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IMPLEMENTATION AND SUSTAINABILITY OF RENEWABLE ENERGY IN AFRICA

The case of Gabon

Bachelor's thesis

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<p>Abstract</p> <p>The aim of the thesis is to search closely the potential of renewable energy sources in Gabon, different factors affecting a sustainable growth of renewable energy in the country and also how to support, promote and encourage the growth of renewable energy resources in Gabon to close the gap of 40-50 % of Gabonese living mostly in rural areas to have access to an unlimited, infinite energy source that will protect and keep our environment safe.</p> <p>Renewable energy sources are limitless and environmentally friendly, making them the only way to protect the climate and achieve energy independence. We are not likely to miss it, as we are currently doing with fossil fuels such as coal, oil, oil and natural gas, which are Gabon's main energy resources. Moreover, it is not only the level of mitigation of fossil fuel consumption that is the main concern that will prompt Gabon to adapt and switch to the use of renewable energy sources. Climate change, caused mainly by carbon dioxide (CO₂) emissions and environmental pollution, is attracting worldwide attention and is forcing institutions, organizations and governments to devise policies that will enable their countries adapting the use of renewable energy sources to reduce minimum minimum pollution because global warming has become a problem and a major problem for today's and tomorrow's world.</p> <p>The main conclusion of the research shows that, Gabon is a country with plenty of natural resources and endowed with abundant renewable energy resources. The estimation of exploitation of hydropower in the country is about 6000 MW, but only 3% that represents 375 MW has been exploited during many years, while 42% of the population remains without access to electricity with a population growth rate estimated at 2,24% per year. There is the need to encourage development of energy diversification by using the different type of renewable energy sources. Fossil fuels should be used with restriction in such a way that will generate revenues to the government as long as possible. The implementation of renewable energy in rural areas will be a solution to reduce the internal dependence and consumption of petroleum products and gas.</p>			
<p>Keywords</p> <p>Energy, Fossil fuel, Renewable energy, Biomass, Sustainable energy, Petroleum, Gas, Electricity, Waste-to-Energy, Climatic protection, Energy independency, Diversification, Energy promotion, Government.</p>			

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1 INTRODUCTION

The content of the first chapter of the thesis introduces the background, objectives, problems and research questions. Thereafter, the limitation, definition of key words and the structure of the thesis are presented.

1.1 Background

The vertiginous rise of oil prices faced in Gabon has plunged the country into a prolonged financial crisis which remain insolved by the government since 2014. The oil production considered as the main fossil fuel energy is still declining in that potential wealthy central African state. Energy is the key of a sustainable economic growth and necessary for all activities. Gabon is independent in its energy supply and the country's exportation is mainly concentrated on crude oil and petroleum products. The growth of the population and renewed economic growth will extremely increase the energy demand for the country in the coming years. At the same time, the carbon dioxide emissions inherently emitted by the current fossil fuel need to be reduced in order to prevent the global warming.

Gabon is endowed with a plenitude of renewable energy potentials. So far, the country does not have any framework regarding renewable energy, which is an important way to fight against poverty and attain the Millennium Development Goals (MDGs).

Nowdays many developing and industrialized countries support the renewable energy use. However, the degree of concern and involvement vary between countries. Finland has a great approach to renewable energy use and the government has designed a regulatory mechanism to promote the use of renewable energy sources.

Finland is considered as one of the world leaders for using renewable sources of energy, especially bioenergy. The country has set goals to promote renewable energy, reduce greenhouse gas emissions and eradicate the energy system that is based on fossil fuels.

1.2 Research objectives

Renewable energy sources are good options because they are unlimited. We will not need to worry about them as we may worry about the fossil fuels which remain a major sources of energy in Africa. Also it is not only the extinction of fossil fuel energy that will move Gabon to adapt and use renewable energy sources. The global warming caused by carbon emissions and environmental pollution forces governments to promote policies of using renewable energy sources in order to safeguard our planet.

The purpose of this study is first, to understand the energy context of the Republic of Gabon, secondly to prove the presence of a potential renewable energy resources which should be valorized, and finally to create an energy planning for the future. The intention of this work is to promote the growth of

renewable energy in Africa, especially in Gabon and use the Finnish renewable energy system as a model to follow.

1.3 Research Problems and Research Questions

The problem of this research endeavor is ***what is the potential of renewable energy in Gabon?***

The aim is to get answers to the following research questions:

- What are the various factors affecting the sustainable growth of renewable energy in Gabon?
- What does make the Finnish renewable energy system successful and what can be learnt to overcome the challenges in the system in Gabon?

1.4 Limitation

The limiting factors that hinder the effectiveness of this research project are based on the access to people, organizations, data linked with renewable energy sources, financial resources and limited literature.

1.5 Definition of key words

Renewable energy sources: The German group EEG defines renewable energy as "hydropower, including wave energy, tidal energy, flux energy and salt gradient, wind energy, solar radiation, geothermal energy, energy derived from biomass, including biogas, landfill gas and municipal and industrial waste. (Katrin Jordan-Korte, 2010).

Fossil fuel: it's defined as fuels that come from old life forms that decomposed over a long period of time. The three most important fossil fuels are coal, petroleum, and natural gas.

1.6 Structure of the thesis

The first chapter gives the background, the research objective information of the thesis and introduces different problems, which lead to 2 different questions mentioned earlier. The second chapter talks about the renewable energy sources and mentions the five important renewable energy sources used to generate energy. The third chapter helps the reader to understand the energy situation in Gabon, gives a general view of the country, the main energy resources base used in Gabon and the production as well as the consumption of energy in Gabon. Chapter 4 presents the development of renewable energy system in Gabon and what the country can learn from the Finnish system through information provided by the Bioenergy association and the two case companies. Chapter 5 contains the methodology and sustainability analysis of renewable energy. Chapter 6 presents the results of the research, the climatic protection, the energy independency and how the use of renewable energy can be a great solution for Gabon. Chapter 7 includes the conclusion and suggestions which can help further research, Gabonese public, institutions and companies that are interesting in the growth of renewable energy in Gabon.

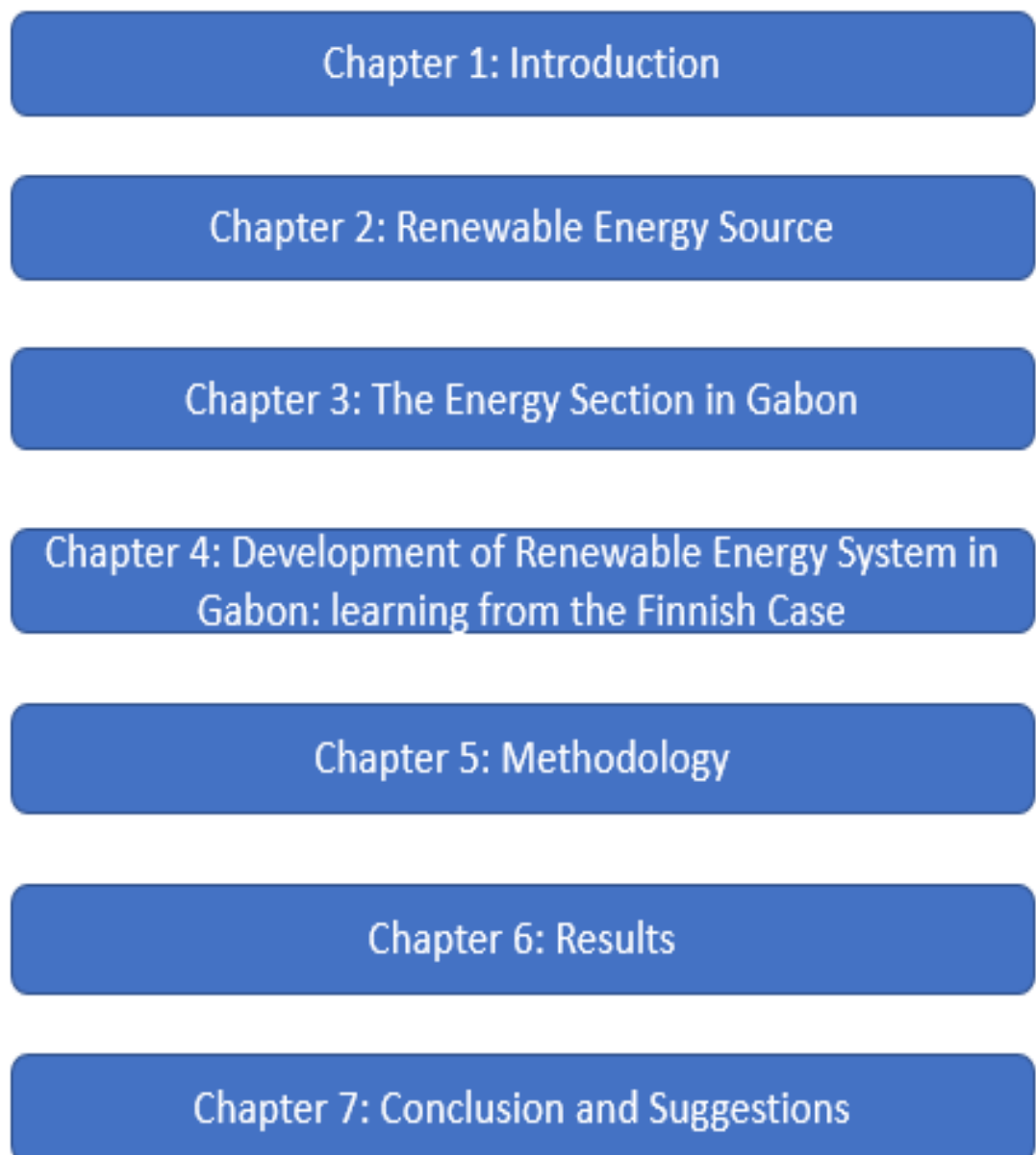


FIGURE 1. Structure of the thesis

2 RENEWABLE ENERGY SOURCES

The content of this chapter gives explanations on the energy process and five type of renewable energy sources that this project is based upon, which are solar energy, wind energy, geothermal energy, bioenergy and hydropower. It also demonstrates how the energy can be generated from the five renewable energy sources.

2.1 Energy Process

Some African countries have already started to pursue renewable energy development. As illustrated in this chapter below , however, there is still huge unexploited potential.

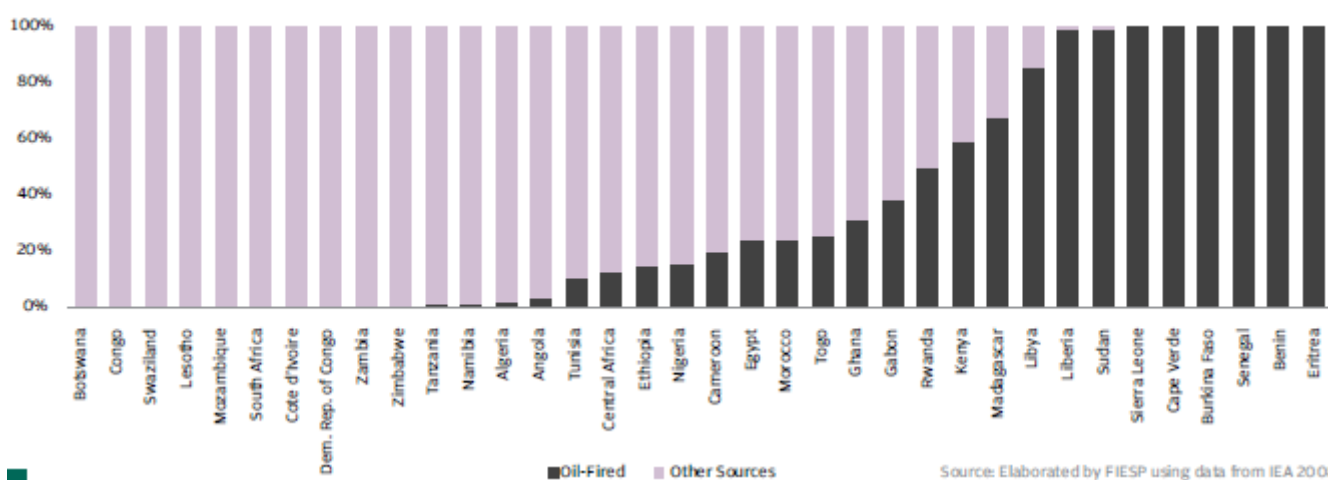


FIGURE 2. Percentage of power produced from oil-fired power plants in selected African countries [%] (FIESP.2009.)

There are four elements deeply associated with the energy process. First of all, there is the origin source that demonstrates where we get our energy from. Secondly, energy production shows different means how energy is generated. Thirdly, energy transfer describes the movement of energy. Lastly, energy consumption provides information about how to save as much energy as possible.

