Potential Contribution of Solar Thermal Power to Electricity Supply in Northern Nigeria

By

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Abstract

Energy is an essential requirement for a reasonable socio economic development in a country; however, its provision depends on availability of energy sources and the required investment. Nigeria possesses abundant deposits of energy sources ranging from fossil fuel to renewable energy sources. Over the years, the level of production of energy from these sources has been considerably low. The present level of electricity supply is short of demand and the supply is not reliable. As the country is experiencing rapid growth in population, adequate energy provision is necessary for corresponding level of production and development. The need for sustainable and renewable sources of energy has emerged globally owing to environmental issues associated with the use of conventional fuel. In order to consider the possibility of harnessing the solar energy resource in northern Nigeria, this study explores the potential contribution of the adoption of Concentrated Solar Power (CSP) technology to the energy system in the far northern States of Nigeria. These States are chosen because the region lies within a high sunshine belt and thus having a daily average DNI of 6.2 KWh/m2 / day and an annual average of 2320 KWh/m2/yr. The annual average DNI in the region is a bit higher than that of the Andasol CSP plant in Spain which is 2090 KWh/m2/yr. The thesis seeks to uncover the potential for CSP in Nigeria, and determine when the cost of energy from CSP will become competitive with the cost of energy from conventional power. Using three possible economic growth scenarios (reference (7%), high (10%) and optimistic (13%) economic growth scenarios) to model future energy demand and supply from CSP and conventional gas plant. The results obtained show possible competition from potential CSP plant in Nigeria depending on the international and domestic gas market. However, continuous payment of blanket subsidy on the domestic price of natural gas in Nigeria will adversely affect potential investment in CSP market in Nigeria.

Declaration

I hereby declare that the work in this document is expressed in my own words. The use of other author's ideas, equations or expressions in any form within this work is properly acknowledged. The document contains a list of references employed for this study.

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Olumide O OGUNMODIMU

Dedication

To my parents, Eliot and Elizabeth Ogunmodimu for your love and support all through my studies

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I owe the successful completion of this work to God almighty the giver of wisdom. I will also like to appreciate the following persons whose help and encouragement have been of great significance.

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Acronyms

AIAE	African Institute for Applied Economics
BECANS	Business Environment and Competitiveness across Nigerian States
BCF	Billion Cubic Feet
CDM	Clean Development Mechanism
CSP	Concentrated Solar Power
CIA	Central Intelligence Agency
CBN	Central Bank of Nigeria
CRS	Congressional Research Service
CoE	Cost of Energy
DNI	Direct Normal Irradiance
DoE	Department of Energy
ECN	Energy Commission of Nigeria
EIA	Energy Information Administration
FCT	Federal Capital Territory (Abuja)
GHGs	Green House Gases
GNESD	Global Network on Energy for Sustainable Development
GDP	Gross Domestic Product
HVAC	Heating, Ventilation and Air Conditioning
IPCC	Intergovernmental Panel on Climate Change
IMF	International Monetary Fund
IEA	International Energy Agency
IPP	Independent Power Producer
ISCC	Integrated Solar Combined Cycle
LCoE	Levelised Cost of Electricity
LFR	Linear Fresnel Reflector
MDGs	Millennium Development Goals
MENA	Middle East and North Africa
MAN	Manufacturers Association of Nigeria
MMSD	Ministry of Mines and Steel Development
NASA	National Aeronautics and Space Administration

NBS	National Bureau of Statistics
NNPC	Nigerian National Petroleum Corporation
NEEDS	National Economic Empowerment Development Strategy
NEPA	National Electric Power Authority
OPEC	Organization of Petroleum Exporting Countries
PCU	Power Conversion Unit
PR	Progressive Ratio
PHCN	Power Holding Company of Nigeria
PPP	Purchasing Power Parity
UN	United Nations
UNDESA	United Nations Department of Economic and Social Affairs

UNITS

GWh	Gigawatt hour
KWh	Kilowatt hour
Kgoe	Kilogram of Oil Equivalent
Mtoe	Million tons of Oil Equivalent
MWe	Megawatt electric
MWh	Megawatt hours
MMBtu	Million British thermal unit
TSCF	Trillion Standard Cubic Feet
TWh	Terawatt hour

Chapter 1

Introduction

Energy provision is an essential prerequisite to a nation's social and economic development. Energy services enable fulfilment of basic human needs such as adequate food supply, lighting, warmth, education and health, which are objectives of the United Nations (UN) Millennium Development Goals (MDGs) (GNESD 2007:5). Access to adequate energy provision remains significant in achieving the MDGs. According to Alam (2006), "energy is an essential force driving all economic activities." In other words, the economic development of a nation is a function of its energy provision. No country can develop beyond a subsistence economy without adequate energy provision for its citizens (Adenikinju 2003). As the world is experiencing rapid growth in population and increase in industrial activities, more energy is consumed, resulting in environmental pollution and an increase in greenhouse gases (GHGs).

However, the world has a wide range of energy sources that can provide energy for decades; the major concern is how to ensure security of supply while minimising environmental impact (Sims et al 2007). The conventional energy sources are fossil fuel based, such as oil, coal, and natural gas. These sources are finite, and not sustainable. Moreover, anthropogenic activities through exploration and transformation of conventional primary energy carriers are causing environmental degradation and change in global climatic conditions. The importance of alternative sources of energy to human health and the environment has informed global renewable energy development through various UN sustainable development programmes. Since the World's Summit on Sustainable Development held in Johannesburg in 2002, the need for renewable energy development has gotten a great deal of attention from world leaders (IPCC 2007).

Renewable energy is energy from natural infinite sources such as wind, sunlight, geothermal, tides, and water. These sources are naturally replenished and are energy carriers that can be utilised in an environmental friendly manner. Renewable energy technologies include hydropower, which is an old source of power generation and presently accounts for about 3.4% and 16% of global final energy and electricity consumption respectively. Others such as modern biomass, wind, bio fuels, solar, geothermal and mini hydro account for about 3% of global energy consumption (REN21 2011). However, renewable energy technology is growing rapidly. For instance, wind energy is growing at about 20% annually and it is widely used in America, Europe and in Asia (Alex 2011). Another fast growing renewable technology is Photo-Voltaic systems' market with about 67, 000 MW worldwide capacity as at December 2011 (EPIA 2012). Bio fuel is commonly used in Brazil and America: it contributes about 18% to automotive fuel used in Brazil (Richard and Lugar 2006). Other renewable energy sources are geothermal and solar thermal plants, which are comparatively used in United States and Spain.

This research work focuses on the feasibility of an emerging paradigm of renewable energy technology in Nigeria. It examines the potentials for Concentrated Solar Power (CSP) plants in selected northern states of Nigeria. The study focuses more on the economic implications of the technology and the future energy demands of the country and the region in particular.

Nigeria is a West African country located at the North of the equator on geographic coordinate 4^0 1' - 13^0 9' North and $2^0$2'- $14^0$30' East (Figure 1.1). Nigeria enjoys a humid tropical climate characterised by hot and wet weather conditions with relatively high temperature throughout the year. The vegetation transits from mangrove forest in the south to tropical rain forest in the inlands and progresses to Savannah and Sahel regions in the north and far north. The variation in the rainfall level across the country is responsible for the differences in vegetation. Southern regions are humid, with high rainfall level. The rainfall level and humidity are lower in the northern region (Library of Congress 2008).

Nigeria is the largest economy in the West African region and the third largest in Africa after South Africa and Egypt (IMF 2011). Nigeria is a vast country, home of Africa's largest population of about 158 million people (UNDESA 2010). It covers an area of about 356, 667 sq miles (923,768 sq km), of which 351,649 sq miles (910,771 sq km or 98.6% of total area) is land (CIA 2012). The nation consists of six geopolitical zones subdivided into 36 states and the Federal Capital Territory (FCT).

Figure 1.1: Map Showing Nigeria Location

1.1 The Study Region

This study examines the energy situation in seven northern Nigerian states, which are Borno, Jigawa, Kano, Katsina, Sokoto, Yobe and Zamfara, all spread across the open Sahel-savannah region from Sokoto in the extreme North-West to Borno in the Chad basin North-Eastern part of Nigeria (Figure 1.2). The estimated land area of the region is approximately 252,102 Square-Kilometres (NBS 2009). The topography is generally flat, and the region has an average daily solar radiation of 7.0 KWh/m^2 (Adeyanju 2011). States like; Sokoto, Yobe and Zamfara derive their names from rivers Sokoto, Yobe and Zamfara, which are important geographical features in the region. Other rivers in this part of the country are Hadeja, Ka, Rima, Bunzuru, Gona, Goma, and Ngadda. These rivers have potential for mini hydro power stations but at present are used mainly for irrigation and fishing.

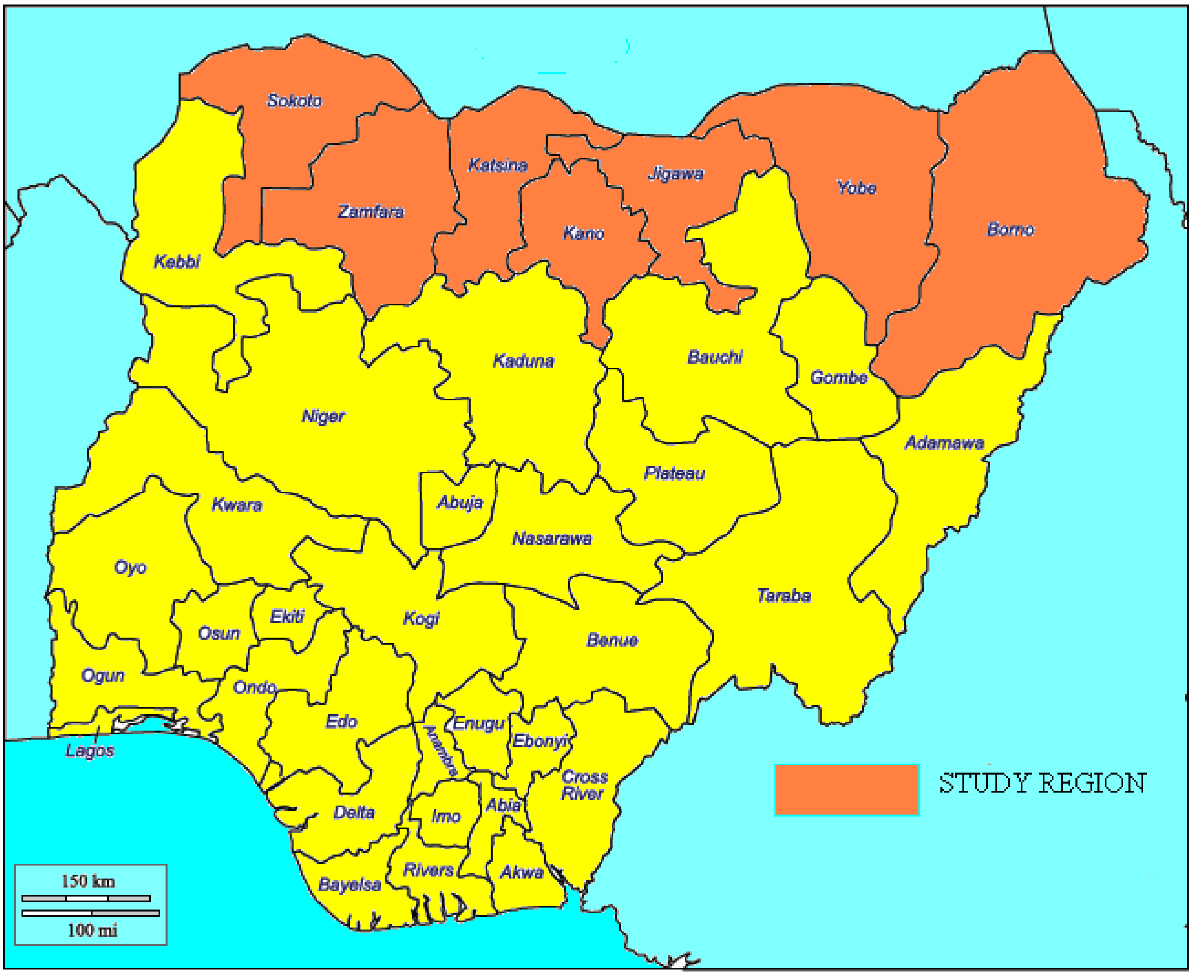


Figure 1.2: Map Showing Study Area

1.2 Research Problem

Despite the abundance of energy sources in the country, Nigeria is faced with challenges of generating and supplying adequate power to meet the country's energy demand (Sambo 2008). The aging power stations can no longer meet the country's energy demand, and a large quantity of electricity is lost in the transmission and distribution system. Power failure in major cities are hampering economic activities hence huge amount of money is spent by industries and private business owners to procure and maintain personal generators (Power Report 2007). These factors stress the need for Nigeria to harness its renewable energy sources especially at a time when the world is clamouring for sustainable energy growth (IPCC 2007).

Power supply from gas thermal power plants complements power production from hydro power plants in Nigeria. However, gas supply to these plants is often being interrupted by militant activities and poor gas supply infrastructure. In addition, the government is presently subsidising the cost of gas to power stations in order to encourage an increase in power generation. This subsidy is not, however, sustainable because it is a blanket subsidy where both the rich and the poor benefit from it. Further to this, the gas consumed locally at subsidised price could have been sold at international gas price to generate more revenue for the country and such revenue can be used in providing infrastructure that will improve power supply in the country. Since the cost of generating power from gas thermal plants in Nigeria is low, the development of other energy sources such as renewable energy may be challenging as subsidy on gas will not allow a competitive energy market (WADE and Iceed 2009).

