

3.1 Renewable energy in Sudan

Sudan is an important case study in the context of renewable energy Sudan's renewables portfolio is broad and diverse, due in part to the country's wide range of climates and landscapes [13]. Sudan energy sector is comprised of electricity, natural gas and petroleum .The primary energy supply mix of Sudan is made of 29% oil and gas, 71% hydropower. The concept and definition of energy security in recent years is more broadened as compared to the 1970s and 1980s concept. The broad definition of energy security contains four major elements physical availability of energy resources, accessibility to energy resources, economic element and acceptability [11].

3.2 Renewable Energy Sources in Sudan

Main renewable energy sources; solar, biomass, wind, and hydropower are briefly explained here.

3.3.1 Solar Energy in Sudan

Solar energy is one of the renewable energy resources with highest potential in Sudan. Being a natural source of energy, solar energy is the most popular one among other sources of renewable energy.

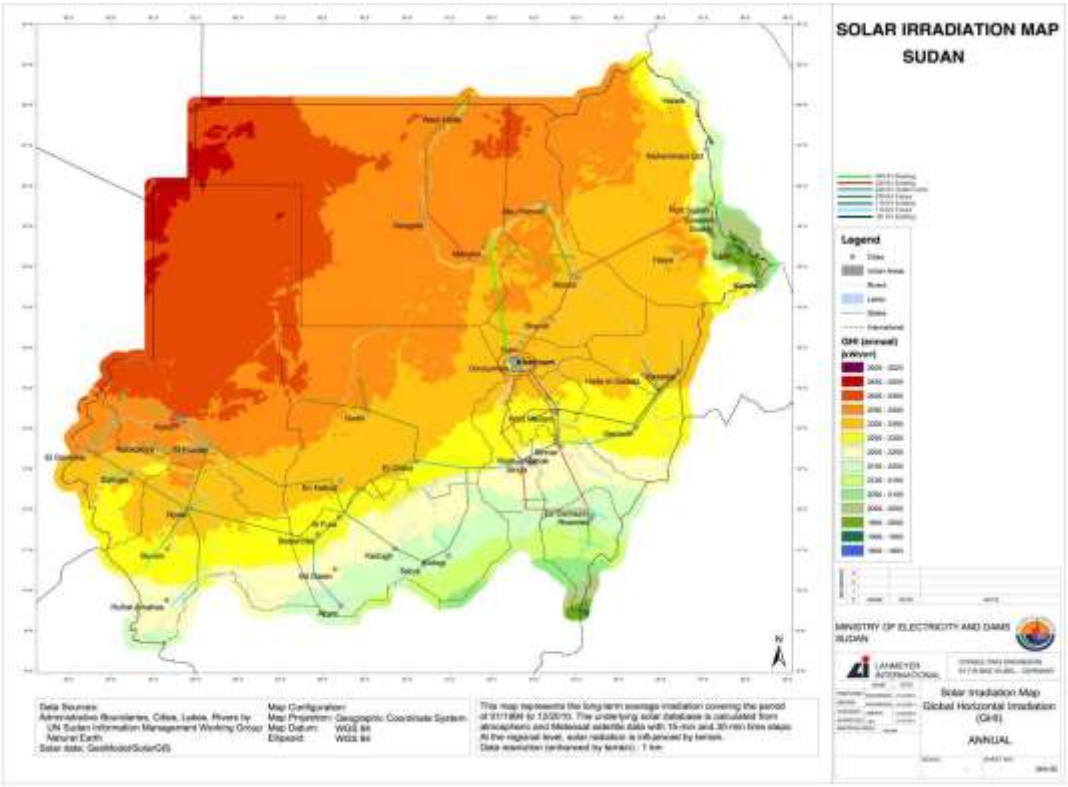

Figure (3.1): Solar map of Sudan (Solar GIS, 2013).

Having a high potential for solar energy due to its geographical position, Sudan 's average sunshine duration total is 9 hours in day and average global horizontal irradiation (GHI) 7.5 -5.8 total radiation kWh/m²-year.the popularly known technologies used to produce electrical energy from solar radiation are,photovoltaic (PV)and concentrated solar power (CSP) also called solar thermal energy[18].

the most common technologies Today for utilizing solar energy are photovoltaic , solar thermal collector and Concentrating Solar Power systems. the solar radiation measurements are very important in order to establish a complete solar map for Sudan. These data are not only useful

for the country under consideration but also for many other countries. This is expressed as the physically available solar radiation on the earth's surface, that is influenced by various factors [17].