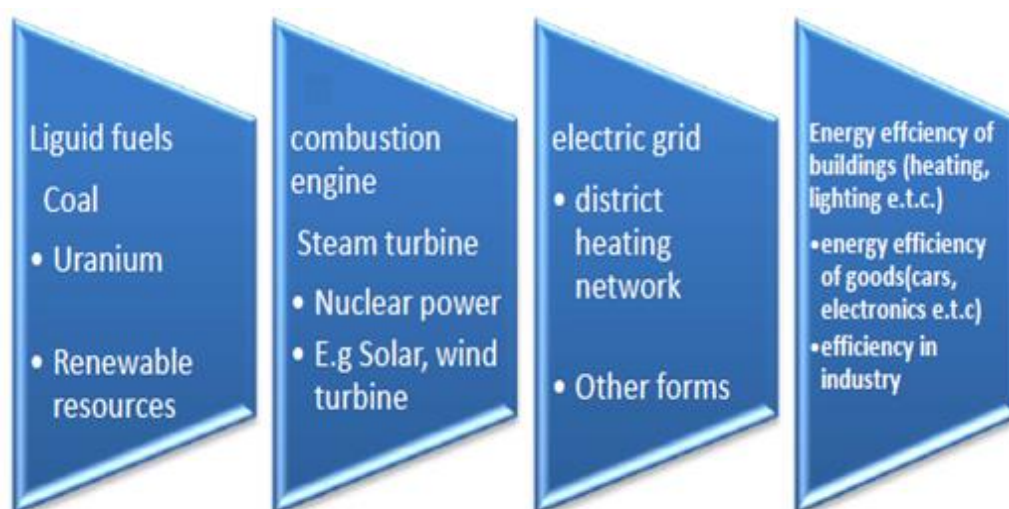


FIGURE 3. Energy Process, (Koskinen 2010.)

To have a good understanding on the research work and the energy sector, it is very necessary to understand some key terms of electric power. Power is the rate of doing work or a capacity measured in watts and represented by the letter P , whereas the energy shows the quantity of Power produced as well as used per time unit and measured in watt hours.

- W: Watt; the power capacity
- Wh: Watt hours, the amount of energy produced or consumed
- WK: Kilowatt=1000 MW
- MW: Megawatt=1000 KW
- GW: Gigawatt= 1000 MW

2.2 Solar Energy

Solar energy or solar energy is radiation and the heat of the sun used to generate electricity. The production of electricity using solar energy can be done by a direct method including the use of photovoltaic energy (PV) and using an indirect method called solar energy concentration (CSP), in which the sunlight is concentrated to boil and heat the water to provide energy. Solar energy mainly concerns the use of solar radiation for the production of electricity. However, apart from geothermal energy and tidal energy, all other renewable energy sources derive their energy from the sun. Figure 4 illustrates how to generate electricity from the sun:

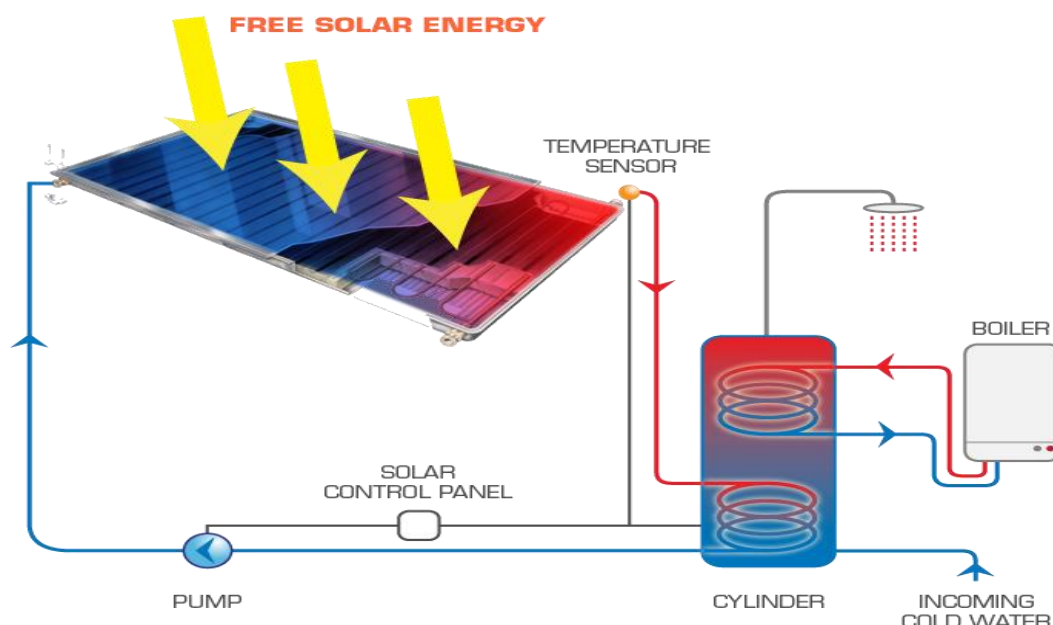


FIGURE 4. Generation of energy from solar thermal method

The energy influx of solar radiation is the expression of the power density used to indicate the number of watts per square meter (Da Rosa, 2008, 521).

2.2.1 Photovoltaic System

A photovoltaic (PV) system is a power system designed by one or more solar panels combined with an inverter, which converts the electric current from DC to AC, and other electrical and mechanical hardware, that absorb and convert sunlight energy into electricity. PV systems can eventually be varied in size from small rooftop or portable systems to large utility-scale generation plants. Mostly PV systems are grid-connected, while off-grid or a minority uses a stand-alone system.

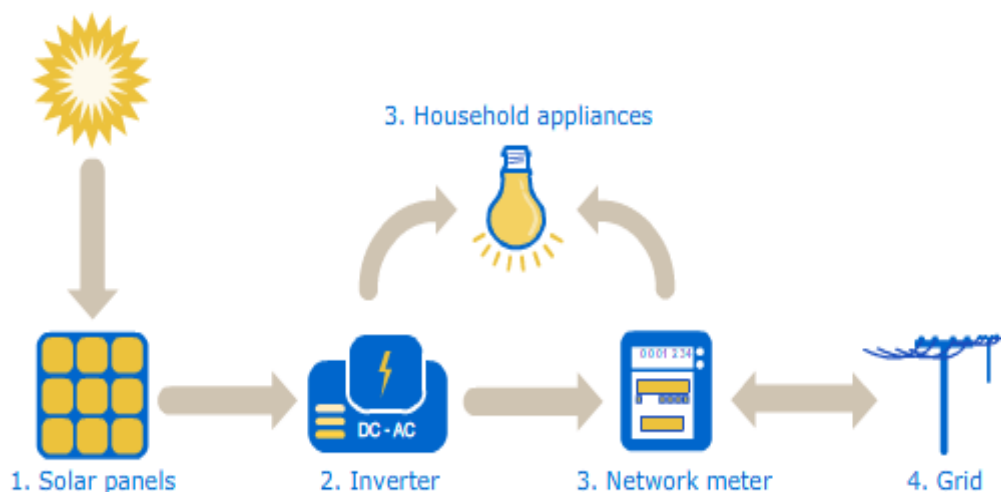


FIGURE 5. Residential grid-tied solar PV system diagram (Pwkits, 2009.)

2.2.2 Solar Electricity

The new power plant technology, focused on the concentration of solar energy systems, uses sunlight as a source of heat. There are three main types of concentrated solar energy: the parabolic-trough, the dish-engine and the electric tower.

Parabolic trough systems preserve sunlight in long curved rectangular (U-shaped) mirrors that concentrate sunlight onto a pipe that passes through the center of the trough and heats the oil in the pipe. The hot oil will be used to boil water in a conventional steam generator to produce electricity. (Sorenson, 2000, 22).

The dish-engine system is used to collect and concentrate the sunlight onto a receiver. The mechanical power is produced by the heat of the fluid within the engine and then used to activate a generator or alternator to generate electricity.

The electric tower system concentrates sunlight on the top of a tower through a receiver. Melted salt heats the receiver. Then, the heat of the salt is used to generate electricity via a conventional steam generator. Figure illustrates how the electricity is generated by the power tower system.

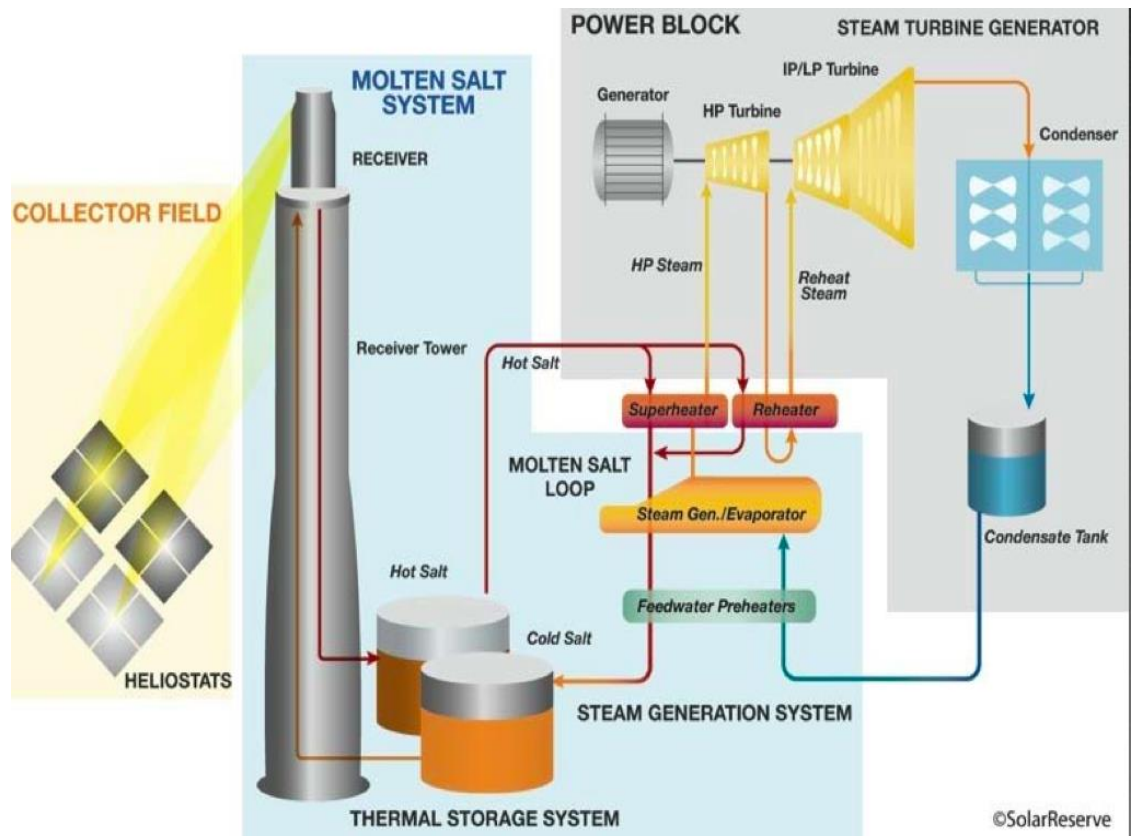


FIGURE 6. Solar power towers with integrated storage (Giles Parkison, 2003.)

2.3 Wind Energy

Wind power is the utilization and conservation of airflow through wind turbines to generate the mechanical power turned by electric generators. The production of wind electricity is constantly increased. The wind speed varies depending on the locations, but the best locations for generating wind power are sometimes remote ones (W.Christian, 2006). The illustration below gives a brief understanding on how the electricity is generated by a wind turbine.

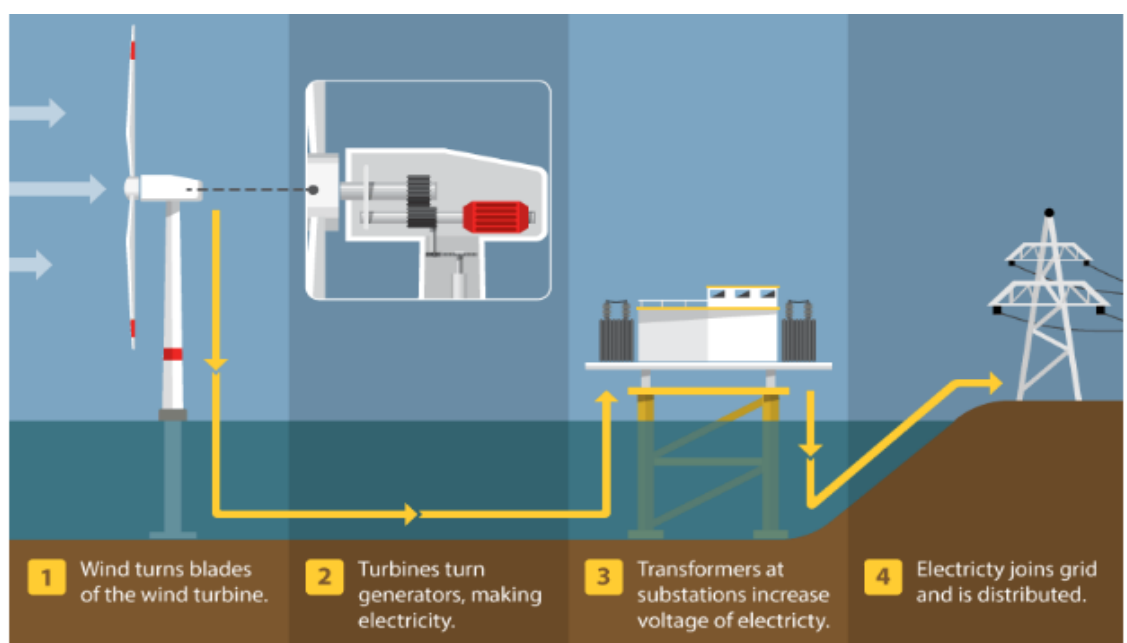


FIGURE 7. Wind turbine operation (W. Kamkwamba, 2015.)