Diversification of Nigeria's energy supply and effective use of its renewable energy potentials is necessary as this will increase power supply to the country and reduce the cost of building infrastructure to transmit power over long distances (Iwayemi 2008). Renewable energy resources in the country include solar energy, mini hydro power, wind energy, biomass, biodiesel, biogas and geothermal energy (Ugah 2011). These sources are not fully utilised in the country's energy mix. The use of renewable energy in Nigeria is basically in solar energy applications such as solar Photo-Voltaic (PV) systems and solar driers. Solar PV are used in street lighting, water pumping (Solar water pumping from boreholes), and in telecommunication to power base stations especially in areas where there are no public power supply. However, the share of solar PV applications in the nation's energy supply is negligible. While Nigeria has the potential to generate a substantial volume of electricity from renewable sources, the potential is not fully utilised. For instance, the solar energy potential in northern Nigeria can meet the region's energy demand if government creates an enabling environment for solar energy technologies (Adeyanju 2011).

1.3 Objectives

The objectives of this project are:

i. To determine future energy demand in the study region based on possible growth in production.

ii. To determine the feasibility of using CSP to complement power supply to the study region (northern Nigeria) and to determine when the cost of energy from CSP will become competitive with the cost of energy from conventional power.

1.4 Key Questions:

The thesis will attempt to answer the following questions:

i. Power supply in Nigeria is below demand due to shortage in supply. ***Considering the available solar energy resource in far- northern states of Nigeria, what are the criteria for the adoption of CSP as a renewable source of power production?***

ii. Bearing in mind the abundant deposit of energy sources in the country and the cheap cost of domestic gas supply to power stations, ***when would the cost of energy from CSP become competitive with cost of energy from conventional power?***

1.5 Methodology

This study will be done through in-depth review of relevant literature on the Nigeria power sector especially publications from government authorities and energy statistics compiled by the Energy Commission of Nigeria (ECN) and the Nigerian Bureau of Statistics (NBS). The Direct Normal Irradiance (DNI) in the study area will be determined through the National Aeronautics and Space Administration's (NASA) satellite data. Electricity intensity in the study region will be estimated by relating available energy in the region to its productivity (KWh/GDP) for the base year. Electricity demand projection will be done using three different scenarios.

- Reference Scenario (7% increase in GDP
- High growth scenario (10% growth in GDP)
- Optimistic scenario (13% growth in GDP)

The Levelised cost of electricity (LCoE) from conventional power plants and CSP would be analysed on a spread sheet to model when energy from CSP becomes economically viable.

1.6 Scope of work

This study focuses extensively on CSP potential and feasibility in selected northern states of Nigeria using NASA's satellite data. This region is chosen because of its solar energy potential and relative favourable conditions for CSP plants. The study does not consider a particular site but does general assessment of CSP feasibility based on available resources and economic activity in the region.

The following areas of interest are beyond the scope of this work

- Consideration of CSP potential on a specific site and precise engineering requirements
- Ground station DNI measurement in comparison to satellite data

1.7 Limitations of the Study

The study is limited by non-availability of adequate data and funding. Sufficient details on power supply to the study region and its power consumption pattern were not available. Satellite data were used because key documents showing ground station measurements of DNI could not be accessed. Specific site measurements and evaluation could not be done due to non-availability of financial support for the study.

1.8 Thesis Structure

The thesis is structured as follows:

Chapter one presents a general introduction to the study

Chapter Two is a background study and an overview of Nigerian energy policies. An outline of the country's energy resources, the current level of utilisation and possible future energy development will be discussed.

Chapter Three focuses extensively on energy situation and productivity in the study region. The present level of productivity will be used to analyse the electricity intensity in the region and possible future energy requirement.

Chapter Four presents details on solar energy potential and feasibility of CSP technology in the study region. An outline of CSP technology in different locations will be discussed alongside available resources for the technology in the study region.

Chapter Five focuses on the economic analysis of cost of energy from CSP in comparison to cost of energy from conventional power under Nigeria condition. Details on price of domestic and international gas will be analysed to know when it will be appropriate to adopt the technology in the nation's energy mix.

Chapter Six presents conclusion and Policy implications

Chapter 2

Background study and overview

In a study done on the economic feasibility of CSP technology in Middle East and North-Africa (MENA) region and Egypt in particular, Franztries et al (2012), and Mosta Elshazly (2011), noted that the solar energy potential in the region can be harnessed in an economically viable manner. These studies describe under what conditions the cost of energy from CSP becomes competitive with conventional energy in the region. Mosta Elshazly (2011) noted that if the cost of fossil fuel increases at constant rate of 1.5% per annum, then the cost of energy from CSP will become competitive with conventional power in Egypt by the year 2050 under a moderate growth cumulative capacity of worldwide installation of CSP and Progressive Ratio (PR) of 0.88. The moderate growth cumulative global capacity is the average rate of global market deployment of CSP. PR describes unit cost decrease with increase in cumulative production, the cost declines by a constant percentage as number of unit product doubles. PR 0.88 means the cost declines by 12% as number of unit product doubles (Neiji 1997:1099).

In Nigeria's case, the solar energy resource for CSP is limited compared to the MENA region. However, in a study conducted by the Energy Commission of Nigeria (ECN) on the energy supply projection by fuel, the country is said to start harnessing its solar thermal potentials from year 2020 (ECN 2011). The future integration of solar energy and other renewable energy sources into the country's energy supply mix as projected in the ECN study was informed by the objectives of the national energy policy and the renewable energy master plan (Sambo 2006). One of the objectives of these documents is to broaden the energy options for electricity generation. Solar energy and seven different types of fuel were used in the ECN optimisation model. Other fuels are gas, hydro, nuclear, coal, mini hydro, wind and biomass.

The region in focus in this study is areas considered most appropriate for CSP technology because of the relatively high DNI recorded from the NASA satellite. Details of this will follow in subsequent chapters. In order to study the feasibility of CSP in Nigeria, it is important to give a synopsis of the energy situation in the country. This chapter gives information on the energy situation in Nigeria as well as the current level of utilisation. It discusses the basic components of the national energy policy and the future electricity demand projections based on GDP growth scenarios.

2.1 Overview of Nigerian Energy and Power Sector

Nigeria has ample varieties of conventional and renewable sources of energy (Sambo 2009). The country is the continent's most prolific oil producing nation, which together with Libya, accounts for 70% of Africa's crude oil reserves (Cole 2004). It has a proven crude oil reserve of about 4500 million tons of oil equivalent (Mtoe) in addition to 4.5 trillion m^3 (187.44 TSCF) of natural gas, and hydropower potential (large and small capacity) estimated at 14,735 MW. Other energy sources include over 4 billion tonnes of coal and lignite, wind power of about 150,000 TJ per year at an average speed of 3.0m/s, 144 million tons of biomass per year and average solar radiation of 6.0 KWh/m^2/day (ECN 2005). Despite the abundance of energy resources in Nigeria, the energy consumption per capita is comparatively low to that of most developing countries (ECN 2011). Figure 2.0 shows Nigerian energy consumption in comparison to some selected developing economies

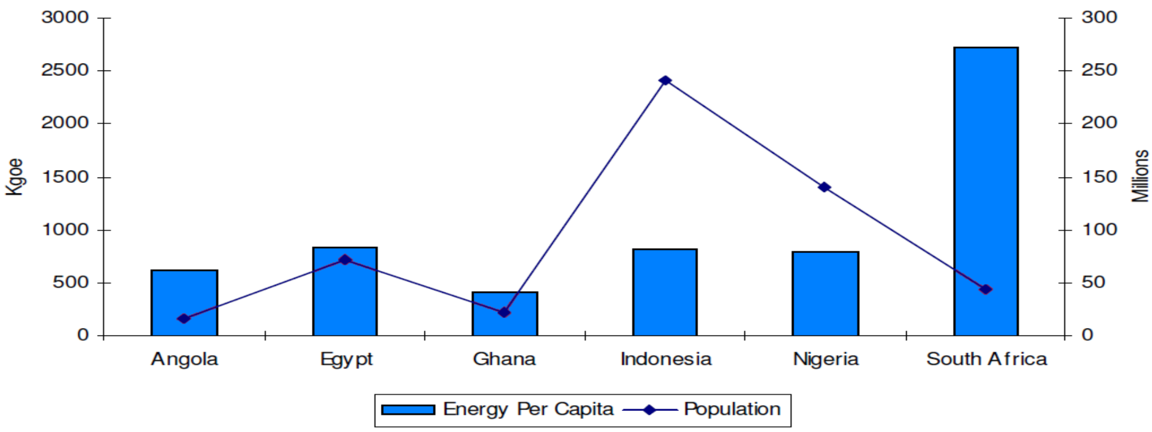


Figure 2.0: Energy Consumption of Nigeria in Comparison to some developing countries in 2004. Source (FGN 2009)

In 2004, Nigeria with population of over 140 million people consumed 776.9 Kgoe of energy per capita compared to the 2596.9 Kgoe of energy consumed by South Africa with population of about 44 million (ECN 2009). It is evident from these Figures that despite the available energy sources, the per capita energy consumption in Nigeria is very low. The low energy consumption can be attributed to persistent power outage and poor indigenous crude oil refining capacity (Oseni 2011). The aging power plants and refineries are now producing below the installed capacity. The inability to produce adequate energy has caused persistent scarcity of petroleum products and high dependence on personal generator for electricity production.

According to the 2009 energy balance published by the International Energy Agency (IEA 2011:213) (Appendix A, Table A1), a greater percentage of Nigeria's secondary (refined oil products) energy supply is imported than is produced locally despite the country's abundant primary energy (Crude oil) production. The IEA data shows that about 95.1% of the indigenous fossil fuel produced in Nigeria in 2009 was exported. The remaining 4.9% was consumed locally as 4.3% natural gas and 0.6% refined oil products (IEA 2009). In order to improve energy supply in the country, Nigeria should concentrate on developing local refinery capacity. This will have the potential to increase local energy supply and reduce the dependence on expensive imports. It is also important to add value to mineral resources before exporting them. Nigeria could focus on refining oil before exporting it, thus generating greater revenue from exports. This extra revenue could be reinvested into the local power sector.

2.2 Conventional energy sources in Nigeria

The major conventional energy sources in Nigeria are coal, natural gas and crude oil. Nigeria is an oil-producing country and active member of the Organisation for Petroleum Exporting Countries (OPEC). The country's crude oil reserve is ranked 10^{th} in the world with estimated value of 36.5 billion barrels of oil in 2007. Figure 2.1 shows the countries with the top 15 crude oil reserves in the world.

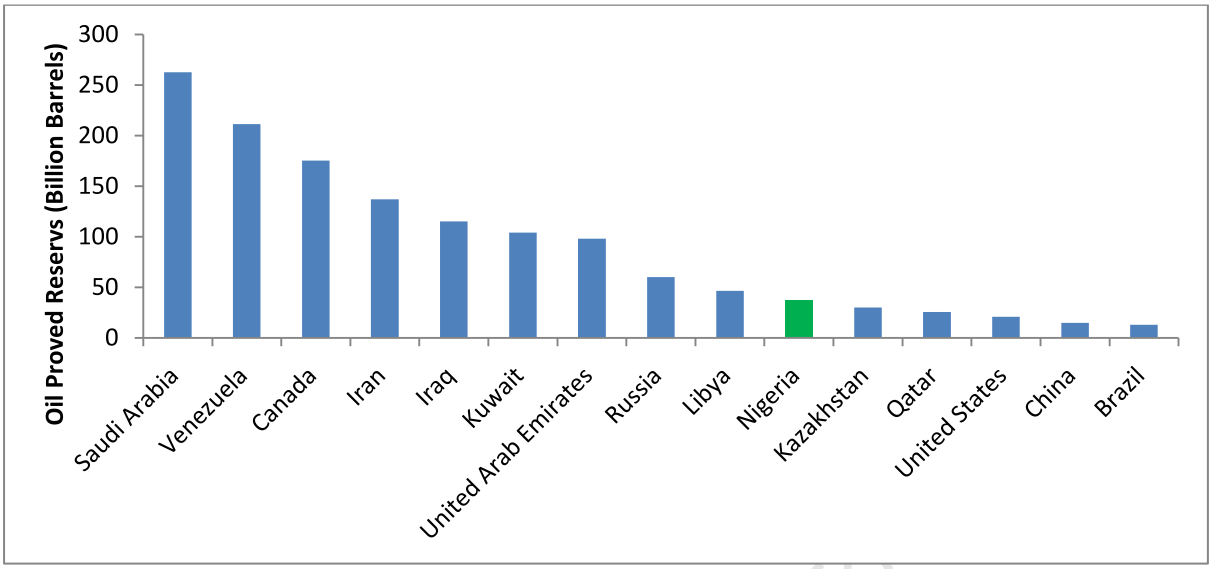


Figure 2.1: Crude oil reserves of different countries (Source: CIA 2012)

Since the discovery of crude oil in 1958, it has become the country's most valuable economic asset. Coal, which used to be Nigeria's main energy source, makes up an insignificant portion of the energy supply since the crude oil discovery, and conversion of railway engines from coal to diesel engines. This decline is visible as depicted in Figure 2.2.