3.3.2. Hydropower Energy in Sudan

The hydropower in Sudan represent the biggest share of about 70% despite the fact that the installed capacity about 54% of the total installed power capacity. hydropower has the advantages of low investment and short period of construction. Therefore, it is an effective way to rural electrification. In addition, agricultural production depend to water in small reservoirs and dams for hydropower and increase the protection against natural disasters.[13]. In 1962 it was a first Hydro power plant to generate electricity from Sinnar Dam with a capacity of 15 MW. Sudan has five hydro power plants with a total capacity of 1,593 MW, are as follows [14]:

- Sinnar Power plant: consists of two units with total capacity of 15 MW. (1962).
- Elgriba Power plant: consists of three pumps Turbine and two units with a total capacity of 17.8 MW. (1964).
- Roseires Power plant: consists of seven units with total capacity of 280 MW. (1971).
- Jabel Awlia Power plant: consists of 80 units with total capacity of the plant is 30.4 MW. (2005)
- Merowe Dam Power plant : its recent and bigger dams which erected in 2009, it is consists of (10) units with total capacity of 1250 MW. Merowe Dam power evacuated via transmission of high-voltage (500 kV) for the first time in Sudan.

Figure (3.2): Merowe Dam_ 1250MW [23].

Hydropower systems is the energy in the moving (falling) water by hydro turbines. The rotating mechanical energy is then converted to electricity in order to meet the market demand, safely, and efficiently. hydropower plants are configured in one of two ways.(river type) projects use the natural flow of a river by diverting it into canals that lead into a power plant. In the second configuration, water is stored in a reservoir (dam) and sent to the power generation turbines as needed.[22]

3.3.2.1 Hydro generation projects in Sudan

To use available hydro potential for the following projects [23].

Table (3.1) a potential of hydro projects in Sudan

No	Project name	Capacity(MW)
1	Up Atbara – Sitat	320
2	Kajbar	360
3	Elgash	312
4	Total	982

3.3.3. Wind Energy in Sudan

Wind is a form of renewable energy, which is always in a non- steady state due to the wide temporal and spatial variations of wind velocity.[24] Wind is a renewable energy, and free energy source that has few environmental impacts and generates non pollution. Wind technology is being used around the world as an excellent means of electricity generation for serving growing energy needs.[22] Wind is indirectly connected with solar energy, due to the fact that the energy from the sun drives the climate pattern and cyclical movement of water vapor and air.[18] A wind map of Sudan was prepared from average powers were determined for each station ,the derived annual average speeds range from 4.2 to 8.1 m/s at 80 m above ground level. Sudan is rich in wind, the mining air speeds to product wind turbine of 4.2m/s in Sudan.

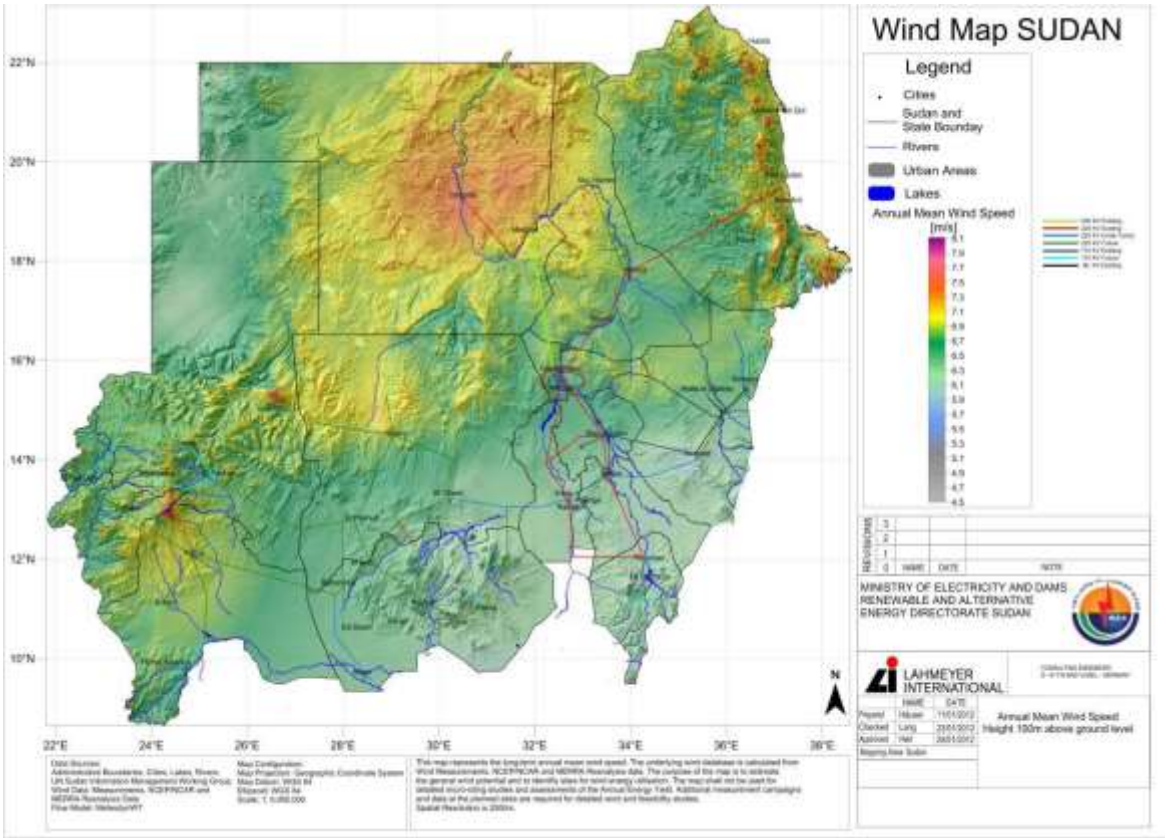

Figure (3.3): wind map Sudan.