All different type of renewable sources of energy are greatly connected with the heat produced by the sunlight. Wind energy also really depends on the heating up of earth's atmosphere. Different fragment of the atmosphere heated throught the sunlight moves hot air upwards, while the cool air sits down to the lower levels. This tranfers of location between the hot and cool air creates wind. The energy of the wind can be then controlled with the help of a wind power plant.

2.4 Geothermal Energy

Sunlight is not the only source of energy to generate the heat. Geothermal energy is produced by the radioactive decay of materials stored in the Earth's crust, which generates a lot of heat, and naturally is released at the Earth's surface.

Geothermal power plants is the utilization and conservation of hot water located a couple of miles or more below the Earth's surface. There are three types of geothermal power plants. The dry steam power plants, can direct steam into a steam power plant to spin the turbine generator.

The flash power plants, through a hot water reservoir, provide a high temperature ranging between 150 and 370 °C which can be flashed into a steam making a generator to produce electricity. In the binary power plants, with a hot water reservoir between 120 and 180 °C pumping through a heat exchanger, the vapour is eventually used to spin the turbine generator to produce electricity (Goldstein, 2012). Figure 8 illustrates in general the geothermal electricity production.

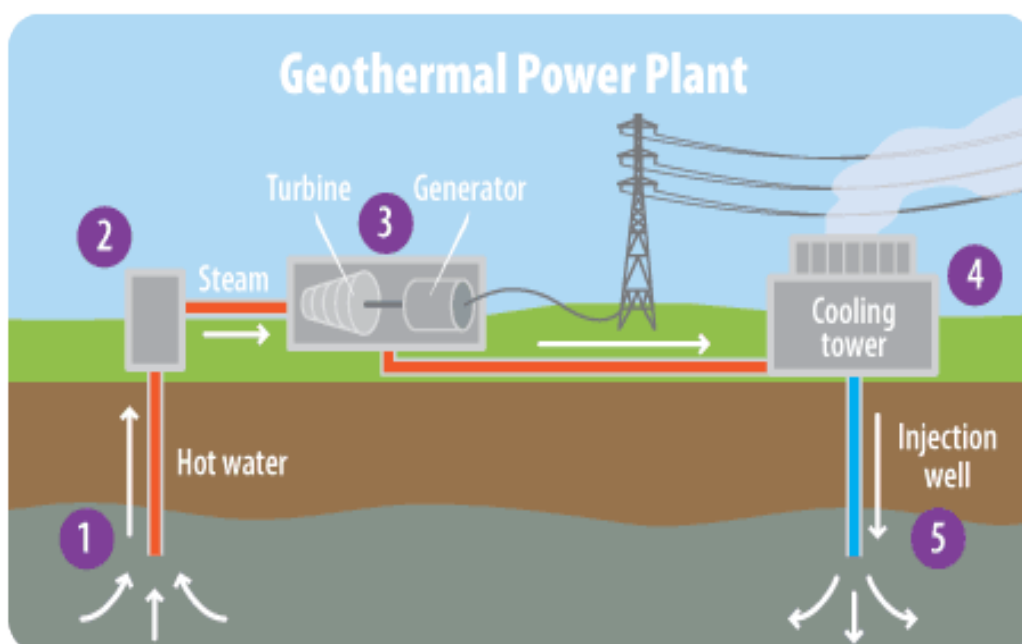


FIGURE 8. Geothermal power plant (W. Kamkwamba, 2015.)

2.5 Bioenergy

Bioenergy or biomass energy is the utilization and conservation of organic component, wood, plants, agriculture's residues as well as municipal and industrial wastes to generate electricity or produce heat from them (Da Rosa, 2009, 569). Bioenergy source does not include organic material like fossil fuel. Figure 9 below provides a great understanding of the main biomass sources:

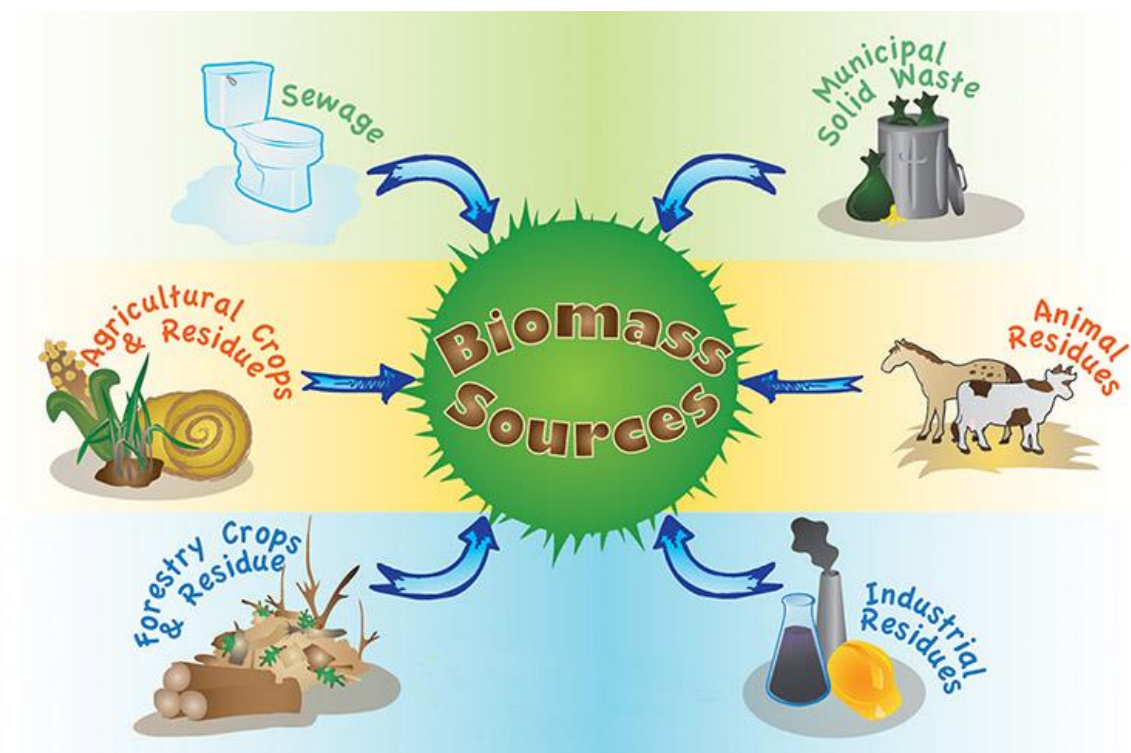


FIGURE 9. Sources of generation energy from biomass (BIC 2012.)

The capture of sunlight and the production of chemical compounds by plants called photosynthesis are the key factors necessary for the production of bioenergy. This creates biochemical transformations in very large quantities and of great commercial value. Photosynthesis usually occurs with less than 8% efficiency. A plant is considered as a structure that supports good organs made of specialized roots that collect nutrients and water. In the process of producing biomass, the materials are usually transported by the sap and the fruits involved in the process ensure sexual reproduction. (Da Rosa 2008, 569.)

2.6 Hydro Energy

Hydropower, also known as hydroelectricity, is energy that uses energy from the waterfall as well as running water to produce electricity. Hydropower is a form of renewable energy that is widely used and can be found almost anywhere in the world. Naturally, hydroelectric power plants can be installed and located in large high-speed dams. Hydropower is one of the cleanest renewable energies with the lowest level of greenhouse carbon dioxide (CO₂) that produces no waste, directly or indirectly. Hydropower produces about 20% of the world's electricity and 88% of that produced from renewable energies. Figure 10 below illustrates the energy's generation from hydropower.

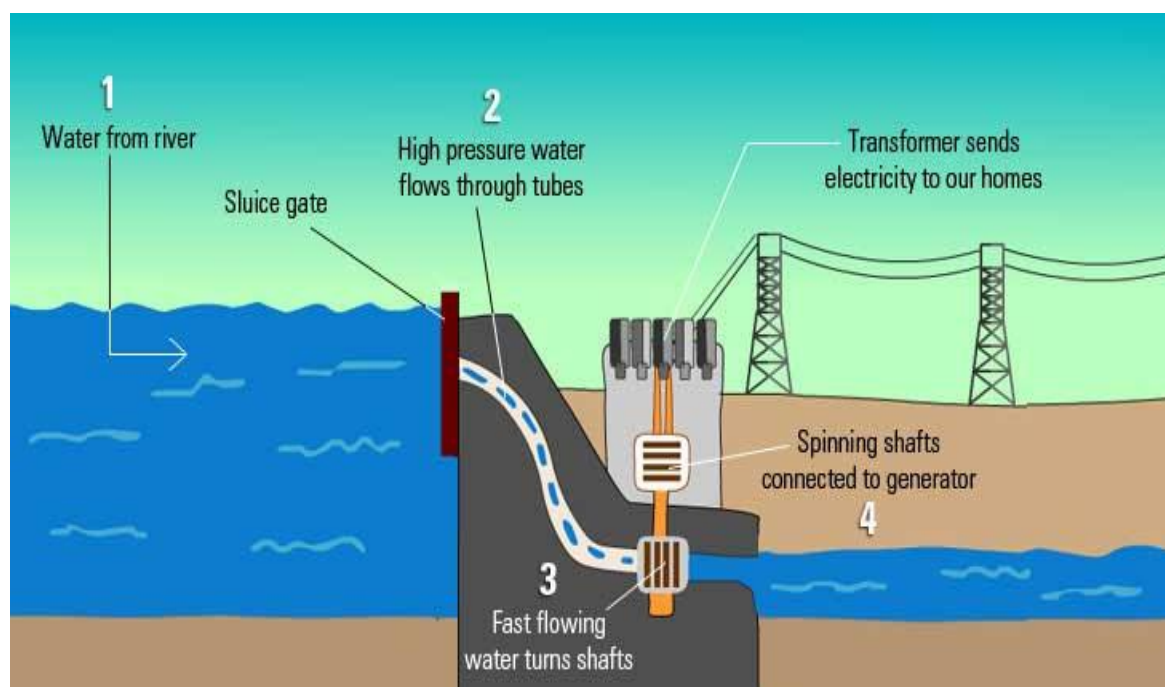


FIGURE 10. Energy production from hydro (EMT 2009.)

Hydropower, like other types of electricity generation, uses a turbine to produce electricity through the energy of falling or melting water that turns the blades. The rotation of the blades turns a generator that converts the mechanical energy of the rotating turbine into electrical energy. The amount of electricity produced by a plant depends on the amount of water flowing and the height at which it falls.

Hydropower storage generates electricity that meets high peak demand due to the flow of water between the reservoirs at various levels. In case of high demand for electricity, an additional production capacity is used. If the demand for electricity is higher, the water is discharged into the lower tank by a turbine. The storage is the most important commercial medium for large-scale energy storage on the grid and improves the daily capacity of the hydroelectric generating system. (Sorenson, 2000.)

3 THE ENERGY SECTOR IN GABON

This chapter focuses on energy resources base in Gabon, and provides other information concerning the energy production and the energy consumption in the country.

3.1 General View of the Country

Gabon is one of the 54 African countries located in the central western region of the continent and sharing its borders with the Republic of Cameroon on the north, with the Republic of Equatorial Guinea on the northwest and with the Republic of Congo on the east and south. The Gulf of Guinea can be observed on the west part of the country.

3.1.1 Political and Socio-Economic Situation

The political situation is marked by the relative stability of the institutions, reinforced by the respect of the constitution and the electoral calendar of the country. This provides a favorable framework for the development of improvement. Following the death of Omar Bongo Ondimba's former president in June 2009, after more than 42 years of government, the country was expected to hold early presidential elections. His son, Mr. Ali Bongo Ondimba, succeeded his father as President of the Republic in August 2009. The country's constitution is responsible for the power structure, which ensures the separation of executive and legislative powers, as well as basic freedoms. The President of the Republic is elected for 7 years without limitation of mandate. Executive power is shared between the President of the Republic and the Prime Minister (Head of Government). The role of the Senate is to be responsible for the political transition, with the transfer of power to its president following the death of President Omar Bongo Ondimba. The Gabonese Democratic Party (PDG, Democratic Party of Gabon) has been in power since 1968; it has 100 members out of 120 and has a considerable influence on the socio-political life of the country.