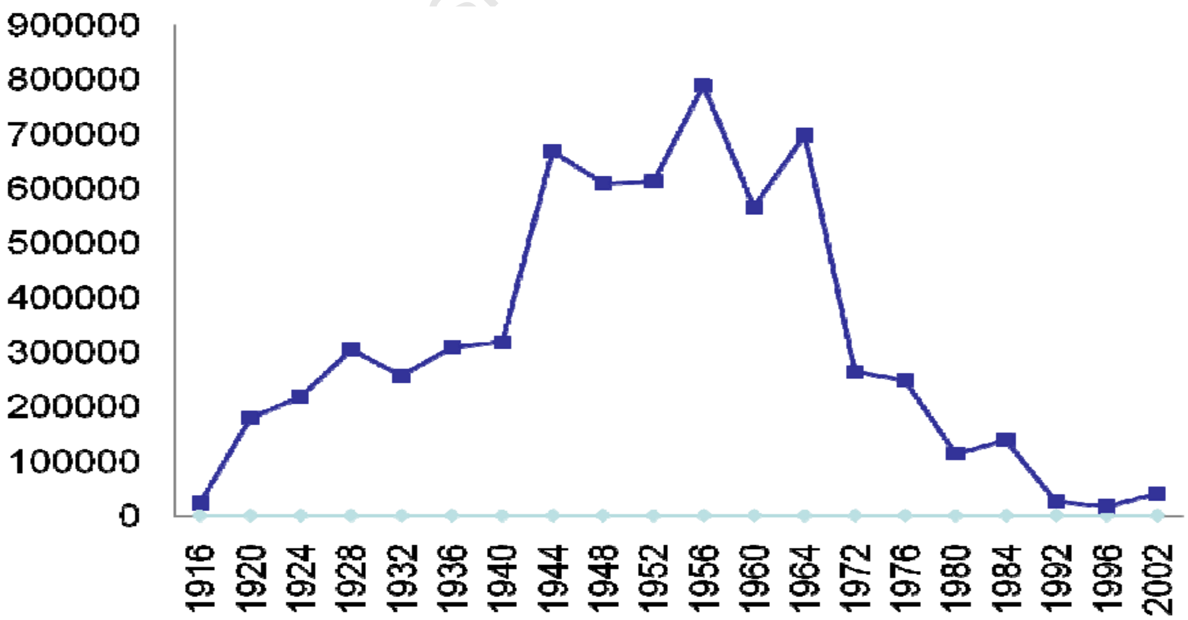


Figure 2.2: Coal production in Nigeria 1912-2002 (Source: Ministry of Mines and Steel Development)

Nigerian coal remains underutilised due to the low state of local consumption. Major local consumers such as cement factories have switched to natural gas partly because of the ease in transportation and cheap domestic gas price. Government in its efforts to improve its domestic gas market has built infrastructure to ease transportation of the product to local consumers. Nigerian coal is of sub-bituminous grade with low sulphur content. The low sulphur content reduces the environmental effects of coal use, such as SO_2 emissions and acid rain; however the impacts are still significant (Babcock and Wilcox 1972). Despite global environmental concerns, coal still plays vital role in the world's energy supply. It accounts for about 41% of the world's electricity generation and it has been the world's fastest growing energy source in the last decade. China for instance provided the energy needed for its fast growing economy from coal in the last decade (World Coal Association, 2012).

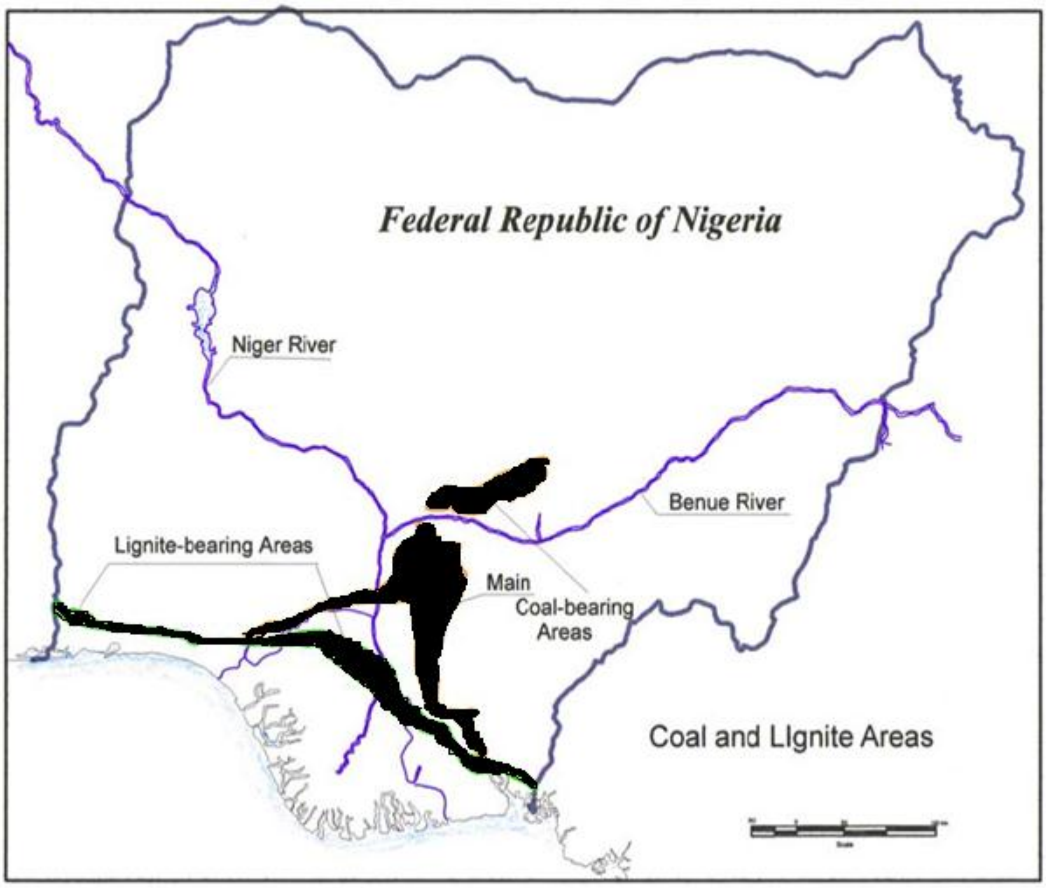


Figure 2.3: Coal and Lignite areas in Nigeria (Source: Ministries of Mines and Steel Development 2010:15)

The Nigerian coalfields are spread across 13 states with a proven reserve of 639 million tonnes and inferred reserves of about 2.75 billion tonnes. The coal and lignite deposits are located along the coastal plain of the Niger Delta areas and close to river Benue and the inlands of the Eastern region of Nigeria as illustrated in Figure 2.3 (MMSD 2010). Efforts to rebuild Nigerian coal market include the adoption of coal in electricity generation and the establishment of coal briquette plants (ECN 2011). Employing coal in power generation will increase power supply in the country especially in areas where coal deposits are found. While coal will contribute significantly to Nigerian electricity production, adoption of briquette as an alternative to fuel wood will serve as a strategy to fight desertification and soil erosion.

Another important conventional energy source in Nigeria is natural gas. The nation has a proven gas reserve of 187 trillion cubic feet, ranked ninth in the world (Figure 2.4) (BP 2011). The largest domestic consumption of gas is in power production. However, poor infrastructure for gas transportation and gas flaring are major challenges limiting gas production and consumption in Nigeria. For instance, out of about 770 BCF of gas produced in 2004, about 325 BCF accounted for domestically and for export, leaving the remaining 445 BCF flared (ECN 2009).

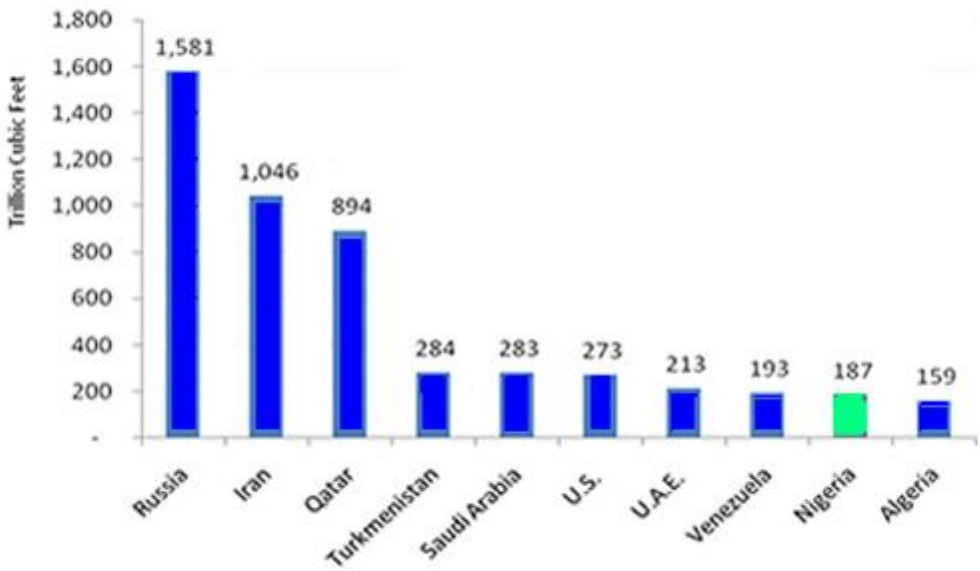


Figure 2.4: Nigerian proven gas reserves 2010 (Source: BP Statistical Review of world Energy 2011)

Gas flaring has been a major issue in Nigeria since beginning of oil production however, efforts by the government to reduce and eventually stop it is being frustrated by poor and inadequate infrastructure. Since 2008, gas flaring has reduced significantly and government has given December 2012 deadline for all oil firms in the country to stop flaring gas (ECN 2009). Worse hit by these challenges is the power sector due to poor gas supply to power plants. Lack of adequate gas supply has reduced the operations of newly constructed Independent Power Producers (IPP) power plants to the extent that absence of gas is preventing about 1,025 MW from being exported to the national grid as at June 2012 (Ejiofor 2012). Government is working out plans to develop domestic consumption of gas and improve its exportation. Plans are underway to complete the West African pipeline project and the feasibility of expanding the project through Nigeria-Algeria Saharan gas pipeline to the European markets (NNPC 2010).

2.3 Renewable Energy in Nigeria

Nigeria has great potential for renewable energy investment. The significant renewable energy sources are solar energy, biomass, wind, small and large hydropower with potential for hydrogen fuel, geothermal and ocean energies (Sambo 2009). Apart from hydropower, which contributes about 29% of Nigeria power generation, renewable energy utilisation is dominated by traditional biomass consumed in households as fuel wood (Akinbami 2001).

According to research conducted by Gaafer and Kouakou (1993) on bio energy potential of Nigeria in 1990, the country's bio energy potential was estimated at approximately 1.2 PJ. In addition, different studies such as Adekoya and Adewale (1991) Ojosu and Salawu (1990) show that there is potential for wind energy in northern Nigeria. According to the Energy Commission of Nigeria (ECN), the current state of exploration and utilisation of these renewable energy resources is very low except the use of hydropower and bio energy. This might be because of the abundant deposit of conventional energy sources and relatively cheap gas market in the country.

2.4 Hydropower in Nigeria

The hydropower potential in Nigeria is estimated at about 14,759 MW for both large and small hydropower. Hydropower currently accounts for about 29% of the total electrical power supply, with about 13% of the nation's hydro potential utilized. The first hydropower supply station in Nigeria is at Kainji on the river Niger where the installed capacity is 836 MW with provisions for expansion to 1,156 MW. A second hydropower station on the Niger is at Jebba with an installed capacity of 540 MW. An estimate for rivers Kaduna, Benue and Cross River (at Shiroro, Makurdi and Ikom, respectively) indicates their total capacity to stand at about 4,650 MW. Estimates for the rivers on the Mambila Plateau are put at 2,330 MW (Akinbami 2001).

2.5 Solar Energy potential in Nigeria

The Nigeria National Energy Policy Document states that 'Nigeria lies within a high sunshine belt and, within the country; solar radiation is fairly well distributed. The annual average of total solar radiation varies from about 12.6 MJ/m^2-day (3.5 KWh/m^2- day) in the coastal latitudes to about 25.2 MJ/m^2 –day (7.5 KWh/m^2- day) in the far North.' Assuming an average solar radiation of 18.9MJ/m^2-day (5.5 KWh/m^2-day) the country therefore has an estimated 17,459,212.2 million MJ/day (17.439TJ/day) of solar energy falling on its 923,768 Km^2 land area (Adeyanju 2011). The average amount of sunshine hours all over the country is about 6.5 hours, with longer sunshine hours and higher radiation in the northern region. In a study conducted by Oparuku (2007), it was noted that the average solar radiation in the country supports the use of solar photovoltaic systems in meeting household domestic energy demand. However, since the use of concentrated solar power (CSP) requires high Direct Normal Irradiance (DNI), it will only be appropriate in northern region which has high DNI and flat landscape.

2.6 Electricity generation in Nigeria

As discussed, electricity generation in Nigeria is mainly from conventional sources. For more than 40 years, electricity production has been from fossil fuel, gas-fired power stations and hydropower stations. Oil and natural gas contribute about 71% to the country's electricity generating fuel. This is mainly due to the availability of these primary energy resources, especially crude oil and natural gas. Figure 2.5 shows Nigeria's electricity generation by fuel.