Generation of electricity by wind energy in Sudan shown in figure (3.3) indicates that Sudan possesses favorable winds particularly in the northern part Sudan has published a wind atlas, are three areas have been identified with a potential to host wind projects:[25]

Table (2.2) a potential of wind projects in Sudan

No	Project name	Wind speed(m/s)	Capacity (MW)
1	Northern Sudan (Dongola)	7.2 at 60 m	100
2	Western Sudan (Jabel Marra)	7.9 at 60 m	20
3	Red Sea area	7.0	180
4	total		300

3.3.4. Biomass Energy in Sudan

Biomass resources have been big used as traditional fuels and are now being promoted as a strategy to achieve sustainable development. Biomass potentials are classified depending on their theoretical, techno-economical and sustainable availabilit.the theoretically biomass potential can be estimated on the basis of biophysical and agro-ecological factors that determined the biomass growth and extension and the residues production ratios.[10]theoretic potential was estimated without any restrictions concerning land availability, conservation areas, areas for food, and technical parameters of energy production technologies. The type of biomass used for energy in Sudan include:[21]

1. Firewood and charcoal.
2. Agriculture residue.
3. Bagasse.
4. Bioethanol.
5. Biodiesel.

3.3.4.1 Firewood and charcoal

Firewood the wood is extremely heavy (specific gravity 1.3),it makes excellent firewood and burns green or dry, with an intense heat to a thick soft-white or pale-gray ash that may be up to 90% calcium oxide. firewood and charcoal production obtained from the agriculture and forestry of Sudan.[21]

3.3.4.2 Agriculture Residue

The portion of agriculture residue used as fuel is very small as the majority is used as animal feed and building material and in pulp and paper industry, On the hand , the agriculture waste is mostly burned during land preparation for the next season, the agriculture waste included the cereals oil crops, and cotton [21]. Using appropriate crop-to-residue conversion ratios, the total residue production quantity can be obtained from the annual crop production statistics for a theoretical estimate of energy potential. The energy potential of each residue depends on the calorific value. These residues may be converted to energy by thermo-chemical or bio-chemical processes. Significant potential for energy crops in Sudan such as Sorghum, Millet, Wheat ,Groundnut, Sesame, Sun flower, Cotton palm oil fruit for liquid biofuel production are also present in the region[26].

3.3.4.3 Bagasse

Bagasse is estimated from the produced sugar, Currently Sudan own six sugar factories, five of them are governmental sector, and one is private sector. The total production of sugar in Sudan about 800,000 tons annually. They are six factories produced sugar in Sudan kennana, new halfa, Gunied, Sennar, Assalya, White Nile. Bagasse is that residuals of sugar cane containing juice crushed and squeezed, Thermal and electric

energy are produced for the own sugar factory production processes, only using sugar cane bagasse as fuel in cogeneration plants. Almost, bagasse specified as one of the important renewable energy source, environmental impact is very limited.[28]

3.3.4.4 Bioethanol

Bioethanol on the Sudan is produced from molasses, kenana sugar company is production all bioethanol, it should be remembered that all bioethanol is for export[21]. the Sudan's largest sugar producer launched an ethanol production plant based on 1st generation technology (molasses fermentation) with the capacity to produce commercial volumes of high-grade ethanol (65 million liters annually). While 90% of this ethanol is presently exported to EU. Preparations are underway to significantly expand production to 200 million liters annually by 2020. Sudan has the potential to use bioethanol it as a fuel for agricultural spray planes.[29]

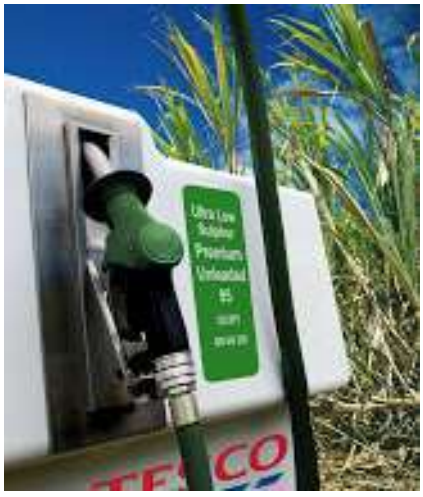

Figure (3.4): Ethanol production in Sudan, is based

Mainly on Sugar cane by-products.[22]

Ethanol Future development is according to the Sugar Sector Strategic Plan 2020, Ethanol production well increase from existing factories, kennana, Sudanese sugar corporation, White Nile and the new factories, from 50 ML to 200 ML in 2020 strategy in figure (3.4).