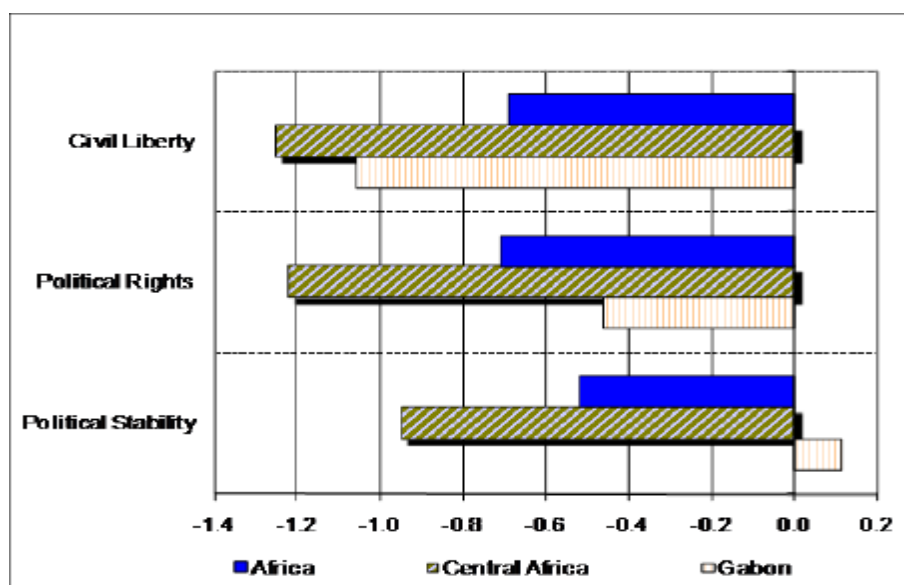


FIGURE 11. Political situation, 2009 Score -4 (less good) to 2.5 (best), (AfDB Statistics Department using data from the WEF, 2010.)

The country's economic growth between 2006 and 2008 was 3%, driven mainly by the performance of the oil sector, which is barely integrated with other sectors of the economy. In 2009, economic growth slowed down, leading to a 1.4% drop in GDP as a result of the international financial crisis, which led to a drop in demand / price for oil and timber (90% of total exports), and the uncertainties associated with a historic political transition. The recovery observed in 2010, with a growth rate estimated at 5.5%, comes from oil activity, supported by the average price of Gabonese crude, up 13.5%. In the medium term, this favorable trend is expected to continue with growth forecasts of 4.2% and 4.9% respectively in 2011 and 2012. The Government's objective is to achieve double-digit growth in starting in 2016 by stimulating the main sectors of the economy, in particular the extractive industries, the hydrocarbon (non-petroleum) and forestry sectors. (African Development Bank, 1996).

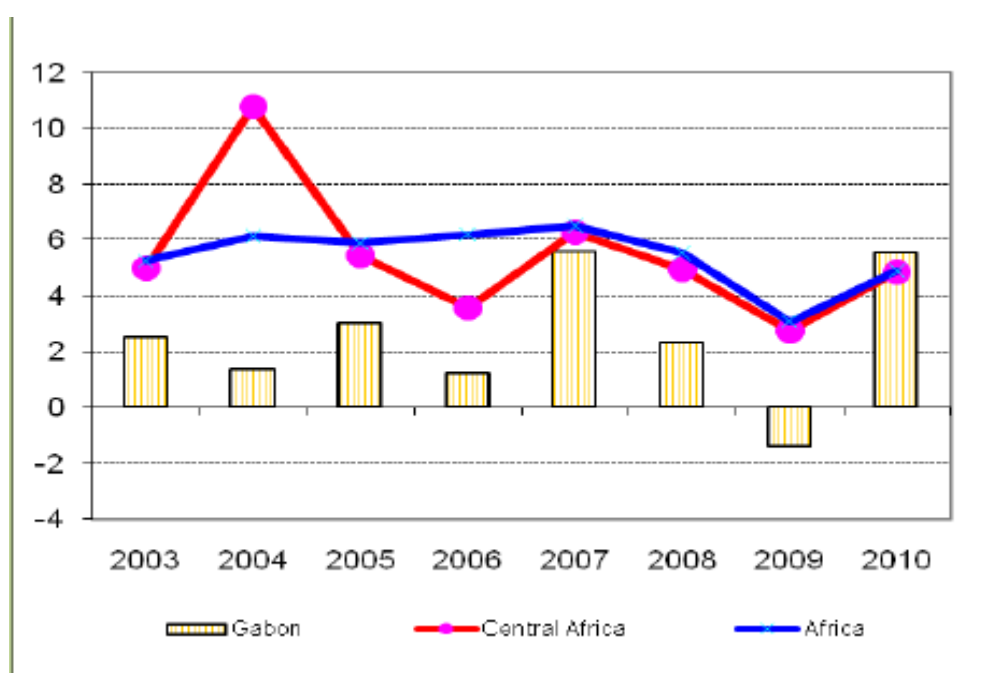


FIGURE 12. Real GDP growth rate (%) (AfDB Statistics Department, African Economic Outlook, April 2011.)

The Gabonese economy is highly under-diversified and depends mainly on global demand for oil, timber and manganese, the main engines of growth. In the primary sector, the share of the agricultural sector has declined slowly but significantly since independence due to oil dynamics, rural migration, and difficulties in transporting and marketing agricultural products due to lack of agriculture and road infrastructure. Because of this trend, almost 85% of the food consumed is imported. In industry, oil is the engine of the national economy and accounted for about 50% of GDP, 60% of tax revenues and 80% of goods exported in 2008-2010. Concentrated in the Port-Gentil region, oil activity peaked in 1997 with 18.5 million tonnes (currently about 12 million tonnes per year). Given this structural decline in oil activity, the government has had to rethink the real sector of the economy by paying more attention to diversification. (African Development Bank, 1996).

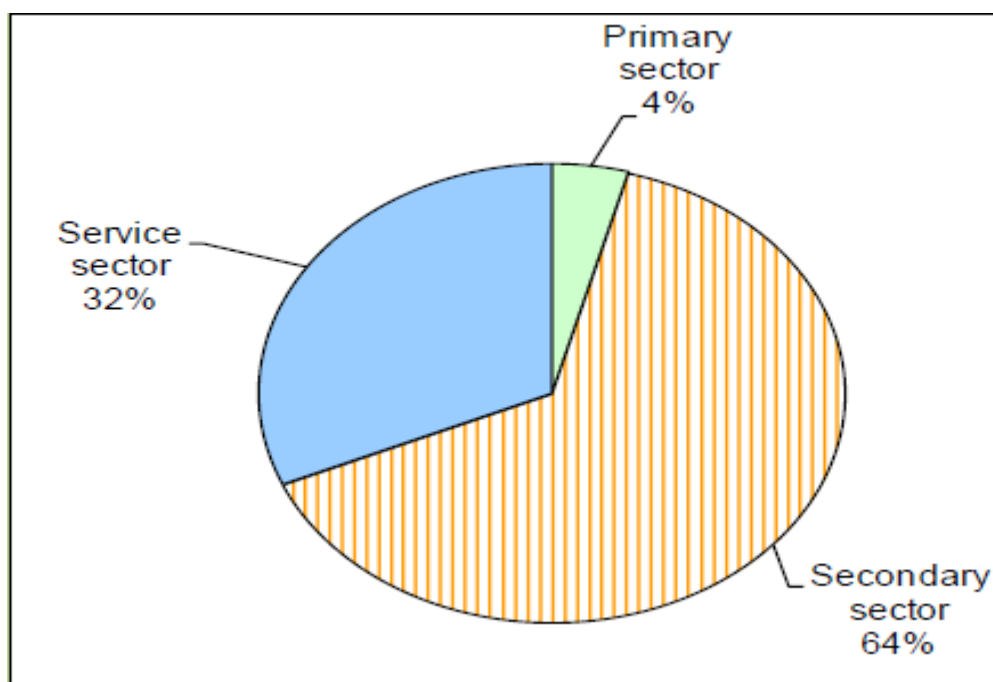


FIGURE 13. Breakdown of GDP by sector (AfDB Statistics Department, 2010.)

Although the timber sub-sector accounts for only 3.5% of GDP and 10% of exports, it remains the largest employer in the private sector (22%). The evacuation and processing of logs is made difficult by the often long distances, the poor state of the road network and the irregular electricity supply.

3.1.2 Geographical and Climatology Aspect

Located on the shores of the Atlantic Ocean in Central Africa, Gabon shares borders with Cameroon, the Republic of Congo and Equatorial Guinea. Gabon is a unique contrast to what one might think in a country straddling the equator. Most of the landscape reflects the influence of Ogooué, the main river of Gabon, in West Africa, between Congo and Niger. The Ogooué basin dominates the eastern two-thirds of the country. There are two other less important areas in the Gabonese landscape, the Woleu-Ntem River basin in the north and an interesting coastal plain to the west and southwest.



FIGURE 14. Geography of Gabon (D. Gardinier, 1994.)

Approaching the country by sea, one of the distinctive features first noticed is the vast park that appears in the hills just beyond the coast. Rather than mangroves, many places have large open meadows on terraces beyond the coast that are mixed with larger tall trees. Beyond the park, the land rises in a long arc of uplands roughly parallel to the coast and separating the upper of the Ogooue from the Atlantic Ocean.

Lakes on the coastal plain below Lambarene collect water for the lower Ogooue River before it empties into the Atlantic. The southern coastal plain is actually an extension of the sandy beaches extending north of the mouth of the Congo. The northern part of the coastal plain is separated from the upper part of Ogooué by a series of plateaus ranging from 1,000 to 2,000 feet (300 to 600 m) above sea level. (Brokken, 1997).

3.2 Gabon's Energy Resources Base

Gabon is self-sufficient in its energy supply. The country is a net exporter of crude oil and petroleum products. Petroleum products are the entirety of the country's energy imports/exports, and totalled 235 ktoe/10,264 ktoe in 2007 respectively.

Hydropower dams in the interior supply 166 MW of electricity and meet 55% of total demand. The main dams of Tchimbelle and Kinguele on the M'bei River supply respectively 69 MW and 56 MW, and Poubara on the Ogooué produces 36 MW. Power supply is also provided by 140 MW gas-fired power plants and 30 MW heavy-power plant. Figure 15 below illustrates the location of the three hydropowers in the country.



FIGURE 15. Existing hydroelectricity dams in Gabon (Sinohydro, 2014.)

3.2.1 Energy Production in Gabon

Gabon is a net exporter of crude oil and petroleum products, exporting about 90% of oil production. In 2010, Gabon's proven oil reserves totalled 3.7 billion barrels and it produced 245,000 barrels per day. Gabon also has small natural gas reserves estimated at 1.2 trillion cubic feet. In 2008 Gabon produced three billion cubic feet per day of natural gas, entirely used to generate electricity and run the country's sole refinery. Installed power generating capacity totals 375 MW, 55% from conventional thermal plants and the remainder from hydropower. In 2008 the country's electricity generation reached 2,040 GWh, 45% of which was generated by gas-fired plants. High rainfall and unique geography make for substantial hydropower potential. The economically exploitable hydro potential is around 76,000 GWh/year, while only 1% of this potential is presently being exploited. (African Development Bank, 1996).

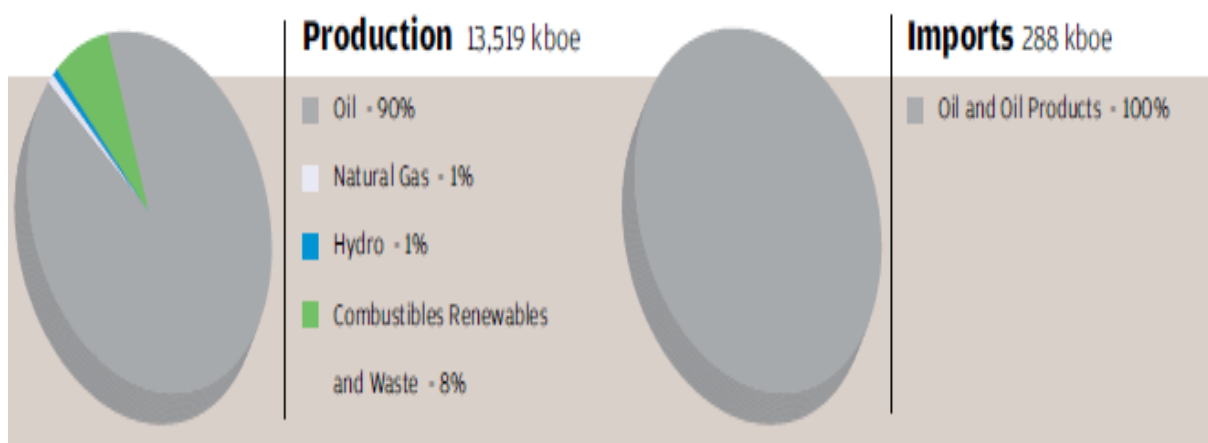


FIGURE 16. Total energy production in Gabon, (ktoe) (AFREC 2015.)