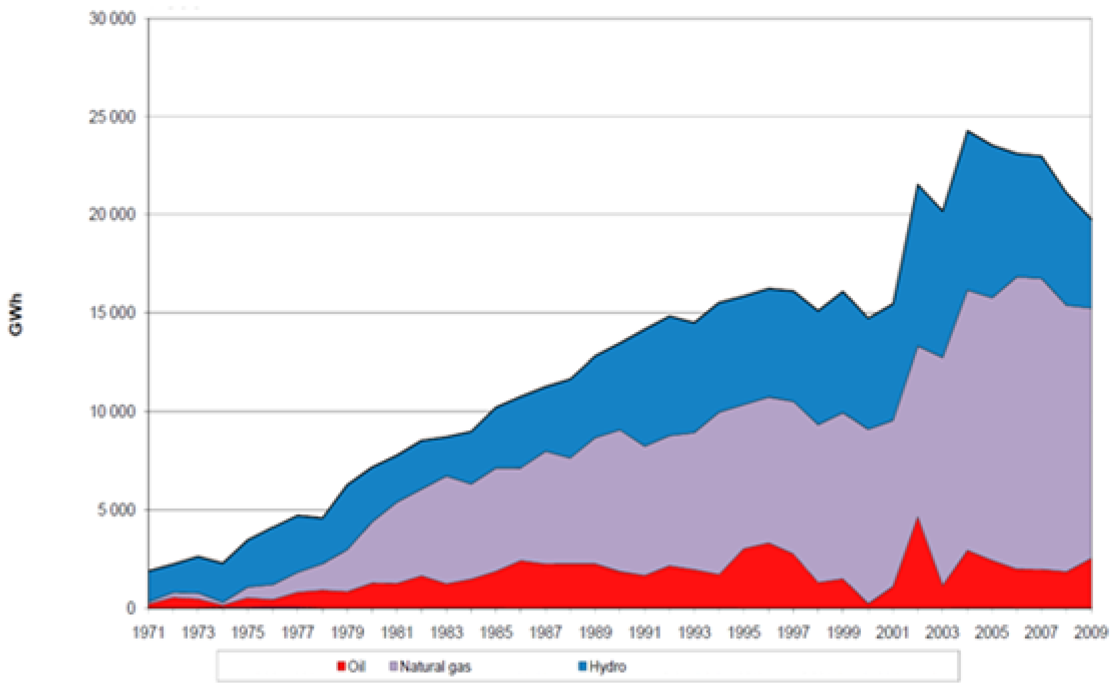


Figure 2.5: Electricity generation by fuel in Nigeria (Source: IEA Energy Statistics 2010)

Nigeria is currently producing electricity from about 14 power stations out of which 11 are thermal (gas) power plants and 3 are hydro. However, new power plants are under construction while approval has been given for the construction of more power plants under the Independent Power Producer (IPP) scheme. Details on existing and potential power stations in Nigeria are shown on Table A2, Appendix A. According to the available data from the Energy commission of Nigeria (ECN) (2010) and Sambo et al (2010), the installed capacity as at December 2009 was 7876 MW, while the average daily power generation was about 2700 MW as against daily peak load forecast of 8900 MW.

Challenges confronting power production in Nigeria include poor maintenance of power stations, poor management, obsolete equipment, lack of equipment maintenance, difficulty in replacing spare parts, and inadequate supply of fuel to thermal power plants. As a result of inadequate electricity supply the nation is experiencing massive suppressed demand thus compelling many domestic, commercial and industrial consumers to procure personal generators. According to a report by the Manufacturers Association of Nigeria (MAN), the manufacturing sector is said to be worst hit by the dwindling power supply in the country.

A minimum of 2000 MW is needed to keep the available industries working at installed capacity while additional 4,000 MW would be needed in the next four years if these factories are to grow (ERIC 2009). The manufacturing sector of the economy relies on diesel to run their plants. A recent survey conducted by MAN on 1,500 manufacturing companies nationwide revealed that members of the association currently spend an average of $6.4 million for the maintenance of their plants, while an average of 8,679,638 litres of diesel are consumed weekly in running these plants with an estimated cost of about $12 million weekly (MAN 2009) . Shortages in power production have drawn the attention of the government to the importance of adequate power supply to the socio-economic development of the country. This has prompted the government to undertake major reforms in the past decade. This includes the privatisation of the sector to encourage foreign investment through an independent power producing (IPP) scheme (Sambo et al 2010).

2.7 The National Energy Policy

The federal government in 2003 approved the national energy policy compiled by the Energy Commission of Nigeria (ECN). The policy document is an overall policy that controls other sub-sectorial energy policies. It gives provision for full utilisation of the nation's energy resources in an environmental friendly and sustainable manner. Due to the importance of the power sector to the economy, the document spells out policies that will ensure energy management such as energy planning and financing in the power sector. In addition, provisions for further utilisation of the country's energy mix especially the renewable sources and the re-introduction of coal for power generation are also included.

Considering the energy projection done by the ECN, the nation's energy demand will continue to increase as population and GDP grows. In order to provide adequate power supply that will meet present and future demand, Nigeria will need to introduce nuclear and solar thermal technologies into its future power supplying technologies. Small-scale renewable energy technologies are envisaged for rural areas because of the prohibitive cost of extending the national grid to such areas. Such technologies will include wind, solar PV and mini hydro systems. The following provisions were also included in respect to power:

- Provision of reliable and affordable electric power for socio-economic and industrial activities
- Intensive development of the nation's electric power with the view of providing power for at least 75% of the population by 2020
- Promotion of private sector participation in electric power development through the involvement of independent power producers (IPP)

Moreover, these objectives will consider the environmental impact of energy provision, because of global call for GHGs emissions mitigation. Future inclusion of coal in the country's power producing fuel will use clean coal technologies while more renewable energy sources will be developed.

The country supports the use of natural gas for power production due to its lower CO_2 emissions. The emission ratio of gas, oil and coal in ratio 1: 1.45:1.95 respectively (CCL 2008) makes gas more advantageous in power generation from the perception of climate change. Concerning gas flaring, the government commits itself to reducing it considerably because of its economic importance. Technologies that will prevent gas flaring are being put in place with the expansion of domestic gas pipeline to power station sites.

2.8 Nigeria's Energy Demand Projection

The Nigerian energy policy and energy master plan were developed from a preliminary study done by the ECN on the nation's future energy situation (ECN 2011:40). Energy demand and supply projection were computed over a study period of 2000 – 2030. Energy demand drivers such as demography, GDP, energy intensities and efficiencies were used in analysing the nation's future energy demand. The study on energy supply projection considered all available energy resources both conventional and renewable sources. An important determinant of energy situation in a country is the nature of its economy; this determines its energy intensity which is calculated as the unit of energy per unit of GDP. The historic average increase in GDP can be used to project GDP growth for a particular country, however, government policies can influence the growth from the 'business as usual' rate.

The Nigerian government has an ambitious plan of meeting the United Nation's (UN) millennium development goals and be among the first 20 developed economies in the world by the year 2020 (UN's Human Development Index (HDI) rating) (FGN 2010). To achieve this target, it was projected that the country will need to grow its economy by an average of 13.8% per annum. Enormous investment will be required in the energy sector to facilitate this growth. As at year 2010, the Nigerian economy was reported to be growing at 7% per annum. Though, the 13% annual growth is quite ambitious, government believe it is achievable. Different economic research studies such as Goldman Sachs Economic Research and studies done by the Central Bank of Nigeria on likely economic growth trend for Nigeria projected Nigeria to be the world's 20th largest economy in year 2025 (Ezirim et al 2010). The former governor of the CBN Professor Charles Soludo however believes that the projections are conservative, as conditions used are based on GDP and environmental growth (Soludo 2006). However, government's determination to diversify the economy and create enabling environment for the realisation of its economic objectives will no doubt increase the economic growth rate from the business as usual scenario.

The ECN study on energy projection uses four assumptions based on GDP growth scenarios. The GDP was assumed to grow by 7%, 10%, 11.5%, and 13.8% for reference growth scenario, high growth scenario, optimistic scenario 1 and optimistic scenario 2 respectively. The reference growth scenario is based on historic average GDP growth rate if the economy will grow at a 'business as usual' rate. In the high growth scenario, agriculture and services, which contribute about 70% to the GDP, is expected to grow more rapidly while other sectors of the economy will be developed.

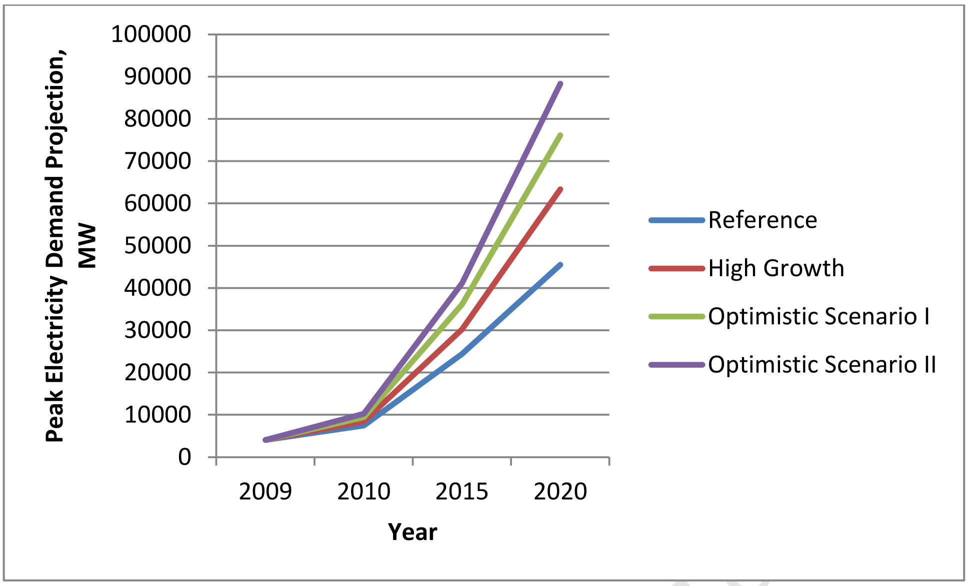


Figure 2.6: Electricity Demand Projection (Source: ECN 2010)

The two optimistic scenarios are based on possibilities of fast growing economy and government's intention to meet the millennium development goals and its year 2020 economic transformation agenda. The projected electricity demand according to the study is illustrated in Figure 2.6. If the country would achieve its year 2020 economic objectives, it should be generating about 88 000 MW of electricity by the year 2020. The corresponding per capita electricity demand will be 2408.8 KWh/cap for a population of 227 million people.

However, the power reform strategy designed in the country's power sector reform envisage 40,000 MW power supply with per capita consumption of 1340 KWh/cap to a projected population of 227 million people by year 2020. The power reform document is designed to fast track the country's power sector development using the following strategies:

- Removing obstacles to private investment in the power sector
- Divestiture of the Power Holding Company of Nigeria (PHCN) (Nigerian national electricity utility company) successor companies which include 11 distribution companies and 6 generation companies.
- Removing barriers preventing adequate gas supply to power stations.

The power reform strategy is believed to address major issues confronting the power sector. Full implementation of this strategy is expected to increase the nation's power supply to 40,000 MW at full operation of installed capacity and 10% transmission and distribution loss by 2020. The installed capacity includes on-going power projects expected to be commissioned before 2020 and the existing capacity (Appendix A, Table A2). The 40,000 MW is the same with the electricity demand projection using the reference scenario of 7% increase in GDP. However, government is optimistic about achieving its 13.8% economic growth and more than 40,000 MW of power supply by encouraging more private investment in the power sector. The divestiture of PHCN and the involvement of IPPs in Nigerian power production are positive steps believed to bring about the anticipated development in Nigerian power supply. The success recorded thus far through IPPs is evidence of possible realisation of the projected 40, 000 MW in year 2020. Appendix A Table A2, shows a list of existing, on-going and approved power stations in collaboration with IPPs in Nigeria.

2.9 Electricity production projection by fuel

Electricity production in Nigeria is currently from two main types of fuel; hydro and gas while the share of renewable energy and other fuels are insignificant (ECN 2008). However, considering the energy policy document and government's determination to broaden its energy supply mix, other types of fuel may feature in future energy supply. About eight types of fuel were considered in an electricity supply projection study done by the ECN. These fuels include; coal, solar, nuclear, large-hydro, mini-hydro, gas, biomass and wind. Figures 2.7 and 2.8 show the electricity production projection by fuel for the two scenarios (reference and high growth scenarios).

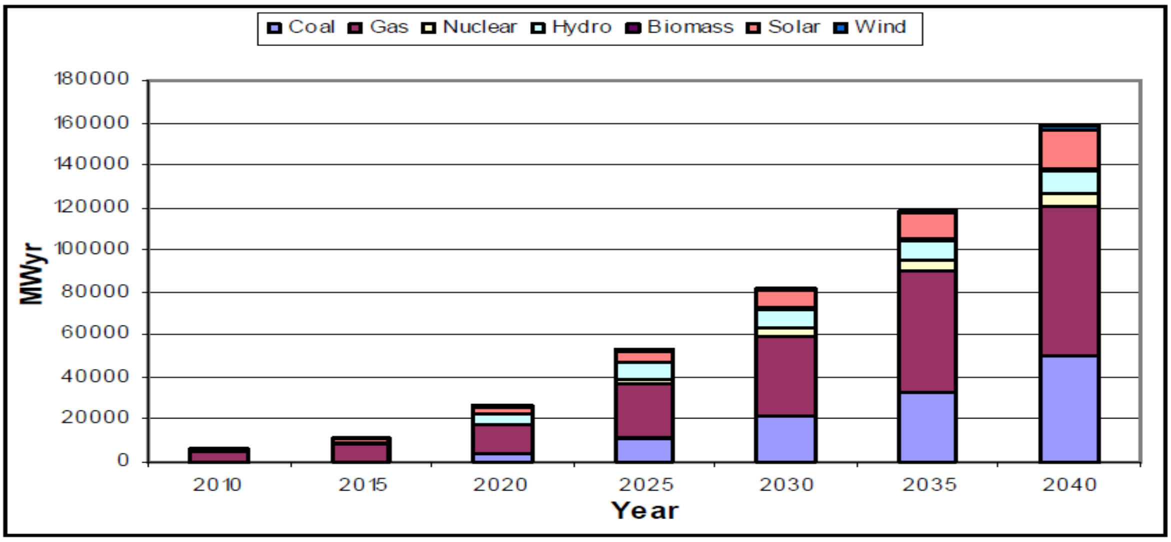


Figure 2.7: Electricity Supply Projections by Source (Reference Scenario)