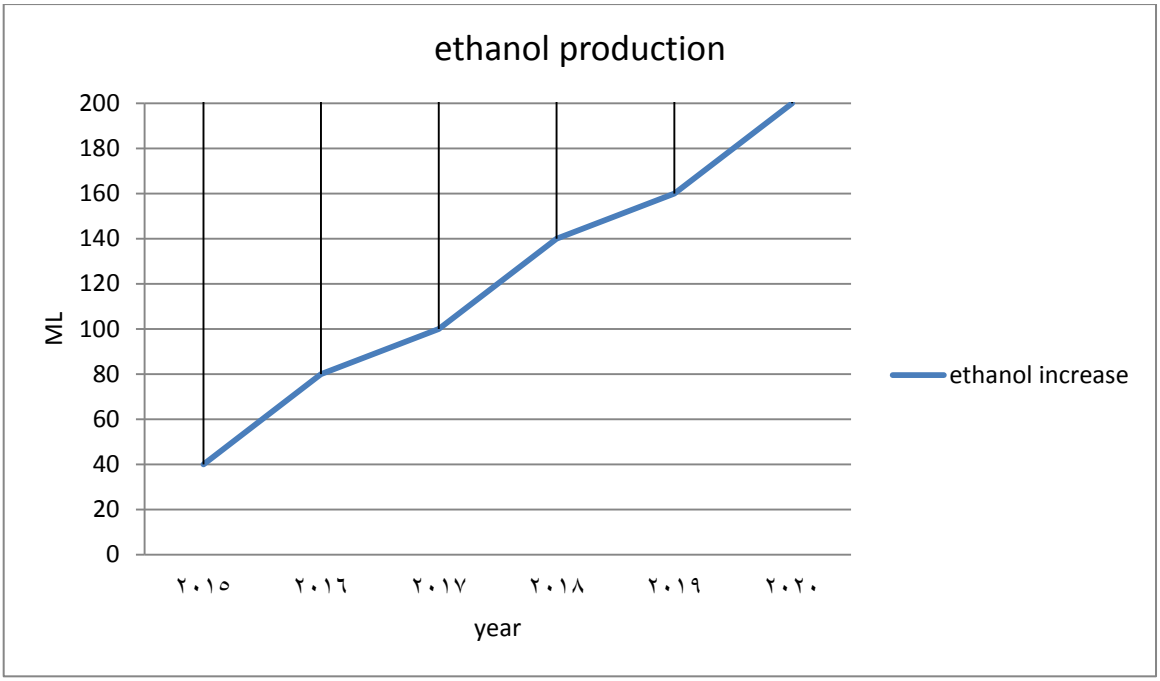

Figure (3.5): Ethanol production forecast in Sudan for 2015 to 2020[29].

3.3.4.5 Biodiesel

The animal fat or vegetable oils are the main sources for the production of bio-diesel Sudan lies in the tropical zone where a lot of raw materials can be grown, (crops include soybeans, Jatropha).Confined to the Sudanese experience in biodiesel production the Jatropha have been cultivated on a small-scale farms[30]While palm oil yield is the highest at about 4 tonne/ha, most vegetable oil yields are under 1 tonne/ha. In general these crops require good arable soils, temperate climate and relatively high rainfall. It is this situation that explains the strong interest in oil-producing perennial or tree species like Jatropha, Castor, Pongamia, Croton and Neem, among others. Among these jatropha has received most attention and investment recently, due to its supposed abilities to produce well in marginal sites with low and variable rainfall [29].

Figure (3.6): Jatropha tree grow in South Kordofan regions [29].

Chapter Four

Results

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Preface

Renewable energy is energy generated from natural Resources such as sunlight, wind, rain, tides and geothermal heat which are renewable. Renewable energy technologies range from solar power, wind power, hydroelectricity, biomass and biofuels for transportation Renewable energy is energy that is generated from natural processes that are continuously replenished.this includes sunlight, geothermal heat, wind, tides, water, and various forms of biomass this energy cannot be exhausted and is constantly renewed.92% of Sudan's primary energy consumption is from fossil fuels, with 8% accounting for hydro. Yet, current installed capacity is for 60% from hydropower the country is making efforts to further integrate other renewable energy resources and aims to have 11% of electricity generation from renewable energy by 2031.