3.2.2 Energy Consumption in Gabon

Around 40% of the urban population and only 18% of the rural population have access to electricity. Gabon has vast forests and primary biomass provides most of the total primary energy supply, at around 56%. Mini hydropower projects are being planned to increase access rates in remote areas, and solar panels have been implemented in 100 villages in the countryside, including schools and shops.

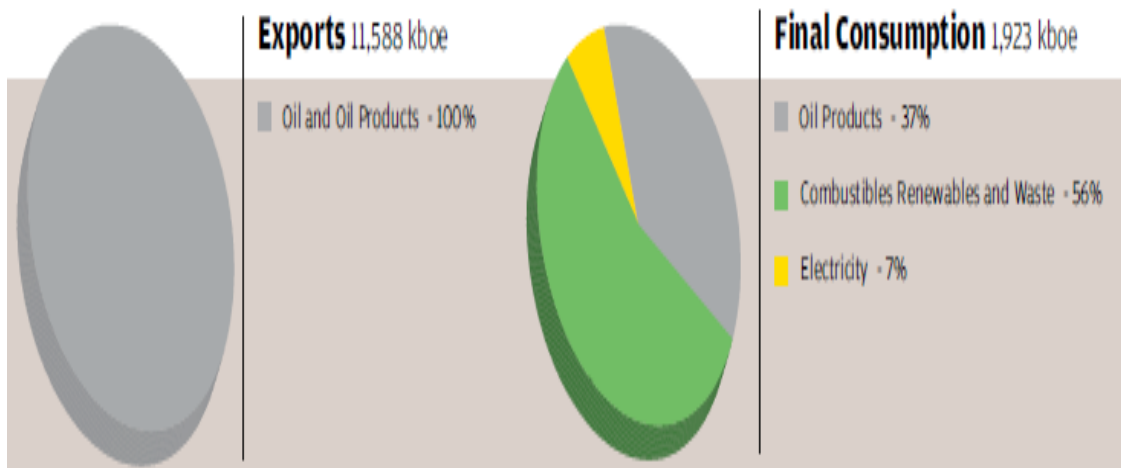
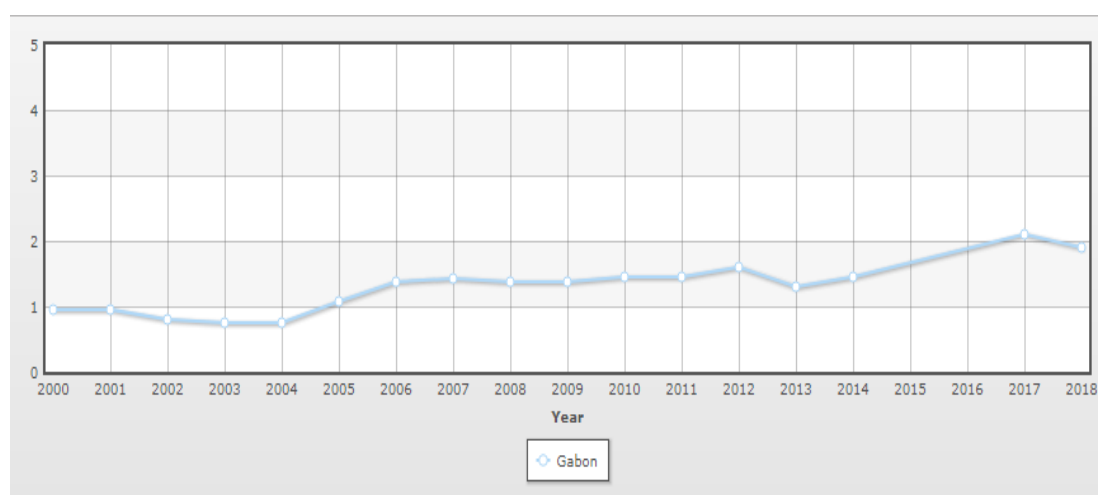


FIGURE 17. Total energy consumption in Gabon,(ktoe) (AFREC 2015.)

The country power capacity is 375 MW, which is not enough to satisfy the population demand. Thus, it will be necessary to double the production to 750 MW for example so that the electricity grid could covered the entire country. However, due to the fact that the Gabonese population increases approximately by 2.24% per year, the distribution network must be extended.



Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2017	2018
Gabon	0.95	0.95	0.79	0.74	0.74	1.08	1.38	1.44	1.37	1.37	1.45	1.45	1.6	1.3	1.44	2.1	1.91

FIGURE 18. Electricity-consumption (billion kWh), (CIA World Factbook, 2015.)

The entry represents the total electricity produced annually, included imports and exports in kilowatt-hours.

4 DEVELOPMENT OF RENEWABLE ENERGY SYSTEM IN GABON: LEARNING FROM THE FINNISH CASE

This chapter discusses about the opportunities and challenges meet for the implementation of renewable energy in Gabon. It provides information about the Gabon's energy planification and also how the country can built a sustainable renewable energy based on Finnish experiences.

4.1 The Potential Renewable Energy Source in Gabon

Gabon is a country rich in natural resources and endowed with abundant renewable energy resources. The most important are solar energy, wind power, biomass, small and large hydropower plants, as well as hydrogen potential, oceans and geothermal energy. The purpose of this study is to examine the potential of the four main sources of renewable energy, namely solar, wind, biomass and small and large sources of hydropower.

4.1.1 Solar Energy Resources in Gabon

Solar energy is the most abundant renewable energy sources and available at any location of the globe, with the values depending on the distance with the equator, for example 1400-2300 kWh/m² in Europe and 2500 kWh/m² in Gabon, Central Africa.

In Gabon there are approximatively 300 days with sunlight a year with an average of 4 kWh/m² of daily sunstroke. The country is strongly forested, which appears for being a real challenges to connect populations to the electricity grid, so stand-alone solar can be only limited to power smaller villages in spite of the €18 million government project implemented to provide solar energy to home, schools and hospital (REEEP, 2012) .

4.1.2 Wind Energy Resources in Gabon

The heavily forested nature of the country reduces wind energy production, but there may be potential along the coast, particularly in the areas of Pointe Denis and Loango National Park. Average wind speeds of up to 6 m / s have been recorded in some parts of the country (REEEP, 2012).

4.1.3 Hydropower Energy Resources in Gabon

Topography and heavy rainfall combine to create ideal conditions for generating electricity from hydropower sources. The exploitation of hydropower in 2011 was about 6,000 MW and only 3 % has been exploited (WEC, 2013). The existing power plants are the dams of Petite Poubara and Grand Poubara on the main waterway of Gabon - the Ogooué river; and two others on the river Mbei, the dams of Kinguélé and Tchimbélé. The sector is expanding with other projects planned on the Okano, Ngounié and Ouue rivers, totaling 502 MW.

4.1.4 Bioenergy Resources in Gabon

Gabon's forests cover a large part of the territory and provide an important part of the country's energy needs (IEA, 2016). Biomass is the main source of energy used by 80% of the domestic sector (REEEP, 2012). The country has international and regional cooperation projects for sustainable forest management and energy use through the Central African Forests Initiative and the International Center for Carbon Sequestration and the biomass energy. As the formal wood sector grows, it is also possible to use wood industry waste to produce energy.

4.2 Various Factors Affecting the sustainable growth of Renewable Energy in Gabon

There are quite a lot of difficulties and barriers that hinder the utilisation of renewable energy sources in Gabon, despite the abundance resources of renewable energy as described above. It is not possible to mention in this study all the factors affecting the growth of renewable energy in Gabon, but the ones chosen in this work will help us to understand the basic problems found with the growth of renewable energy in Gabon.

According to the Energy policy of Gabon (J13-00604), Patrick Yalis Ongalla, electricity manager on his country report (Tokyo, June 2013), has identified and mentioned different factors hinder the growth and use of renewable energy in Gabon. Among of them, there are:

- Difficulties with the obtention and monitorization of energy data
- Institutional and regulatory aspects: there is no institutional and regulatory framework requiring transmission of energy data to the Ministry in Charge of energy; there is no agency able to issue licenses to companies that will provide smaller capacities of renewable energy electricity.
- Difficulties and challenges with the development of energy balance
- Financial barriers
- Political barriers: The Gabonese energy sector is regulated only the government and this factor really affect the growth of the renewable energy sector in Gabon.
- High initial investment cost, because renewable energy is quite expensive and makes the electricity produced by the renewable energy system to have high initial cost, which reduce the penetration of the renewable energy electricity system into the Gabon market.

4.3 Gabon's Energy Planification

The energy planification 2010-2020 target to implement in Gabon a sustainable energy platform based on energy mix of biomass, gas and hydro. The energy policy also has objectives to strengthen a regional cooperation between transmission and energy distribution inside the region. To that end, a national transmission network has been planned to be constructed between 2010 and 2018 with a national load-dispatching centre (IEEJ, 2013).

Energy intensity (the ratio of energy consumption quantity to economic unit of output) was 3.1 MJ per US dollar (2005 PPP dollars) in 2012. Compound Annual Growth Rate (CAGR) between 2010 and 2012 was -3.80. (World Bank, 2015). The share of renewable energy in Total Final Energy Consumption (TFEC) was 69.6%. Traditional solid biofuels represent the largest share of renewable sources, accounting for 53.4% of the TFEC in 2012, compared to 31.0% for modern solid biofuels and 3.2% for hydropower (World Bank, 2015). Renewable energy sources accounted for 41.7% of electricity generation in 2012 (World Bank, 2015) and the country's target is 70% by 2020 (REN21, 2014). Gabon wants 80% of the energy supplied by renewable energies to be by 2020.

Target	Indicators	Year					
		1990	2000	2010	2012	2000-2010	2011-2015
7.1 By 2030, ensure universal access to affordable, reliable and modern energy services	7.1.1 per cent of population with access to electricity	73	74	82	89.3		
	7.1.2 per cent of population with primary reliance on non-solid fuels	45	63	76	78.68		
7.2 By 2030, increase substantially the share of renewable energy in the global energy mix	7.2.1 Renewable energy share in the total final energy consumption		78.3	74.5	63.0	69.57	
7.3 By 2030, Double the rate of improvement of energy efficiency	7.3.1 GDP per unit of energy use (constant 2011 PPP \$ per kg of oil equivalent)	-	-	12.5	13.2 (2011)		
	Level of primary energy intensity(MJ/\$2005 PPP)	2.7	-	3.4	3.1	3.27	3.15

FIGURE 19. Gabon's progress towards achieving SDG7 (world Bank 2015, 2016.)

4.3.1 Energy Demand Projection

Statistics used in this stage of the thesis have been registered since 2000, the year of the last publication of the energy situation in Gabon.

The overall demand is distributed among the following subsectors, in 2000:

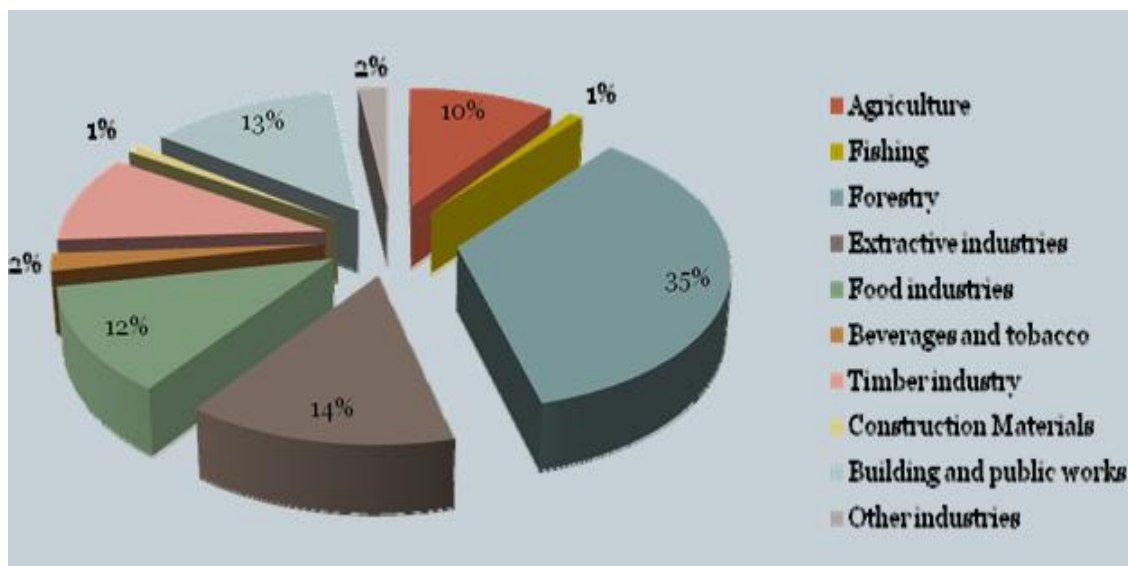


FIGURE 20. Energy demand in oil industry (IEEJ, 2013.)