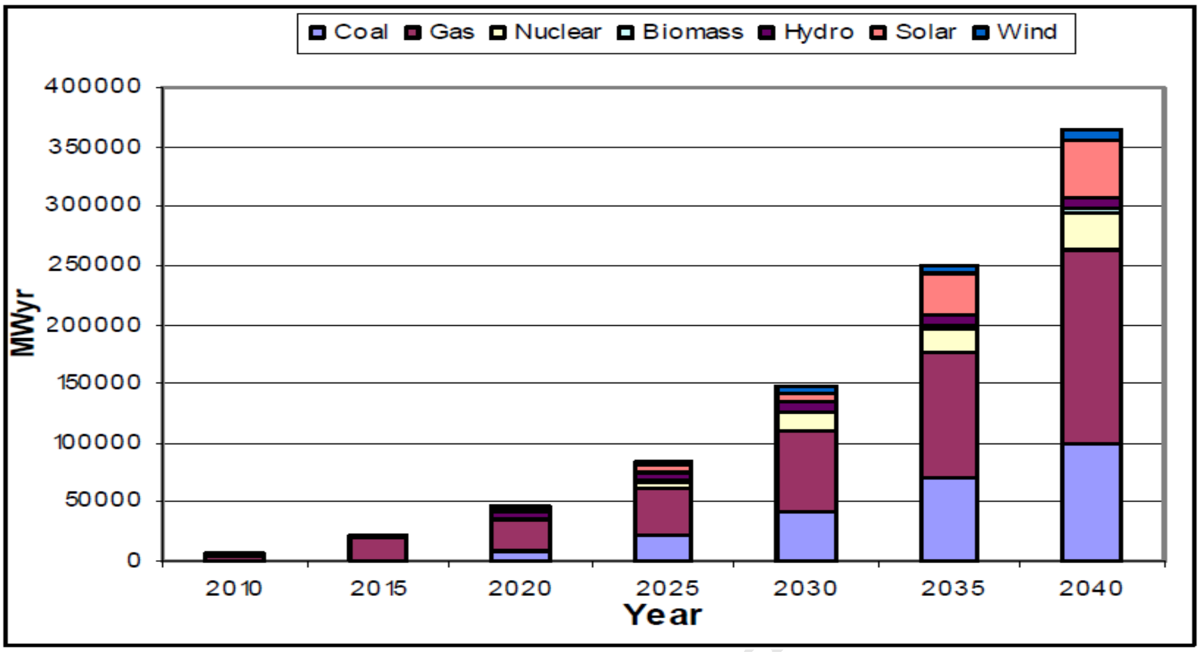


Figure 2.8: Electricity Supply Projections by Source (High Growth Scenario)

The result shows that the pattern of energy supply fuel will change over the study period. The introduction of other fuel especially coal, solar and nuclear will reduce the percentage of gas consumption in the mix from 80% in 2010 to about 40% in 2040 for the two scenarios (ECN 2011). The use of coal can make a significant contribution to the country's energy production based on the available coal resource. However, due to emissions associated with coal utilisation, renewable energy sources such as solar and wind energy are considered as potential mitigation options.

2.10 Nigerian Renewable Energy Master Plan

The renewable energy master plan produced in 2006, articulates Nigeria's vision of developing a sustainable economy and roadmaps for achieving this objective. The master plan envisions an economy that will move gradually from fossil fuel dominance to one driven by increasing share of renewable energy in the Nigerian national energy mix. In order to achieve this objective, government plan to encourage the use of a less carbon intensive technology. Instead of utilising its abundant fossil fuel deposits in its energy sector, government plan to employ the use of renewable energy sources to reduce its GHGs emissions. However, the document does not specify a particular time for implementing this plan. Short, medium and long term projections were made for the share of renewable energy in the following proportion 13%, 20% and 36% respectively. In the roadmap document designed for the actualisation of this projection, government plans to create an enabling environment for private sector's investment. Such encouragement includes exploitation of renewable energy resources at a price which promotes the realisation of equitable and sustainable development. (Sambo 2009)

2.11 Current Solar Energy Status in Nigeria

Solar energy used in electricity generation in Nigeria is limited to solar PV system applications for off grid power supply particularly in remote areas (ECN 2011). Other applications include street lighting, solar water pumping system and power back up systems to complement power usage at homes. An estimate of about 50 MW capacity of solar PV system is currently installed (ECN 2011), the share of solar energy is projected to increase with the expansion of PV systems for off grid power supply and the introduction of solar thermal technology.

2.12 Electricity Production from Solar Thermal Power Plants (CSP)

Solar thermal power could start contributing to Nigerian electricity production as from the year 2020 according to the ECN energy projection report (ECN 2011: 67, 71). Figure 2.9 shows the electricity production projection from solar thermal plant for two different GDP growth scenarios (reference growth & high growth). A minimum power supply of about 1000 MW is expected from CSP by year the 2020 for both scenarios. Subsequently, electricity production from CSP will increase rapidly. The inclusion of solar thermal power in the nation's future electricity production is driven by possible capacity expansion in electricity generation. Meeting the nation's economic objectives and subsequent increase in GDP growth rate will require increase in electricity production capacity and diversification of electricity production resources. Diversification of electricity generation resources will ensure security of electricity supply. For instance, Nigeria at present generates about 70% of its electricity from gas thermal power stations; possible interruption in gas supply will hold the nation's electricity supply to ransom. Further to this, the nation's renewable energy master plan envisions an economy that moves gradually from fossil fuel dominance to increasing share of renewable energy sources. In order to achieve this objective, the nation's solar thermal capacity will make a substantial contribution.

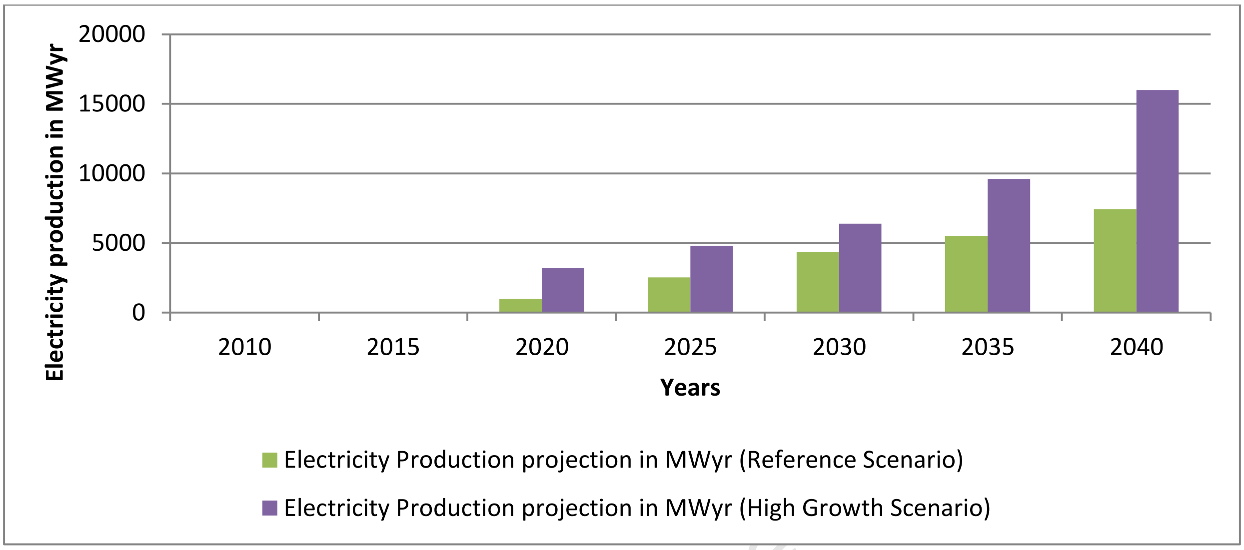


Figure 2.9: Electricity installed capacity Projection from Solar Thermal Plant

Chapter 3

Energy and economic situation in the study region

The previous chapter gave general background information on the energy situation in Nigeria, and the conceptual framework for improved power supply to the country. It presented the inadequacy in power supply and possible power production projections as predicted by the Energy Commission of Nigeria (ECN). This chapter presents the energy and economic situation in the study region as the basis for future energy demand and economic output. According to Ugur and Ramazan (2006), there does not seem to be a consensus on the direction of Granger causality[1] between energy consumption and economic output probably due to the different energy consumption patterns and various energy sources of different countries. However, most studies consent to a relationship between energy consumption and production (Ramazan and Ugur 2004). This study examines the energy consumption in different economies and their level of production in comparison to the study region. The results show a strong relationship between energy and production. While some countries' economies are energy intensive in terms of their level of production and energy consumption, countries with low energy consumption have low level of production.

Economic output projection in this study is grounded on three scenarios which are the possible GDP growth patterns for the country and the study region. The three scenarios are: reference growth, high growth and optimistic scenario which involve 7%, 10% and 13% GDP growth respectively. While the reference growth is achievable (based on business as usual trend) the high and the optimistic growth require political will and a pragmatic approach from the government. However, as energy demand increases, the need to meet the demand will

[1] Granger causality is a statistical hypothesis test used to determine whether one time series can be used to forecast another.

also increase and hence, the need to harness more energy producing resources. In addition to other energy resources in the country, there would be need to harness the solar resource in the study area as from year 2020 according to the ECN energy supply projection. Details on the energy situation and projection are discussed in the following sections:

3.1 Electricity Supply and Economic activities in the Region

According to business environment report on Nigerian states compiled by the African Institute for Applied Economics (AIAE) (BECANS 2007)[2], the total estimated supply capacity to the seven states in the study region was 255 MW (418163 MWh/yr) in year 2007 (Appendix A3). It is important to consider that due to the inadequate power supply in the country, power is only available to the public for an average of six hours every day. However, the higher supply capacity in Lagos provides conditions that better support economic output. Evidence of this corresponds to the production level of Lagos and the study region. While the per capita output of Lagos was 3696 (PPP $) in 2007, that of the study region was 1136 (PPP $).This further suggest a relationship between energy consumption and economic output.

3.2 Industrial and commercial activities in the region

Industrialization enables a nation to fully utilize its economic potentials and depend less on foreign finished goods (Adenikinju 2005). It accelerates economic growth and diversifies production and commercial activities especially in a region with enormous deposit of natural resources and great agricultural potentials. Manufacturing and commercial activities in this region rely on personal generators because of the dwindling power supply to the region. The inadequate power supply has led to poor economic output, and even the complete closure of certain activities (Giginyu 2011). Though, manufacturing industries in the country are generally affected by the poor power supply, the industries in Lagos – Ogun in the West-1 industrial areas have better access to power supply compared to the study region. Better access to electricity in the Lagos- Ogun industrial areas could be a result of proximity to power generating stations. For instance, Egbin thermal power station (1320 MW capacity)

[2] BECANS Business Environment Report for each state.
Borno (BECANS 2007: 13) Jigawa (BECANS 2007: 13) Kano (BECANS 2007:13) Katsina (BECANS 2007:11) Sokoto (BECANS 2007: 12) Yobe (BECANS 2007:13) Zamfara (BECANS 2007:13)

and Omotosho thermal power plant (785 MW Capacity) are situated in Lagos and Ogun State.

On the other hand, Kano State which used to be the industrial centre of the northern region has lost over 498 industries since 1999. The major cause of this damage is low voltage supply to industrial areas which has caused serious damage to industrial equipment (Karofi 2007). The remaining industries in Kano state rely mainly on personal generators for their operations as shown in table 3.0; the self-generating capacity for industrial operations in Kano State is more than the available supply. This evidence shows how essential power supply is for productive industrial activity in a country.

The survey conducted by the Manufacturing Association of Nigeria (MAN) in 2009 revealed that it is more expensive for manufacturers to run their plants on diesel powered generators than to maintain their plants. In addition, about 10% of manufacturing firms operate at 49% of installed capacity, while 60% were barely able to cover their variable costs (Aderibigbe 2010).

Table 3.0: Results of 2007 Power Audit by MAN

s/n	Industrial Areas	No of Industries	Power Demand (MW)	Self-installed generating capacity (M VA)
1	West 1 (Lagos & Ogun States	871	484.53	311.18
2	West 2 (Oyo, Osun & Ekiti States	175	33.58	9.776
3	Edo and Delta States	44	11.82	27.95
4	Rivers, Abia, A/Ibom & C/River States	90	39.1	35.141
5	Anambra, Enugu & Imo States	164	81.4	69.555
6	Plateau, Gombe & Bauchi States	28	30.2	47.675
7	Kano State	106	160.73	201.998
8	Kaduna, Sokoto & FCT	22	22.8	25.548
	TOTAL	1,500	864.16	728.821

Source: Manufacturing Association of Nigeria 2009

Figure 3.0: Group of artisans in the study region operating on generators. (Source: Ahmed 2011 (ICRC Presentation))

The adverse effect of a 'generator-running' economy is evident from the cost of production and commercial services. The cost of setting-up a small business for traders and artisans must include the cost of purchasing and running a generator. Figure 3.0 shows group of artisans in the region operating on personal generators. Traders of perishable products spend additional cost on preserving their products if they cannot afford high wattage generators to power refrigerators. From the above discussion it is evident that it is crucial for the cost of power for commercial activities to be reduced. In order for this to happen, a power supply network that is less dependent on diesel generators needs to be developed. Improvements in the electricity grid network would go a long way to achieving this.

3.3 Household energy demand and supply

This acute electricity problem also affects household energy usage in the region. This development has made women and children less productive; school aged children and women spend ample time fetching water and wood fuel for cooking, an exercise which would have been easier done if there were adequate power supply (Mshelia 2012). The situation is even getting worse with increase in population and low generating capacity. According to a survey conducted by the Nigerian Bureau of Statistics (NBS) in 2007, on households' electricity supply in the region, about 58.4% (over 3 million) households lack access to electricity while out of the 41.6% which have access (households which are connected to the grid), 37.2% depend on supply from the national grid only. The percentage that use supply from the national grid only, are mostly poor people who cannot afford the cost of procuring or running private generators(NBS 2007). Out of the remaining 4.4%, 2% complement power supply from the national grid with supply from private generators while 2.2% either rely on supply from private generators or community generators (NBS/CBN/NCC 2008). Comparing the household electricity supply in this region to other zones in the country, as shown in Figure 3.1, the study region has the lowest household access to electricity. The states considered in this study are spread across the North-East and North-West zones of the country.