4.2 Result and Discussion.

4.2.1 Evaluation of Renewable Energy (Hydropower) in Sudan.

Show in this figure(4.1) The hydropower in Sudan represent the biggest share of about 70% despite the fact that the installed capacity about 54% of the total installed power capacity .Sudan releases plans to add 500MW of hydroelectric capacity by 2020.Sudan has approved the ministry of water resources and electricity for enhancing electricity power service plan ,a document detailing how to increase hydroelectric power generation in the country from 1500 to 2000MW by 2020.Sudan would like to complete dam construction at the 320MW upper Atbara and sited ,

this project includes dam on upper Atbara river and sited river in eastern Sudan[31].

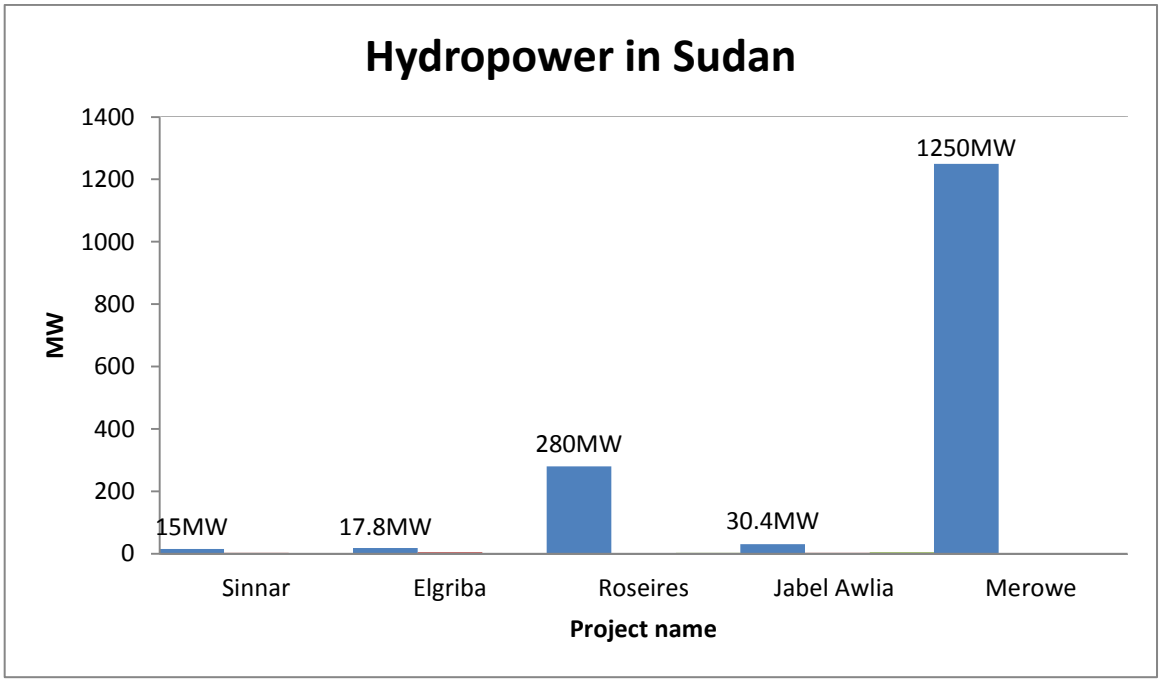

Figure (4.1): Evaluation of renewable energy (hydropower) generation in Sudan.

Needed energy: the Sudanese ministry of electricity announced that it routinely faces a 5% deficit in electricity Supply during peak hours. Electricity from 1250MW Merowe hydropower facility Sudan largest capacity hydroelectric project, cannot fully power Khartoum a lone even if it is operating at its maximum capacity [23,31].

4.2.2 Evaluation of Thermal power plant in Sudan.

Show in figure(4.2)the thermal electricity generation in Sudan by traditional fossil fuel Sources(thermal power plant), the installed thermal power generation is about 46% of the total installed public power generation(hydro + thermal) is 1650MW.