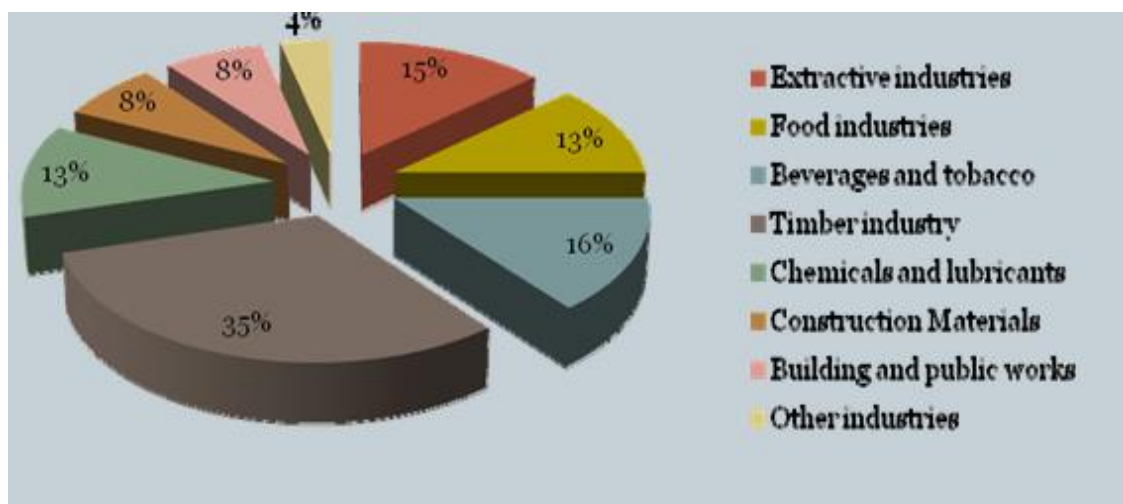


FIGURE 21: Energy demand in other industry (IEEJ, 2013.)

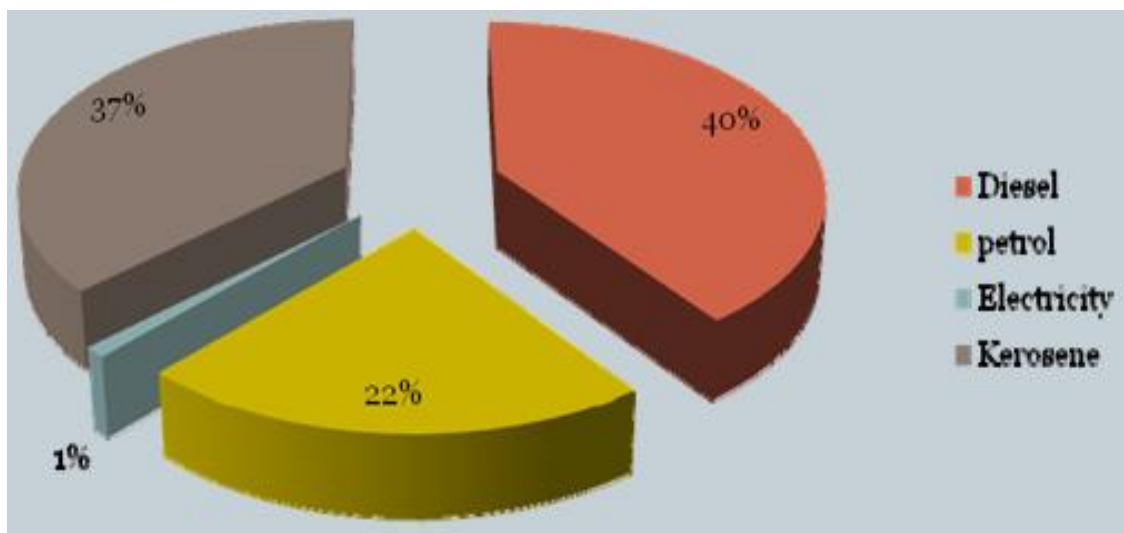


FIGURE 22. Energy demand in Transport (IEEJ, 2013.)

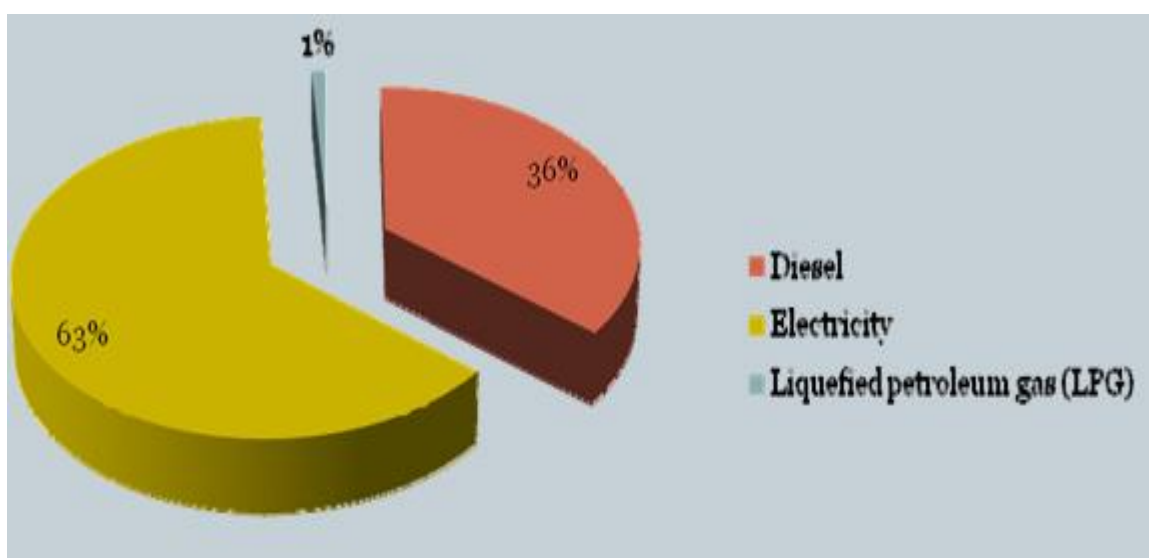


FIGURE 23. Energy demand in Tertiary sector (IEEJ, 2013.)

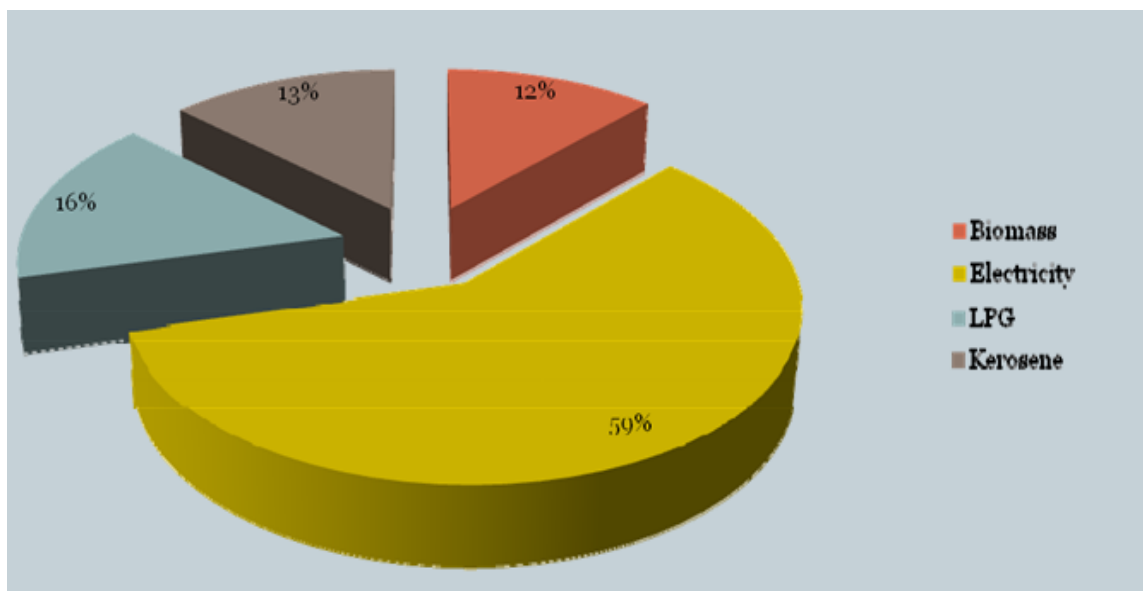


FIGURE 24. Energy demand in households (IEEJ, 2013.)

Petroleum: Demand for petroleum products is intended to increase rapidly in the coming next ten years if the number of industrial projects are achieved, but also because of the new household lifestyle.

Gas: Gas consumption will continue with the same trend because of it uses for the production of electricity as well as in fertilizants industry.

Electricity: Electricity demand is growing fast with a rate of up to 6% per year since 2000. This trend will continue to rise exceeding 12% per year by 2020, due to the development of industrial projects and also changes in household lifestyle.

4.3.2 Energy Supply Projection in Gabon

Petroleum: Proved reserves can secure energy independence for more than 40 years. But the refining capacity need to be increased ,

Gas: Proved reserves also are huge to assure energy independence for several years. But the country needs to focus on large investments.

Electricity: Hydropower potential is expected to face the demand increased. But the country must diversified the energy production and developed other Renewable energy sources.

4.4 The Finnish Case: a model of learning for Gabon

The Finnish example in particular shows how individual protagonists through researches have realized different efforts, development as well as collaboration between scientific organizations, energy associations and industries involve in the sector of renewable energy sources can bring to a growing new high-tech industry. Motiva oy in Finland has made an analysis of that improvement over the past decades and the targets set for 2020. Figure 25 illustrates the developments in Finland closely.

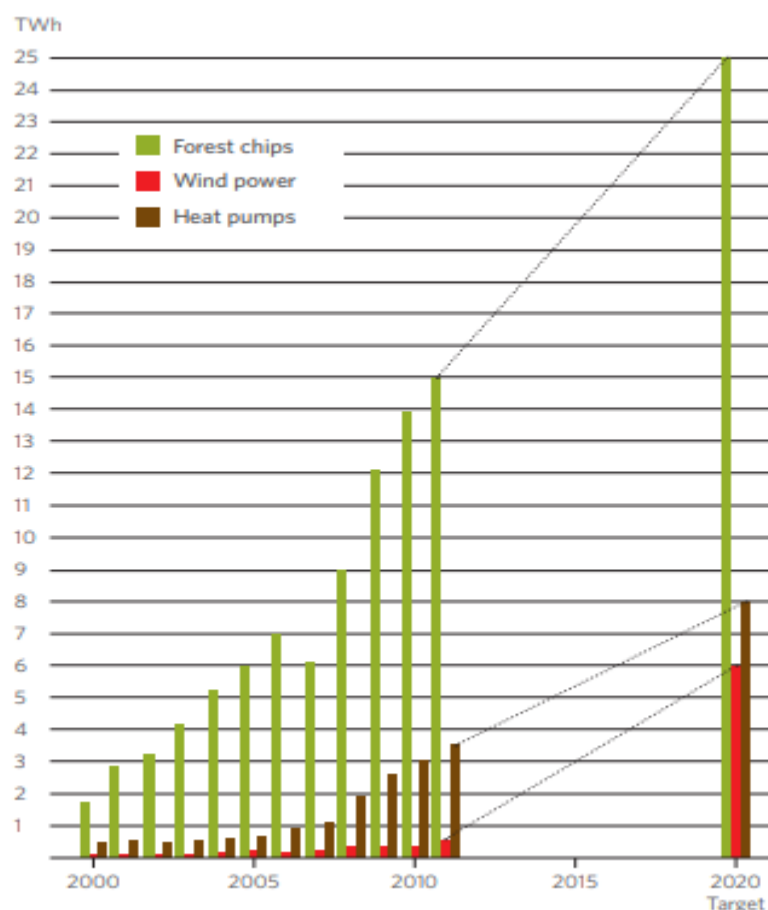


FIGURE 25. Energy production by forest chips, wind power and heat pumps in Finland (Motiva, 2008.)

The main reason explaining the strong growth of the renewable energy supplies in Finland can be considered as political strategies. A system based on a public legal and economic framework has been implanted in the country during the past years to bring up the renewable energy sources the opportunity to be present on the market despite their high cost. Aside of that, different programs, support from energy associations and the government have given the development of renewable energy sources an initial boost. Renewable energy use has extremely increased in Finland during the past years.