Household electricity consumption in this region is mainly for lighting and cooking. Since the region is relatively warm, space heating and water heating are not common. Other use of electricity in households is to power electrical appliances for entertainment, communication and laundry services. Power consuming activities like cooking and ironing are done when there is supply from the national grid, because most people cannot afford high wattage generators that will give the desired power output. Only 13% of the total households in the region use electricity for cooking while 23% use electricity for lighting.

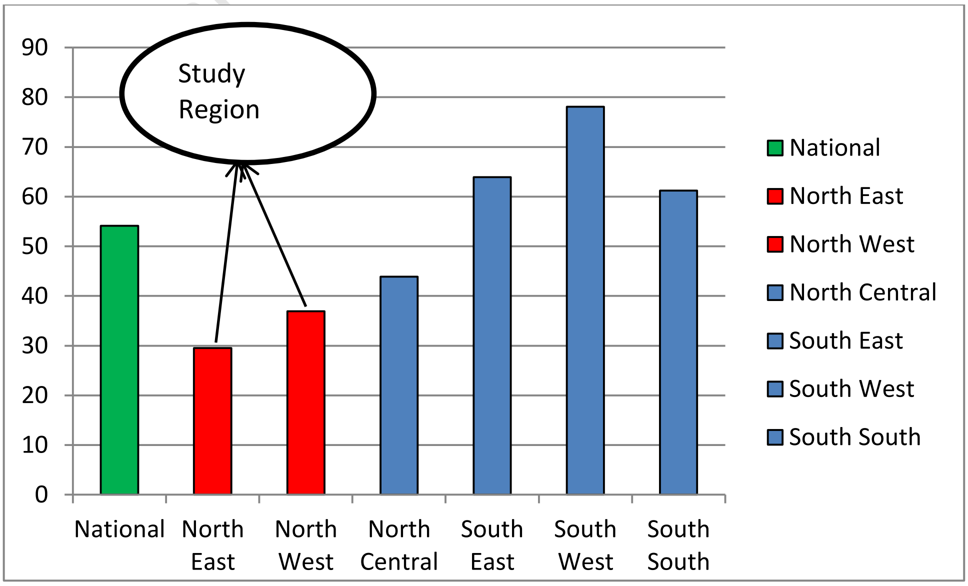


Figure 3.1: Percentage of Households that has access to electricity in the six geopolitical zones of Nigeria

3.4 Economic Activities in the region

These states have similar economic activities and climatic conditions. Agriculture is the mainstay of their economy (Ahmed 2011). The agrarian activities include crop, livestock and fishing farming. Some major agricultural products in this region are groundnut, guinea corn, maize, millet, cotton, gum- Arabic, among others. Prominent livestock productions are cattle, sheep, goat, and poultry. Figures 3.2 and 3.3 show that the livestock densities and agricultural products in this region are higher compared to other parts of the country. Apart from agriculture, the States are rich in mineral resources. Gold, chromate, quartz, diamond, manganese, gypsum and mica are some of the mineral resources found in the area.

Commercial and industrial activities in the region have reduced significantly since 1960 owing to poor power supply to the region (Ahmed 2011). However, the region is known for trading, handcraft works like leather works, weaving, and wood works. There are about 400 firms producing items like textile materials, foot wears, cosmetics, pharmaceuticals, enamel wears, bicycles, plastics and agricultural implements in Kano state. Other important firms in this region are agro-based firms producing dairy products, vegetable oil, groundnut oil and animal feeds. Fertilizer blending plants, soda ash factories and flourmills are found in Yobe state. (BECANS 2011)

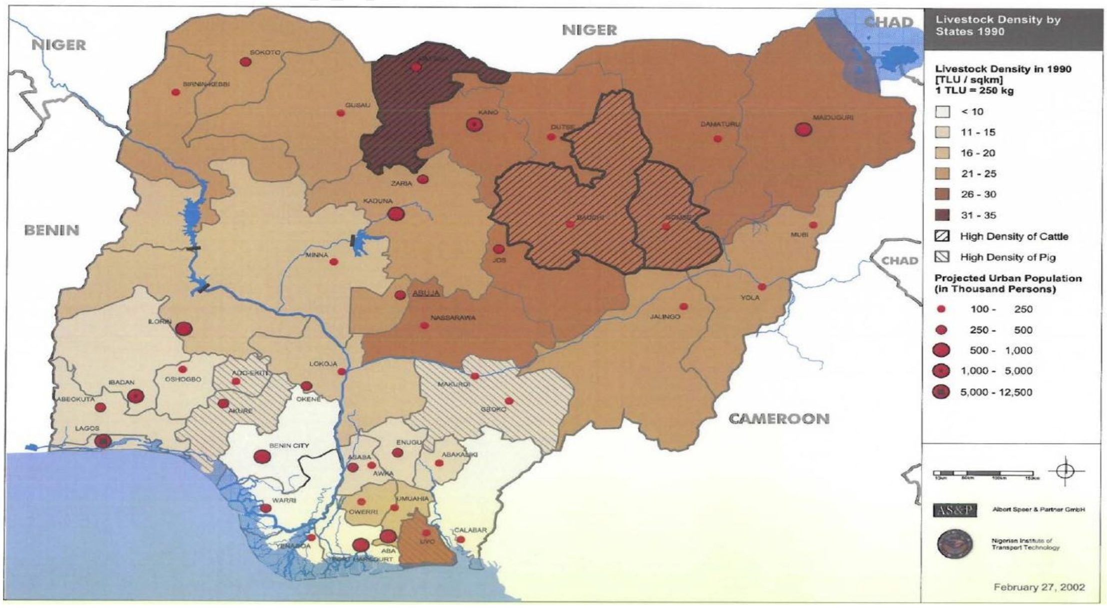


Figure 3.2: Map showing livestock density in Nigeria (Source: Nigerian atlas of social studies as referenced in Ahmed 2011 (ICRC Presentation))

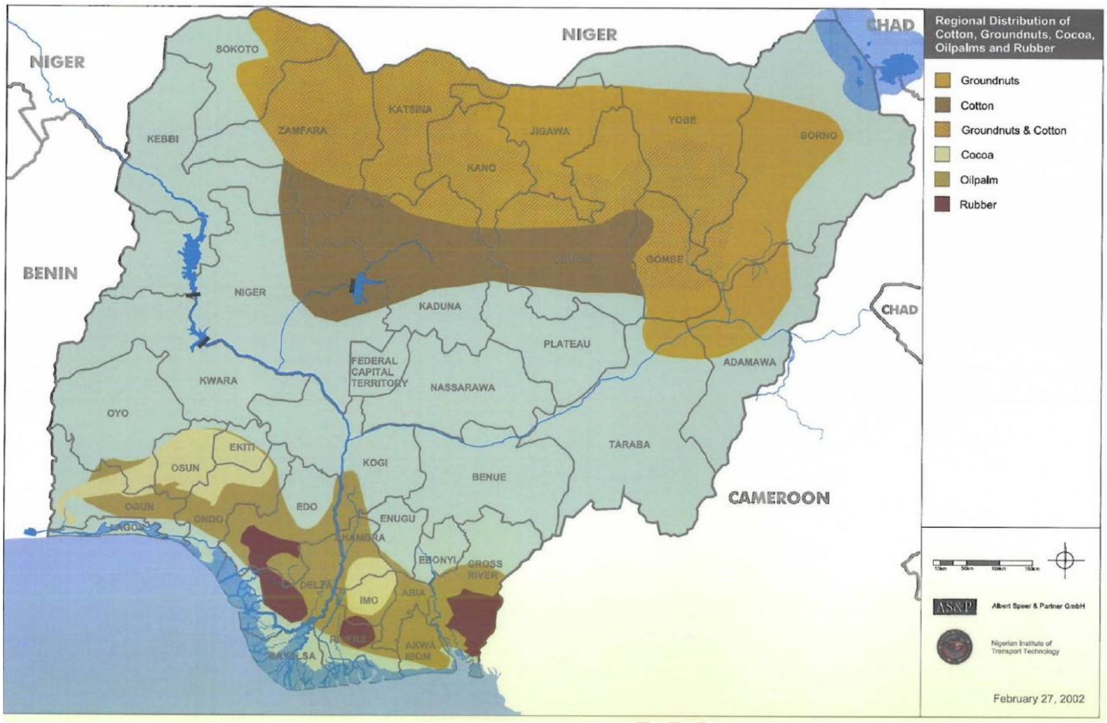


Figure 3.3: Map showing regional distribution of main agricultural products in Nigeria Source: RIM as referenced in Ahmed 2011 (ICRC Presentation))

Table 3.0 shows per capita GDP of each state in the region, with an estimated population of 33, 037, 366 and GDP of $ 37, 532,882,448 (Purchasing power parity), the per capita GDP of the region in 2007 was $1136.06 (NBS 2009). Since energy is essential for production, adequate energy supply could increase per capita production in the region.

Table 3.1: Per Capita GDP (PPP$) of the States in the study region

Sates	GDP (PPP$) Per Capita
Borno	1241
Jigawa	685
Kano	1318
Katsina	1038
Sokoto	1301
Yobe	867
Zamfara	1258

Source: adapted from NBS/CBN/NCC Social-Economic Survey on Nigeria, 2008 and C-GIDD data 2007

3.5 Electricity Consumption and GDP.

Energy intensity as measure of unit of energy consumed per unit of GDP produced (IEA 2001) can be used to draw a relationship between electricity consumption and corresponding GDP. In this study, electricity intensity is limited to electricity consumed in a year and production in terms of GDP. As shown in Figure 3.4, there exist a relationship between electricity consumption and GDP. Further to this, high electricity consumption supports high levels of economic development as seen in the case of America (Ibitoye and Adenikinju 2006). There are a number of factors that influence the energy intensity of a country these include: the standard of living, weather condition and structure of the national economy. For instance, each citizen of America consumes about 39.3 KWh of electricity per day as against 0.39 KWh consumed in Nigeria (IEA 2009). The reason for this wide gap in energy consumption can be linked to the structure of the economy and low level of infrastructural development in Nigeria. For instance, American economy is highly dependent on energy consuming activities such as well-structured service delivery (transportation, work, food leisure, housing, etc) (Schmitz 2007) and mining activities which is vital to the economy (NMA 2000). However, as plotted in Figures 3.4 and 3.5, the level of electricity consumption of most countries is proportional to the production level.

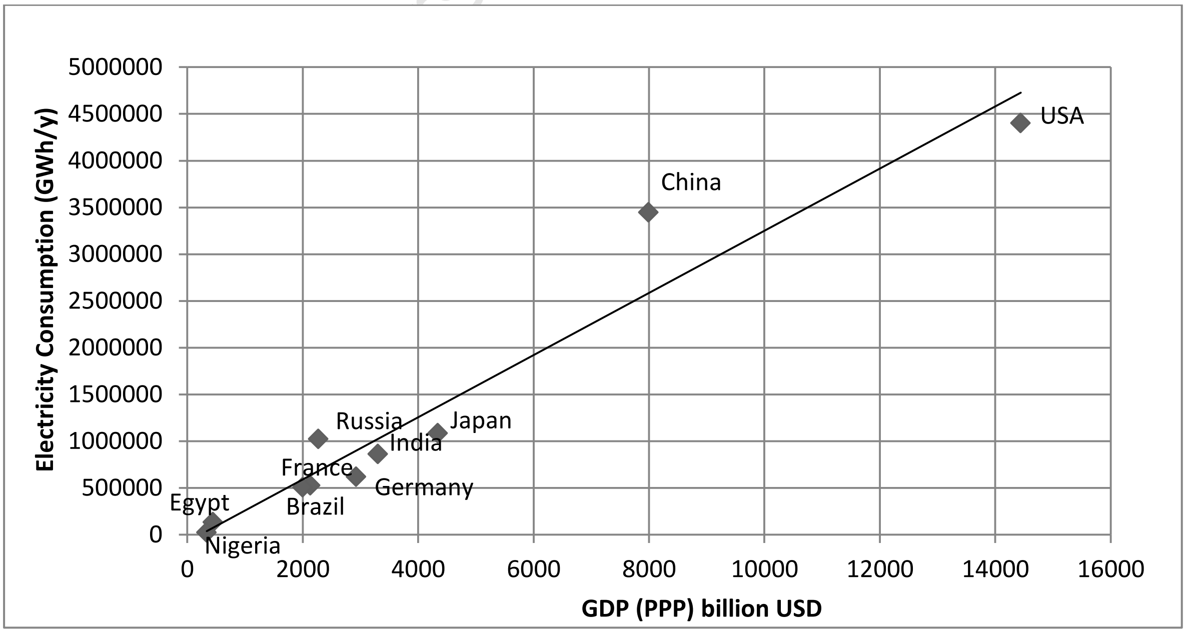


Figure 3.4: Electricity Consumption versus GDP for selected countries (2009) (Adapted by the Author from CIA world fact book and IEA statistics 2009)

In addition, the relationship between production and electricity consumption can further be analysed by comparing countries with different economies, populations, and regions as illustrated in Figures 3.5 and 3.6. Electricity consumed per capita according to Figures 3.5 and 3.6 is proportional to the production level across different economies. The production level in developing countries such as Nigeria and DRC is comparatively low so also the per capita electricity consumption.