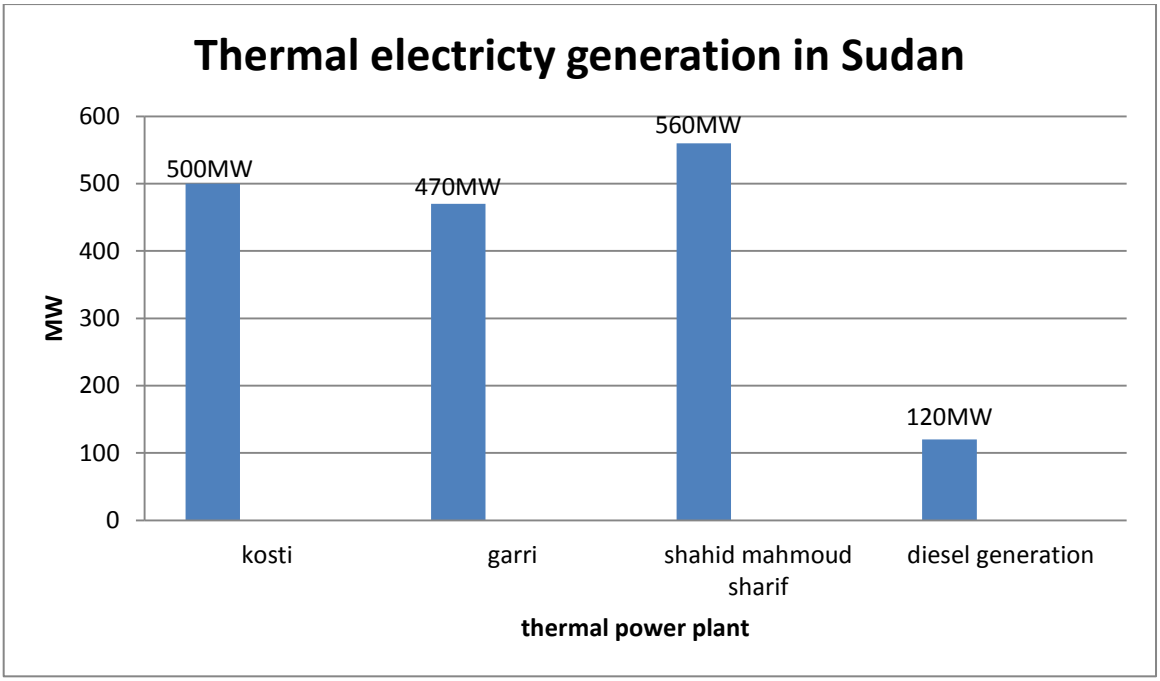

Figure (4.2): Evaluation of Thermal electricity generation in Sudan.

The energy conservation scenarios include rational use of energy policies in all economy sectors and the use of combined heat and power systems, which are able to add to energy savings from the autonomous power plants [16]. Thermal electricity generated in the country is expected to jump from 900MW to 3555MW by 2020 where plans initially aim to link the national electricity network with the towns of Darfur, Blue Nile and the South Kordofan region [17].

4.2.3 Estimating of Renewable Energy in Sudan.

Show in this figure (4.3)The renewable energy in the Sudan 2031 the renewable energy includes about 29.3% of total installed power .the renewable energy share of about 13.6% of electricity generation in Sudan 2031 show in figure (4.4).The main components of the renewable energy and usage any available alternatives .

The local availability of potential indigenous energy resources in the Sudan that could be used to replace fossil fuel energy to use generation electrical[10].