There is a diversity range of energy supply in Finland, with no single fuel domination the supply mix. In 2011, primary energy supply was approximately 34.8 mtoe. Oil 27.3 %, biofuels and waste 24.1 % and nuclear energy 18 % were the main used sources.

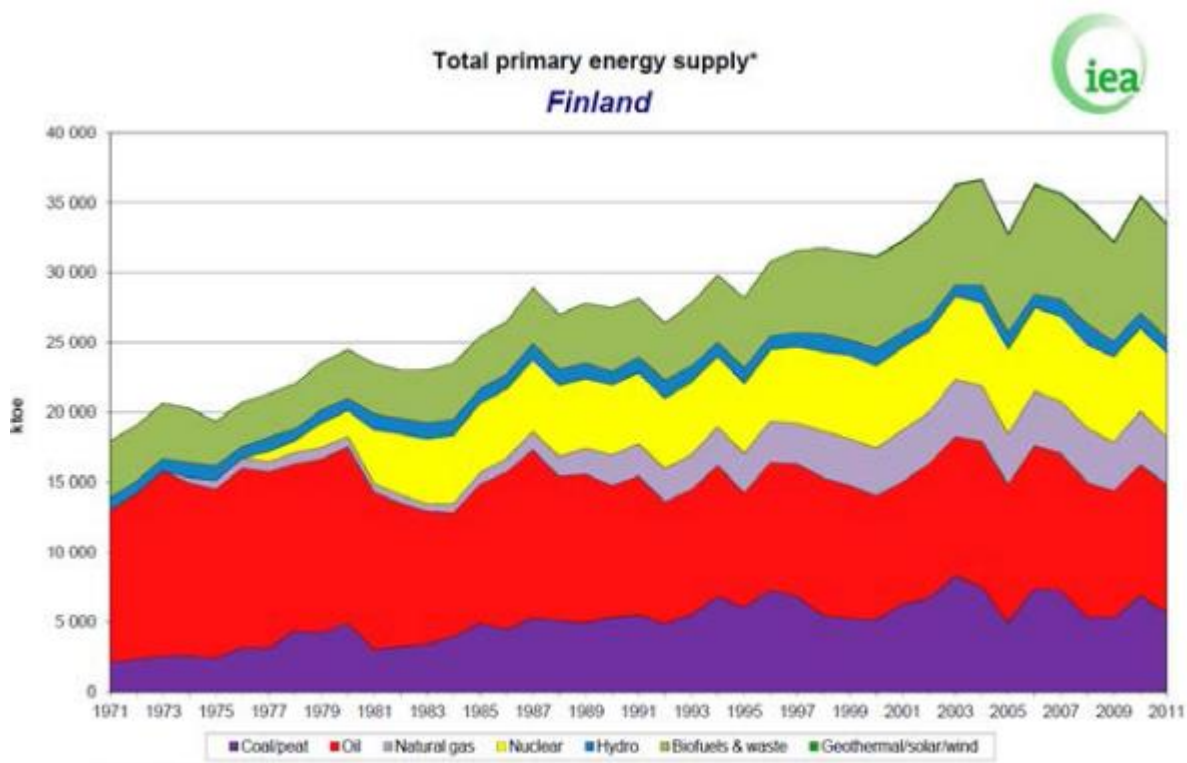


FIGURE 26. Total primary energy supply for Finland in 2011 (Motiva, 2006.)

The energy consumption in Finland is very high. The geographical location of the country in northern hemisphere associated with a cold climate and significant heavy industry sector are the primary causes for the enhanced energy use.

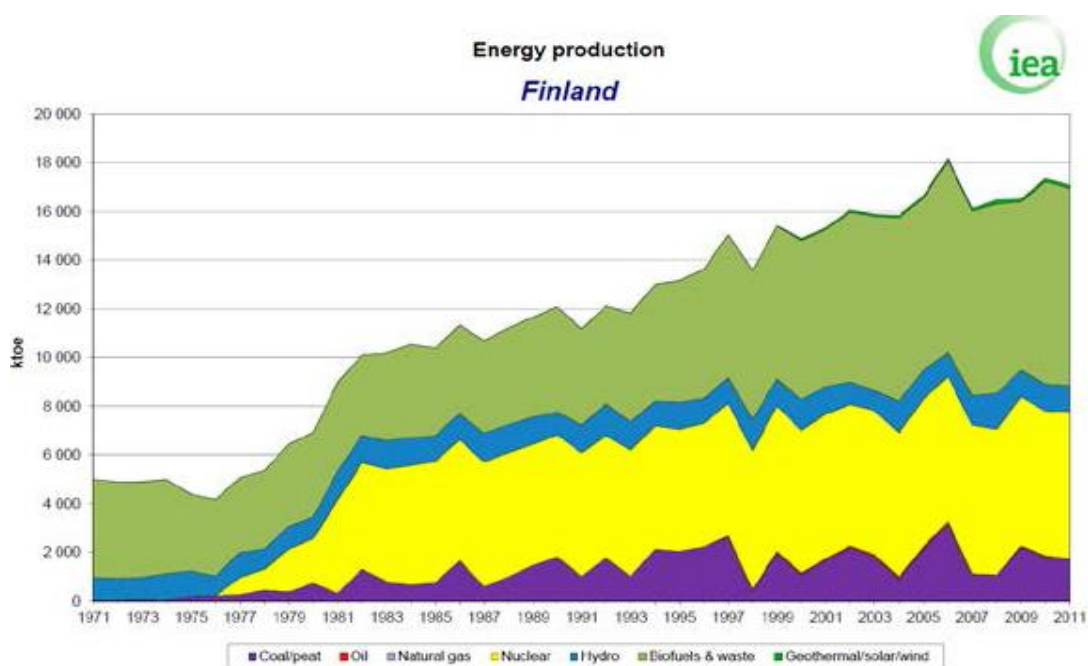


FIGURE 27. Energy production by fuels in Finland for years 1971-2011, (Motiva, 2006.)

Electricity in Finland has been produced from various sources with different proportions through the years. Figure 28 illustrates that approximately 67.7 terawatt hours (TWh) of electricity and heat were generated during 2012. The progression of utilization of renewable energy has continued, and the share was higher than a year before.

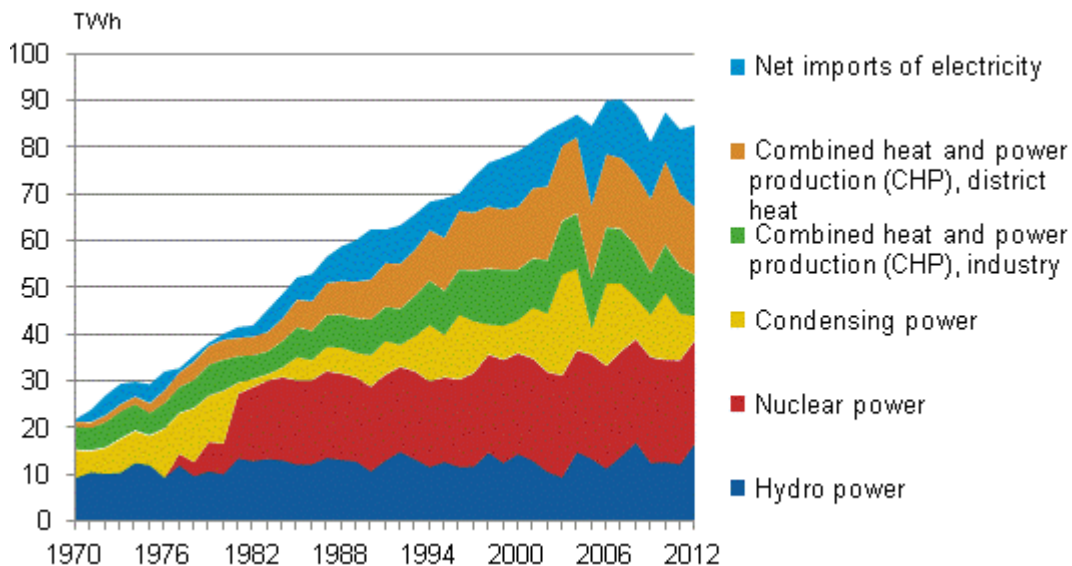


FIGURE 28. Electricity generation in Finland from various sources in different years, (Motiva, 2006.)

Every year, proportions of fossil fuels and peat considerably decrease. Approximately 28 % and 14 % of the energy sources for electricity and heat productions are covered respectively by fossil fuels and nuclear power.

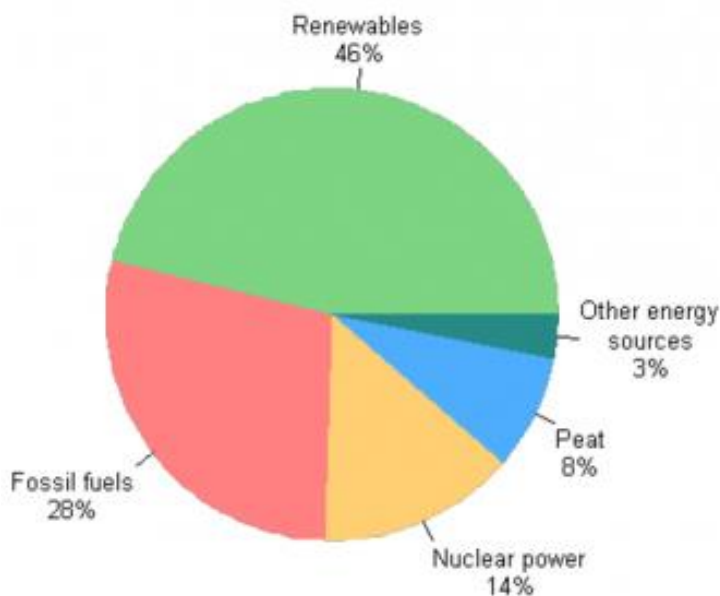


FIGURE 29. The usage of primary energy sources for the production of electricity and heat in Finland in 2012, (Motiva, 2006.)

Renewable energy use has extremely increased in Finland during the past years. In Finland bioenergy, fuels from forest industry side streams, other wood-based fuels in particular as well as hydropower, wind power and ground heat are the main forms of renewable energy sources used in Finland. Among

this variety in renewable energy sources, bioenergy remain the most popular in the country. Many companies existing in the Finland are specialized in converting waste into energy. For the purpose of our study, the researcher will focus on the Biomass use in Finland as a potential example to African countries, especially Gabon.

The thermochemical process is the conversion of a wide range of biomass to energy. According to its chemical composition, biomass can be from different sources. Agricultural residues, corn stover, rice and wheat straw, and even grapevine prunings are important sources of biomass. Other sources of biomass that can be also considered a source of biomass are yard and municipal waste as well as food processing waste and animal waste from livestock facilities.

The thermochemical conversion of biomass to energy can be carried out using a number of different processes (Jay Cheng,2009). Among these processes, there are:

- Combustion for the production of steam and power
- Gasification for the production of a synthetic gas that can be used for power/ heat generation, transportation fuel, and chemicals.
- Pyrolysis for the production of a liquid that can be used for transportation fuel or a source for chemical feedstock.

Figure 30 below illustrates the thermochemical processes.

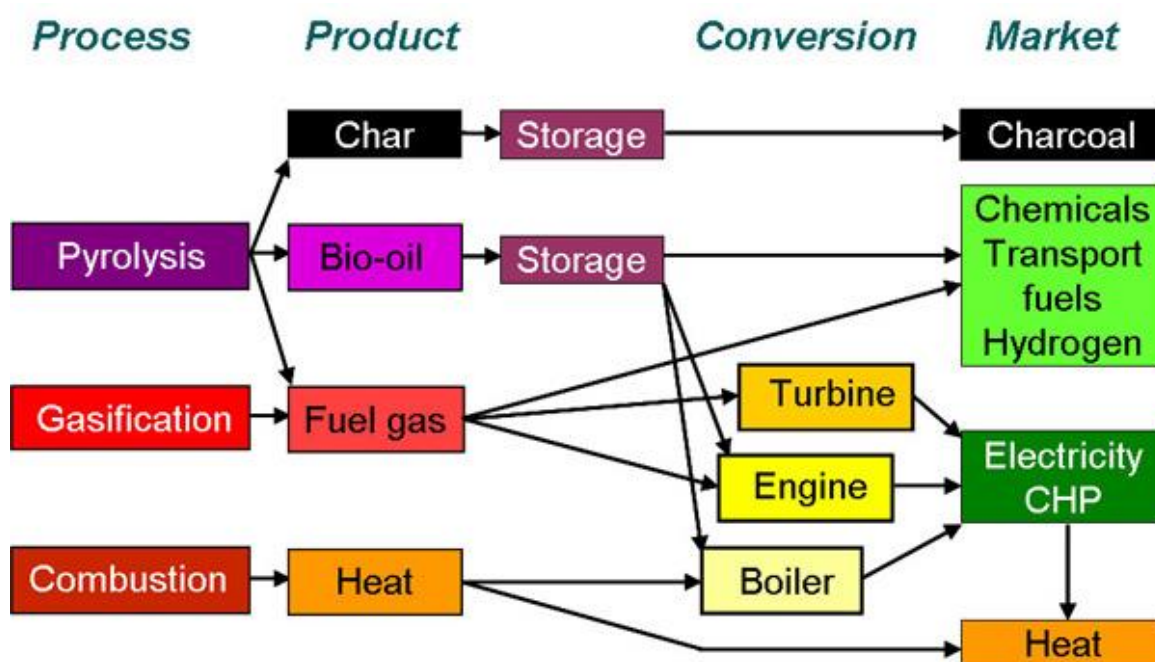


FIGURE 30. Applications of biomass thermochemical conversion processes, (G. Brammer, 2002.)