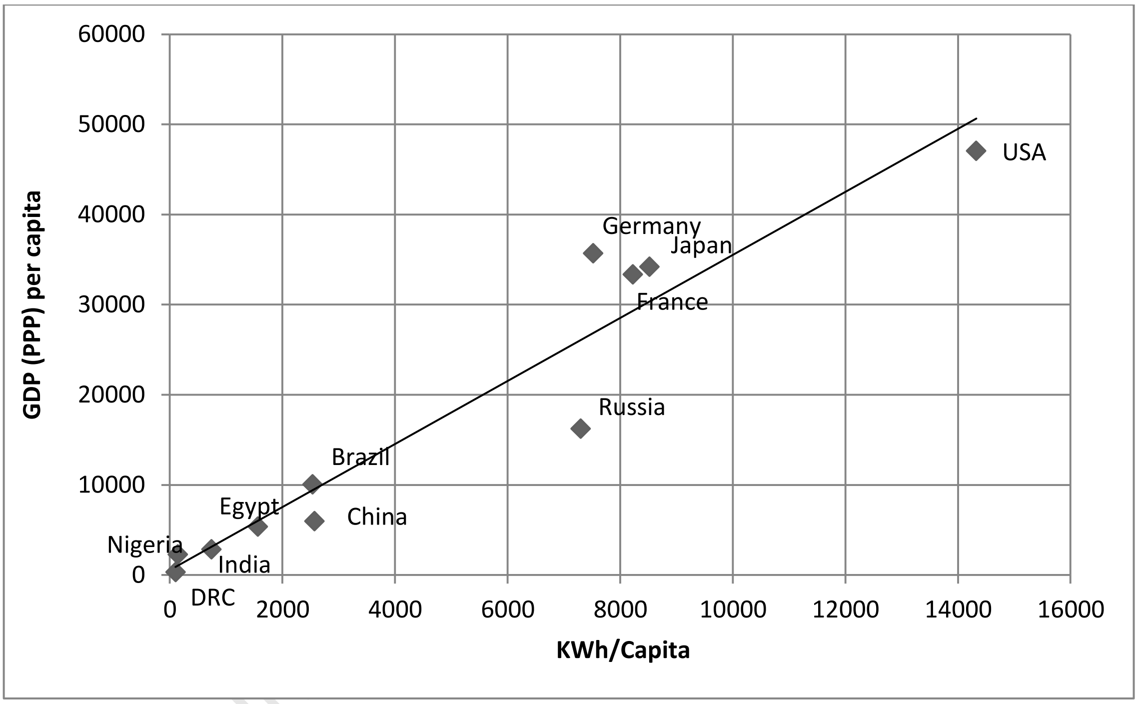


Figure 3.5: GDP per capita and Electricity use per capita for selected countries (2009) (Adapted by the Author from CIA world fact book and IEA statistics 2009)

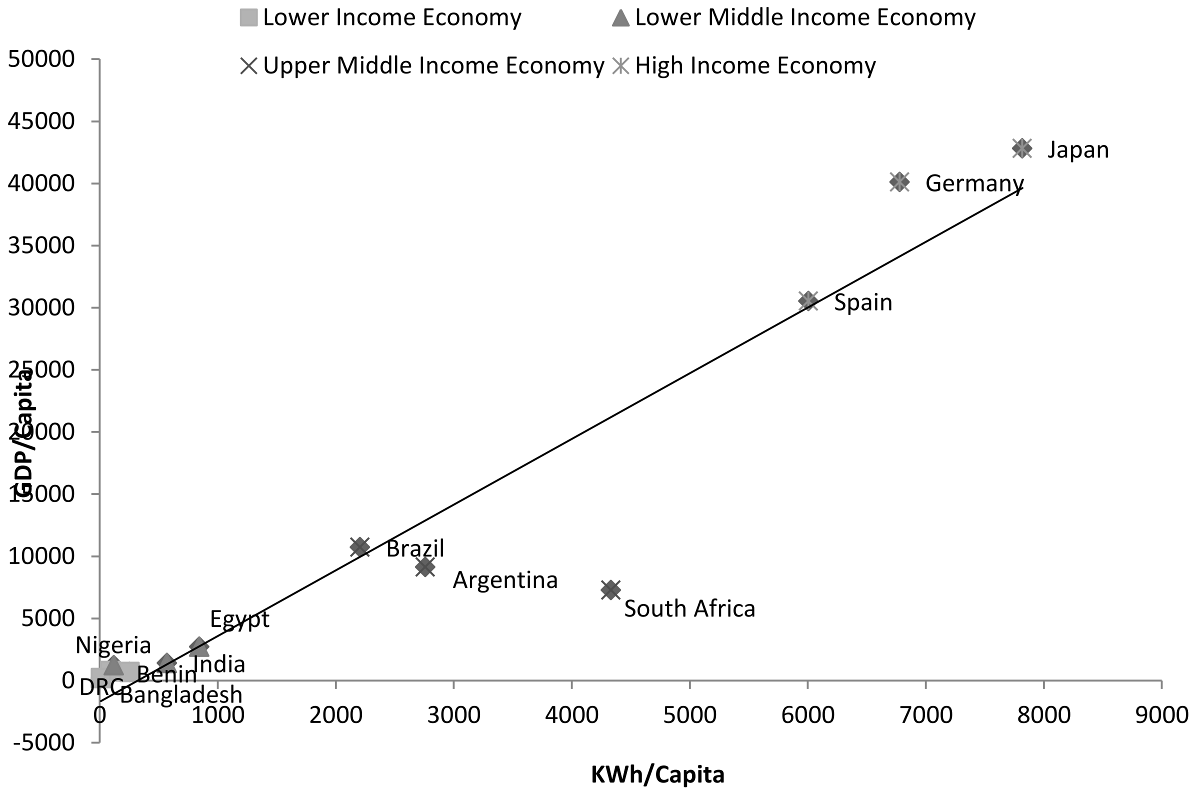


Figure 3.6: GDP per capita and Electricity per capita of selected countries with different economies (2012) (Data source: World Bank 2012)

As illustrated in Figure 3.6, South Africa consumes higher level of electricity to produce similar GDP as Argentina owing to the nature of its economy. Nevertheless, efficient use of energy will lessen electricity consumption in an energy intensive economy like South Africa. However, there seems to exist; a correlation between production and energy consumption for the four classes of economies (Lower income, lower middle income, upper middle income and High income economy) as divided by the World Bank.

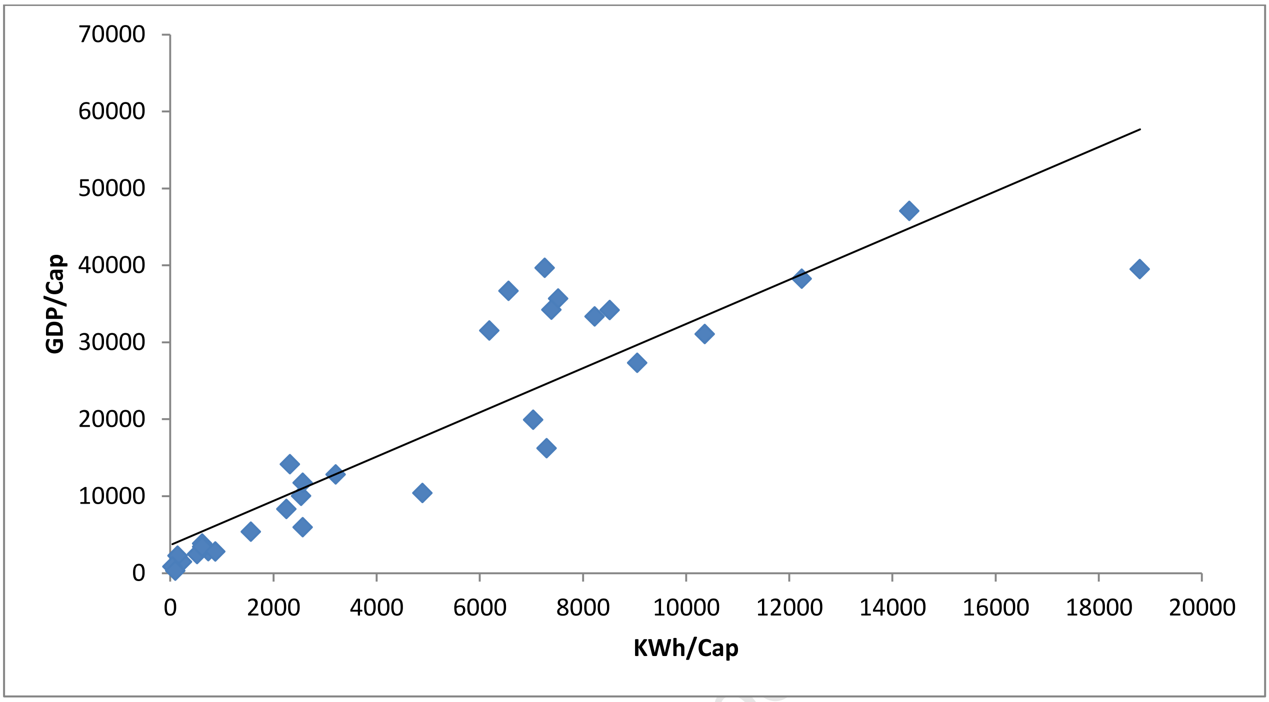


Figure 3.7: GDP per capita and electricity per capita of selected countries representing 77% of the world population, 84% of world GDP and 83% of world electricity consumption in 2009. (Data source: IEA and CIA world fact book 2009)

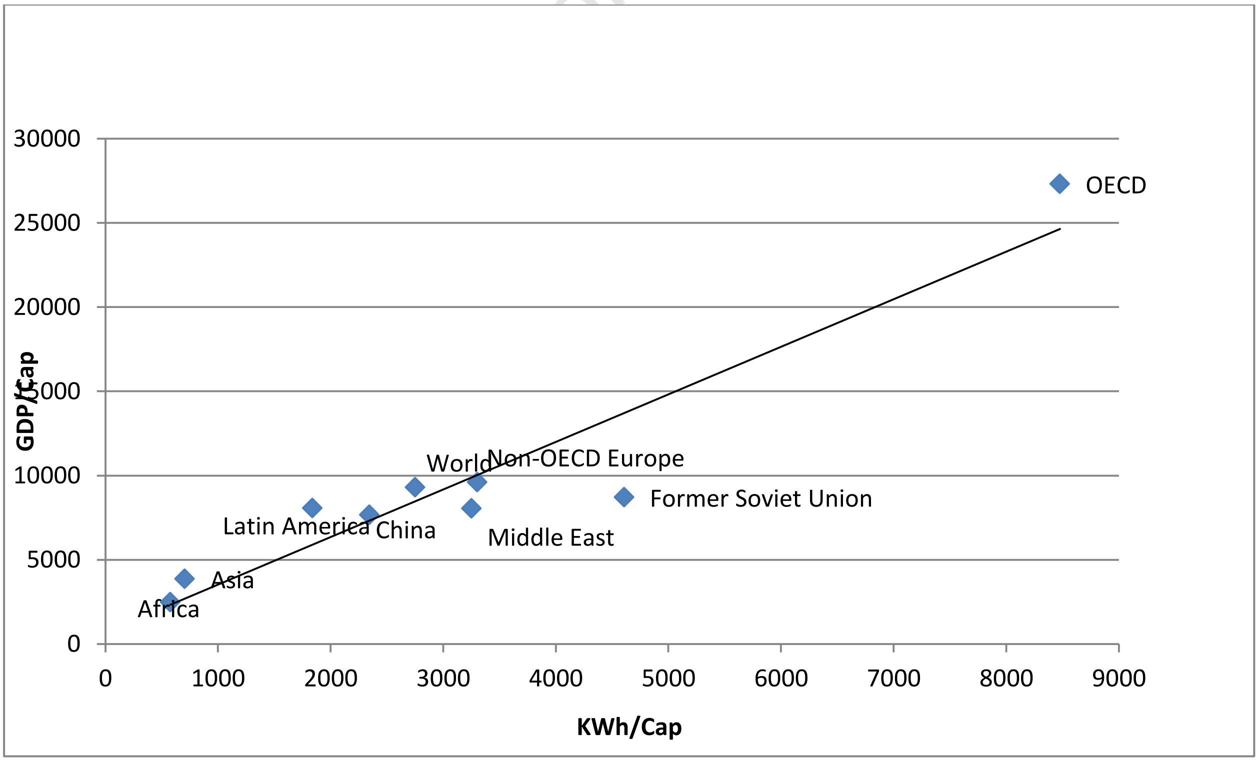


Figure 3.8: GDP per capita and electricity per capita of selected regions in 2007 (Data source: IEA 2009)

As shown in Figures 3.6 to 3.8, there exist a strong correlation between energy consumption and economic output (Schmitz 2007). In a study conducted by Ibitoye and Adenikinju (2007) on ‘the future demand of electricity in Nigeria’, a comparison of different developing economies shows a cluster at the initial stage of development as shown in Figure 3.9. However, rapid economic development owing to right strategy and increase in energy production has helped some countries to break loose from the cluster. An example of Chile is illustrated in Figure 3.9. A similar economic growth is predicted for Nigeria if the National Economic Empowerment and Development Strategy (NEEDS) programme is achieved (NPC 2004). NEEDS is an economic development programme aimed at achieving the UN MDGSs. Based on NEEDS, Nigerian economy is predicted to grow at a minimum GDP growth of 10% annually. This development according to the ECN, (2011) will require massive investment in the power sector.