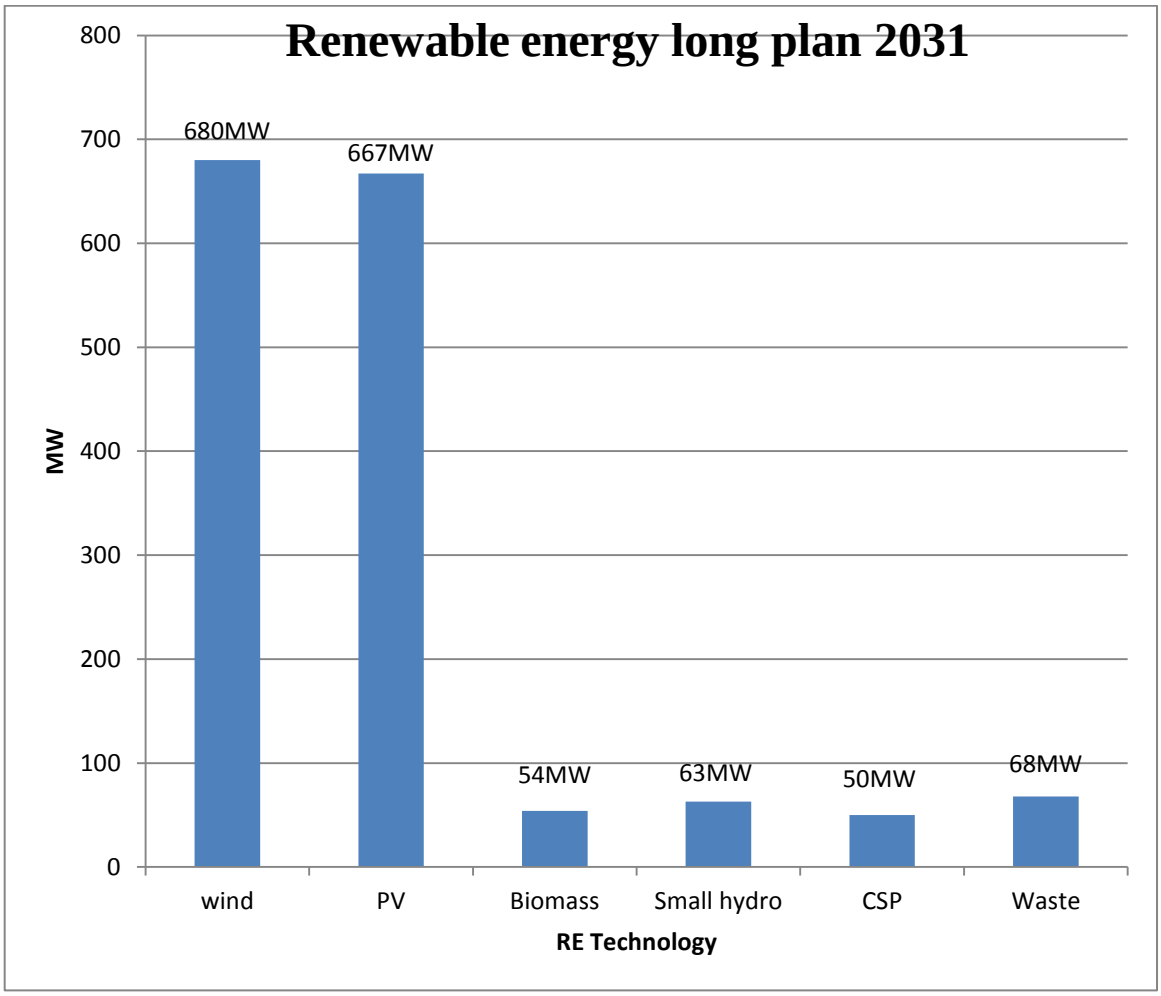

Figure (4.3): Estimating of Renewable Energy in Sudan in 2031.

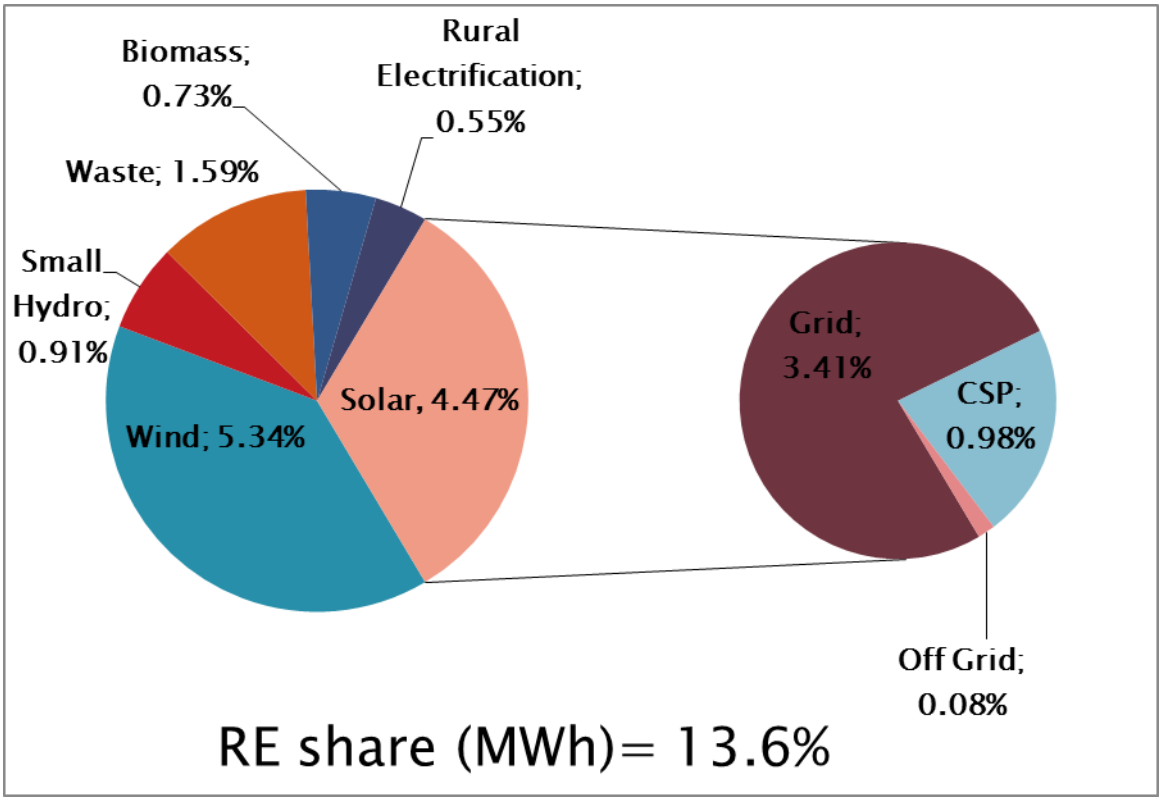

Figure (4.4) Renewable energy in Sudan is share 13.6% in 2031.

Table (4.1) : Comparison between of renewable energy and thermal power in Sudan.