Gasification uses high temperatures under reducing conditions for the production of a combustible gas mixture. Only partial oxidation takes place under gasification conditions at temperatures that range from 800 °C to 900 °C. The combustible gas produced can be burned in a boiler or used in a gas engine or turbine for production of electricity. Pyrolysis is the conversion of the biomass to a liquid, gaseous, and solid fraction by heating in the absence of air. (Jay Cheng, 2009.)

4.5 Case companies in Finland

Here is the brief description of two case companies operating in Finland with Biomass and a public institution for the promotion of the renewable energy sources.

4.6 Watrec Oy

Watrec Oy was established in July 2003, with the mandate for developing waste-to-energy industry. The first company's project was finalized in 2005, being the first large-scale co-digestion plant in Finland. The company has set a goal to lead Waste-to-Energy industry in Finland and internationalize the market. The mission and vision of Watrec is to achieved success and sustainability in business processing as much wastes as possible and to make a wide contribution in fighting global warming and climate change.

Watrec biorefinery processes organic waste material to raw materials for natural fertilizer production in a biological anaerobic process that strongly reduces greenhouse gas emissions, odour problems, and nutrient leaching. Wastes from municipalities, agriculture, industry, and food production are all sources of renewable energy. Around 10-15 % of the energy production is used in the digestion process.



FIGURE 31. Watrec's Waste-to-Energy description

Watrec Oy has realised several projects in different regions of Finland and intends to expand internationally its activities. In Kuopio region, a biogas plant was implemented during 2013-2014, with a capacity of 60,000 t/year and able to produce 34 GWh/year of bioenergy; full output capacity of produced biogas is over 3.5 MW.



FIGURE 32. Kuopio Biogas plant

4.7 Riikinvoima Oy

Riikinvoima Oy was founded in December 2012 by eight municipal waste management companies. The main task of Riikinvoima Oy is to provide recyclable municipal waste to energy. The company's power plant produces electricity and heat by burning waste. The power plant's incineration capacity is around 145,000 tonnes of municipal waste per year. This means, fuel efficiency is approximately 53 MW. The annual electricity production by the power plant is sufficient for about 4300 homes and district heating for about 10,000 homes.



FIGURE 33. Riikinvoima Oy

The company has a power plant with 54 MW of capacity, which means yearly 90 GW/h electricity and 180 GW/h of district heating. In other words electricity from the power plant is enough for 64 000 locals residents and district heating 10,000 single-family houses needs. The company Andritz oy remains the leading supplier of power plants. (The company official website, 2018.)

4.8 Bioenergy Association of Finland

The Bioenergy Association was founded in 2012 to promote bioenergy sector in Finland. The association has over 270 member organisations. It represents the entire bioenergy sector from land ownership to forest and energy companies, and technology and research in the field. The association promotes the preconditions of renewable energy production, competitiveness and sustainability of economic growth of bioenergy. The association aims to increase the share of renewable and domestic energy to half of the entire energy consumption in Finland. The association aims to strengthen the position of sustainable bioenergy as Finland's largest energy source and get recognition for peat's role in the Finnish energy system. (ALTENER, 2006.)

5 METHODOLOGY

The materials used for this project were found online. Academic literature in forms of books and official publications and reports were used for general theoretical understanding about renewable energy sustainability and implementation. Online publications from the Ministry of Oil, Energy and Hydraulic Resources of Gabon, African Development Bank and Federation of Industries of the State of Sao Paulo, research institutes, companies and Finnish Bioenergy Associations were the main material used, as they provide up-to-date numbers on problems and progress to develop the use of renewable energies in Africa. Based on scientific researches, both renewable energy and fossil fuel present an environmental impact.

5.1 Sustainability Analysis of Renewable Energy

On this stage of the study, a hypothetical sustainability analysis is provided. With the needs to save our environment from negative impacts, sustainability effects should be taken into consideration even for renewable energy. The sustainability analysis of renewable energy of this thesis looks at the environmental, life-cycle, climate, and other impacts of renewable energy technologies. Renewable energies aim to alleviate problems such as air and water pollution, excessive use of water and soil, loss of wildlife and its habitat, public health problems and global warming caused by fossil fuel. The intensity of the environmental impact would vary according to geographic location, climate and other factors. Moreover, the goal of the thesis is to make the reader to understand the fact that there is non-zero impact of those alternatives. According to the Environmental Impacts of Renewable Energy Technologies, the sustainability analysis of renewable energy is focused on the Biomass. (Union of Concerned Scientists, 2014.)

The case study is based on the environmental impact of the use of biomass energy in Finland. Assessing the environmental impacts of bioenergy production is a challenge because direct and indirect emissions come from every phase of production. Long-term planning and wise land use can minimize environmental impacts.

Most of CO_2 emissions in Southwest Finland come from power plants which use fossil fuels as the main resources. The utilization of biomass in energy production has only a minor or no contribution to acidification. The use of fluidized bed boiler has proved that fuel can be burnt with a combustion efficiency of over 95% and the CO_2 can be greatly minimised by addition of limestone or dolomite for high sulphur coals. Low combustion temperature eliminates NO_x formation. Nitrogen oxides affect negatively the formation of ozone in the lower parts of the atmosphere. Thus, there is no emission levels when using fluidized bed boiler for wood and other biomasses as energy and do not have an important negative impact on the ozone layer. Particulate matter emissions generated by power plants are also similar, depending on what type of fuel is used. This can be explained by the need of efficient particle filters in larger scale plants. To reduce particulate matter emissions, highly refined fuels such as pellets must be used. The utilization of biodiesel instead of ordinary fossil diesel, can strongly decrease emissions to 20-39%. Combustion of wood using basic equipment on a household scale is a

source of particulate matter as well. However, since this kind of energy production takes place in less populated areas of Finland, it can not be significantly contributed to negative health effects. (Hirvonen, Katariina, 2013.)

Crop and field biomass result in nutrient loads that contribute to the eutrophication of aquatic systems. The amount of load depends on many factors such as plant cultivation practices, their location and area. With perennial plants, the vegetation is sustainable and the nutrient loads can be reduced even by 20 to 25% unlike annual plants for which the impacts may be exactly the opposite. Soils without vegetation cover are vulnerable to erosion and landslides, two factors contributing to eutrophication in the form of increased nutrient loads. Harvesting the common reed (*Phragmites australis*), an uncultivated plant, for energy production is a potential way to remove nutrients from aquatic systems. In some areas this is a problem as large areas of reed beds can serve as a buffer and protect against coastal erosion. (Hirvonen, Katariina, 2013.)

The study of different live organisms and the extincted species in some area can help to assess biodiversity. The most considerable negative impacts on biodiversity are resulted in the early stages of bioenergy production in agricultural, coastal or forest environments. The recession of some habitats of species may be caused by production transport and refinement. As said earlier on this project, the concentration of emissions greenhouse gases widely vary from renewable energy to fossil fuel. Technologies associated with large water withdrawals for cooling and other operational requirements should be potentially strained in the region where water shortages are a problem. Smart decisions about the deployment of particular technologies so that the most abundant local resources can be used as efficiently as possible and overall impacts are minimized.

6 RESULTS

The conversion and the utilization of energy under different forms intentionally are made by human beings, that's why Dr. Webber of university of Austin Texas in 2013, said: "Energy is the defining element of humanity", because only human can convert both mechanical and chemical energies into the desired forms. The analysis and findings part of this final thesis will be focused on three most important factors on energy, which are climatic protection, energy independency and renewable energy and diversification as a real solution.

6.1 Climatic Protection

Climate change is one of the major challenges of the 21st century. It's very clear that severe impacts can still be avoided through efforts to transform the current system. Renewable energy sources have enormous potential to reduce greenhouse gas emissions from fossil fuel combustion and thus mitigate climate change. Since 1850, the use of fossil fuels (coal, oil and gas) has largely dominated energy supply, resulting in a sharp increase in carbon dioxide (CO₂) emissions, which had increased to over 390 ppm. (Ottmar Edenhofer, 2012.) Some options for lowering greenhouse emissions can be focused on energy conservation and efficiency, fossil fuel switching and renewable energy.

6.2 Energy Independency

Renewable energy sources such as solar, wind, hydro and geothermal energy are more advantageous than fossil fuels because they do not release directly greenhouse gas emissions. Renewable energy sources are also unlimited, infinitely available resources especially solar and wind as well. They improve the quality of air and public health contrary to fossil fuel which damage the land.

The utilization and development of renewable energy is the only way to achieve energy independency, on both national and individual levels. The more we will use renewable energy sources in a country, the less we will need to rely on using carbon based fossil fuels, therefore there will be improvements to a greater economic, political, and environmental stability.

6.3 Renewable Energy and Diversification as a solution in Gabon

Here are different ways and means how the Republic of Gabon can find a solution their energy, environmental and economy problems:

- There are a lot of unrecyclable plastics, organic matter like baby diaper which need to be recycled and be burned through a boiler to make fuel pellets.

- Organic waste through anaerobic decomposition can be converted into biogas to generate CH₄ or RNG or biogas, and to be used as natural gas for cooking, heating and power generation.
- Landfill gas is the popular one to mine biogas at landfills by punching holes in landfill to capture the biogas that comes out from the anaerobic digestion of municipal solid waste. The landfill prevents oxygen from getting down to the decomposition, so it's like a huge anaerobic digester. Those gases, can be collected and then used to make electricity.
- Another solution which can be used is to convert agriculture manure and wood residues to biogas through anaerobic digestion to generate electricity and increase the access to electricity.

Based on these suggestions, there is an opportunity to consider seriously environmental problems and find solutions to resolve them.

7 CONCLUSION AND SUGGESTIONS

The aim of this thesis was to find out how to sustain, promote and encourage the development of renewable energy sources in Gabon, to provide electricity to the 42% of Gabonese who do not have yet access to energy, but also to use energy source that is environmentally friendly, unlimited and infinitely available to help the country to achieve energy efficiency as well as its economic growth. A good conclusion can be achieved through combining all the information found.

7.1 Conclusion

Gabon is a country with plenty of natural resources and endowed with abundant renewable energy resources. However, the power capacity is only 375 MW, which is not enough to cover the electricity grid of the entire country, when the exploitation of hydropower is about 6000 MW. Thus, it will be necessary to exploit more the resources and extend the distribution network increase due to the fact that the Gabonese population increases by 2.24% per year.

There is the need to encourage development of energy diversification by using the different type of renewable energy sources. Fossil fuels should be used with restriction in such a way that will generate revenue to the government as long as possible. The implementation of renewable energy in rural areas will be a solution to reduce the internal dependence and consumption of petroleum products and gas.

During this project, the researcher discovered that electricity demand in Gabon remains high in rural areas. However, supply is insufficient and constant to meet demand, leaving many Gabonese citizens with no choice but to use conventional private power generation systems.

The potential of renewable energy resources in Gabon is very big compared to fossil energy resources. Solar, wind, hydro and biomass have significant potentials to enhance and provide electricity access to all Gabonese and contribute strongly to a sustainable development.

7.2 Suggestions

The results of the research help us to bring out some suggestions. It is clearly evident that renewable energy is actually used in Gabon. However, there is need for promoting and giving access to all layers of society. In view of this, government and private sector should support the creation of development centers and an establishment of energy extension outfits. The existing thesis and development centers must be supported and improved to carry out quality research and improvement activities, while the energy extension centers should be charged to diffuse and demonstrate activities of the renewable energy system.

There is a need to stimulate collective efforts to reverse deforestation by strengthening and rewarding community efforts in sustainable management of forests and other local natural resources.

All of the suggestions, actions and implementation strategies to promote the growth of renewable energy sources and practices will only be achieved and realized through institutions that will be responsible for sustainable energy promotions. In this regard the Government of Gabon should approve and release a comprehensive National Energy Policy for the country and also a regulatory mechanism design to identify organizations, institutions and local government levels that will be mandated to ensure the implementation of projects and programs of renewable energy.

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