S/N	Energy source	Characteristics of Energy Source
1	Solar Power	• Location of solar panels is important, areas that are cloudy cannot produce solar power unless you install more panels. • The initial cost of purchasing and installing solar panel is high. • PV panels are made up of silicon and other toxic metals like mercury, hence imminent environmental pollution which renders inequality in PV cells. Very high technology can avert the worst of this effects. • 60% of the sunlight gets wasted and not harnessed since most of solar panels have 40% efficiency. This renders it inefficient. • Solar is not reliable since it can be operated at night, takes large space for big companies to install solar arrays.
2	Wind Power	• Doesn't produce the same amount of power every day since the strength of wind is not constant. • Wind turbines are noisy, Pollutants are produced during manufacturing of wind turbines. • Difficult some times to get wind farm site since most of the people think country site should be left untouched for wind farm. • Some people see wind turbines to be generally ugly and therefore it disfigure the country site. • Limited in unit capacity hence required many unit to supply a high population.
3	Geothermal Power	• Geothermal energy cannot be moved easily. Unlike oil or electricity.

		• Location of geothermal power is normally a problem since it has to be located near geothermal activity. • Another downside to geothermal energy production is that a hot spring for geothermal activity can suddenly shut off without any rhyme or reason. There is no way to predict this. In some cases, this shut off can last years, causing disaster to anyone relying upon energy produced by the spot. • Along with the heat, there are other chemicals that can come up along with the energy. Among these are many hazardous chemicals such as mercury, hydrogen sulfide, and ammonia. These chemicals can pollute the air. • Geothermal technology can be expensive. While the cost of infrastructure has already been stated, there is also the cost of the initial drilling process, which can be rather expensive. • Many people speculate that there is the possibility that extracting geothermal energy can cause earthquakes.
4	Hydro Power	• Hydropower plants have longer life and its efficiency does not fall with age. • The plant is highly reliable and it is the cheapest in operation and maintenance. • The rapid changing load can be varied and met without any difficulty. • Such plant has constant speed and constant frequency and, Standby losses in hydro plant are minimal. • Needs no fuel since water is the source of energy, hence operating costs are low and there are no problems of handling and

		storage of fuel and disposal of ash. • Since no smoke and ash is produced during operations, The hydropower plant is clean and neat. • This plant can serve other purposes apart from generation of electricity; it can be used for irrigation, flood control and navigation among others.
5	Thermal Power	• Diesel plants cannot supply overloads continuously. • Diesel unit's capacity is limited. These cannot be constructed in large size. • Diesel useful life is very short, it's about 10 years. • Operating cost is high due to high cost of fuel. • Maintenance and lubrication cost is also high as compared In the case of other plants. • Noise from the exhaust is a serious problem.

Chapter Five

Conclusion and Recommendations

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The research aims at depicting an up to date assessment of the energy situation in Sudan With regard to diversification of energy resources, reduction of dependence resources fossil fuels and to maintain the safe energy resources, the growth of renewable energy resources simultaneously and to increase the share of the renewable energy among other sources in Sudan, carries very important role.

The incentives that are granted to generate the renewable energy resources, specially solar , wind and biomass power are reasonably lower than the relevant African countries in Sudan. Relevant economic analysis must be updated and greenhouse gas emissions must be taken into account in the light of the global petroleum price increase projections for sound evaluation of incentives on renewable energy resources stronger and encouraging legal initiatives must be taken toward efficient use of the renewable energy potential other than hydro electrical power[22]. On the other hand, existing legal requirements limits the permitted maximum established power potential. Sudan has a steadily increasing requirement for fossil fuels for both land and air transport, The following conclusion can be drawn from this research work:

1. To evaluation of renewable energy resource(hydro power) in Sudan show in figure(4.1) the hydropower in Sudan represent the biggest share of about 70% despite the fact that installed capacity about 54% of the total installed power capacity. Sudan to increase hydropower generation in the country from 2000 MW by 2020. Plan of ministry of water resources and electricity.

2. To estimating technical potential energy with existing energy system, the renewable energy resource include(solar, wind, biomass, waste and small hydro), show in figure(4.3) the renewable energy includes about 29.3% of total installed power and to share of about 13.6% of electricity generation in Sudan that try to use less fossil fuel to decrease the greenhouse gas emission.
3. To evaluation of thermal power plant in Sudan, Sudan has a steadily increasing requirement for fossil fuels for both land and air transport. The installed thermal power generation is about 46% of the total installed public power (1650MW) in the figure(4.2).
4. In comparison between renewable energy resource and thermal power in Sudan. The renewable energy has two great advantages compared to fossil fuels. Firstly the renewable energy resources have on greenhouse gas emission, secondly the renewable will be the future energy when fossil fuels are spent. The fossil fuels is expensive these results will be useful for energy resources planning.

5.2 Recommendations

The following recommendations are made in reference to this study:

1. Thermal energy is expensive and could remain as a short term solution to power need in Sudan.
2. The only way for Sudan to response to energy crises is by establishing renewable energy supply for long term energy needs.
3. To assess the net effect on greenhouse gas emissions of replacing fossil fuels by renewable energy, we need to analyze emissions throughout the entire process of producing, transporting and using the fuel.

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