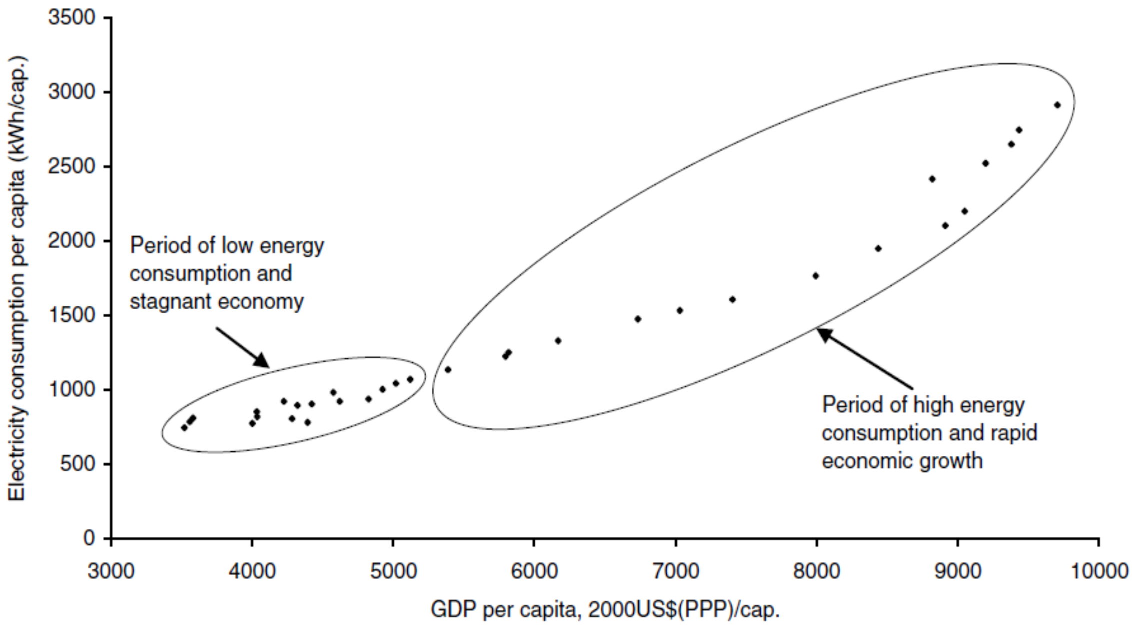


Figure 3.9: Annual electricity consumption versus GDP, Chile 1971-2003 (Data Source: IEA 2005 as referenced in Ibitoye and Adenikinju 2006)

3.6 Electricity Demand Projection for the region

As discussed, public electricity supply to the study region is inadequate to meet the level of demand. In order to meet the present and future energy demand, more energy supply is required in the region. Using 2007 as base year, Figure 3.10 shows an estimated energy demand and supply deficit for each State in the region. The energy consumed in the region in 2007 was 557,550 MWh as against required energy of 2,230 GWh needed for the available infrastructure (BECANS 2007). Meeting the energy demand in this region will require economic growth that exceeds the business as usual scenario (GDP growth rate (r) equations 1 -3 on page 38). However, electricity demands in this region will likely increase with increase in population and GDP growth. The suppressed energy availability (Figure 3.10) could be responsible for the dwindling industrial and commercial activities in the region. The present electricity supply is only available for an average period of seven hours a day. Some who could afford private generators complement electricity supply from the national grid with generators while others suspend their operations till there is supply. In order to meet the unsatisfied demand, an uninterrupted electricity supply would be required. The total energy consumed in the region in 2007 according to the available data from BECANS (2007) economic report is used as basis for possible future energy consumption in the region.

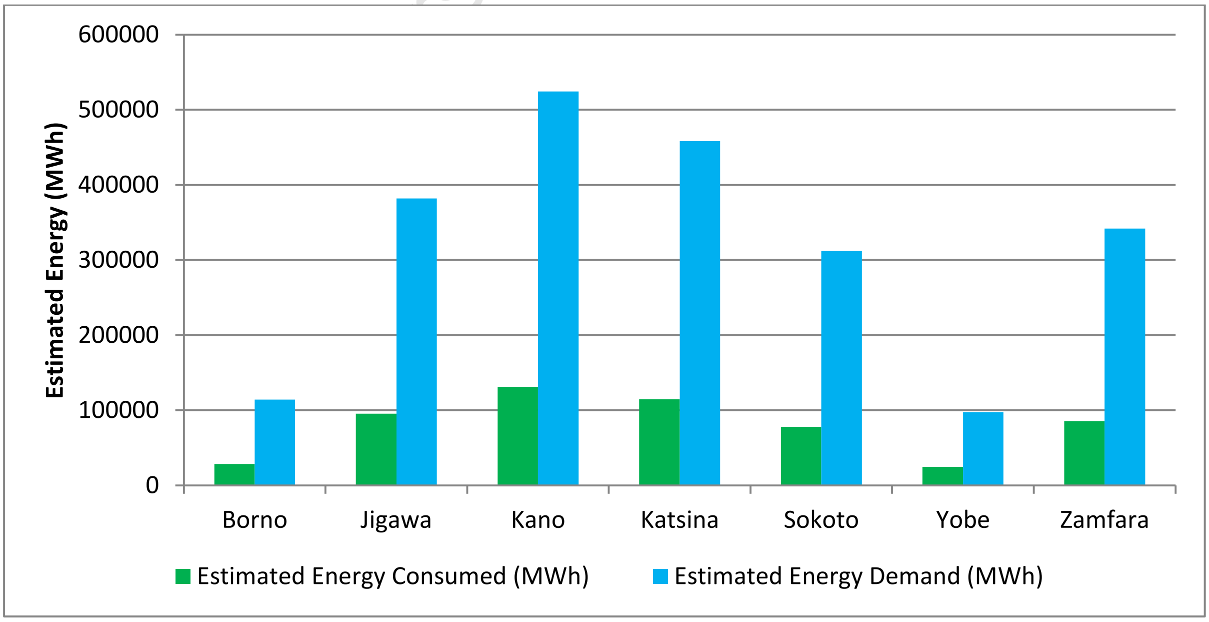


Figure 3.10: Estimated Energy Demand and Supply deficit for the Study Region in 2007 (Author's own calculations based on BECANS States Reports 2007

The following section discusses the electricity demand and demand projection for the region. The projection is based on three different GDP scenarios as specified in the nation's energy policy document and discussed earlier in this study. The energy consumed in 2007 is used as basis for possible energy projection trend. This is because energy capacity expansion is included in the GDP growth scenarios as discussed in GDP – Electricity relationship. The first scenario describes the power demand projection based on the reference GDP growth of 7% while the other two are high GDP growth of 10% and optimistic GDP growth of 13%. The following equations are used in modelling the electricity demand projection for the study region over a period of 50 years.

$GPY = GBY \times (1 + r)^{py-by}$ ------------ (1)

$E\,I\left({}^{MWh}/_{GDP}\right) = \frac{electricity\ demand\ in\ (mega\ watt\ hour)\ for\ base\ year}{GDP\ of\ base\ year}$ --------- (2)

$PED = E\,I \times GPY$ -------------- (3)

$GPY = GDP\ for\ Projected\ Year$

$GBY = GDP\ for\ Base\ Year$

$r = rate\ (\%\ increase\ in\ GDP)$

$py = projected\ year$

$by = base\ year$

$E\,I = Energy\ Intensity$

$PED = Projected\ Electricity\ Demand$

The projection assumes constant energy intensity for the period. Energy efficiency measures and cost of energy are possible factors that might influence energy intensity in an economy. If these variables are constant, the above equations can be used to determine energy projection for the study region. Equation 1 is used to determine GDP growth projection for the three scenarios discussed above. Equation 2 is used to determine the energy intensity for the base year, while the product of equations 1 and 2 gives the projected electricity demand for the three scenarios. The result of the projection model is shown in Figure 3.11

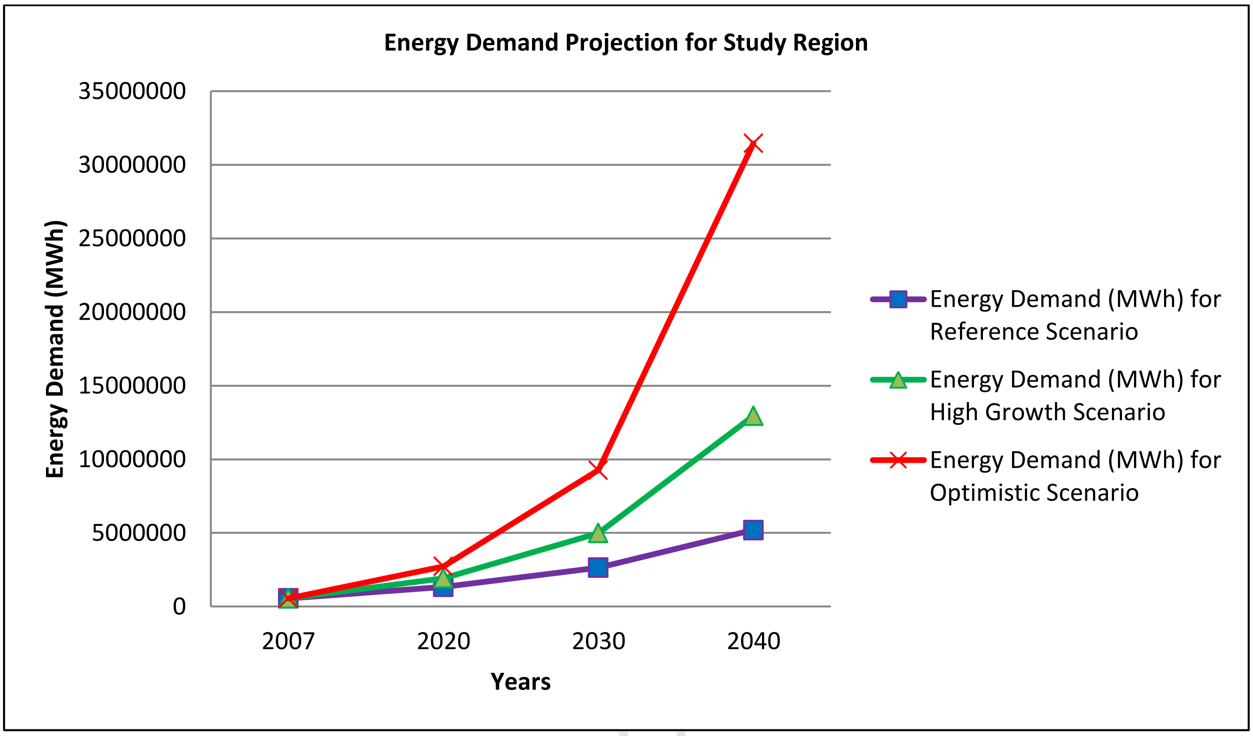


Figure 3.11: Energy Demand Projection

3.7 Result Analysis

The result of the projection shows that for the region to meet the year 2020 economic objectives as stipulated in the country's energy policy, an ambitious 2,731 GWh of energy would be required. However, meeting this demand is assumed to include the use of solar thermal power system as projected in the national energy policy document (ECN 2011) discussed in the previous chapter. The adoption of solar thermal power technology will complement power supply to the region. A decentralized solar thermal technology in the region will supply adequate power and compensate for possible power loss in transmission from centralised thermal power plants in the Southern part of the country.

At reference and high growth scenarios, energy demand of 1,344 GWh and 1,925 GWh respectively would be required by the year 2020. Comparing the above result to the energy production projection from solar thermal plant discussed in chapter 2, CSP's supply capacity in the region for reference and high growth scenario is assumed to be 1,000 MW and 3,200 MW in year 2020. At 40% capacity factor the corresponding energy production will be 2,190

GWh and 7,008 GWh respectively. Subsequently, energy production from CSP is assumed to increase for both scenarios (reference and high growth scenarios) to 3,504 GWh and 16,263 GWh in the year 2040. Although, the projection extends to year 2050, the realisation or failure to achieve the vision 2020 objectives will determine the future energy demand pattern. If government could achieve its year 2020 economic objectives, such that the rate of GDP growth increases from the business as usual trend, the corresponding economic output will require increase in energy production capacity. However, while the reference scenario is somewhat achievable, the high growth and optimistic scenarios will require enormous investment and political will.

3.8 Summary

As discussed, poor power supply in the region has significantly hampered commercial and industrial activities. In order for commercial and industrial activities to expand in the region, it is imperative that an adequate and reliable power supply capacity is developed. An improved power supply not only has the potential to revive economic activities, but can be an important factor for addressing the challenge of energy poverty in the region. In addition, energy has been described as a major driver of economic production. This relationship shows that a sound energy supply is necessary to support an increase in per capita production. Hence, to achieve this, it is important that the indigenous energy resource of the area be utilised. The major energy resource in the region is solar energy. One of the ways solar power can be harnessed is by employing the use of CSP technology. Adoption of CSP technology can improve energy security in the region from both supply and cost perspectives. Generating electricity from CSP will complement power supply from the Southern region and compensate for possible interruption and loses that might occur in transmission. Increase in electricity supply can reduce the cost spent on private generators to meet suppressed demand. Details on CSP requirements for the region and its economic implications are discussed in succeeding chapters.

Chapter 4

CSP technology and solar power potential in the study region

The potential energy source in the study region is solar energy. The region lies within a high sunshine belt with enormous solar energy potential. It enjoys an average daily sunshine of about 6.5 hours and an annual average daily solar radiation of approximately 7.0 $kw/m^2/day$ (Bala et al 2001). The average annual Direct Solar Irradiation (DNI) varies from 2238.9 $KWh/m^2/yr$ in Kano to 2534.8 $KWh/m^2/yr$ in Sokoto. On average, the region receives about 2200 KWh/m^2 of solar energy annually (Usman 2012:2) over an area of 252,102 km^2 (NBS 2007). If solar PV modules covered roughly 1% of the region's land, the annual generation capacity at 25% load factor would be about 554×10^3 GWh of solar electricity. This is about 29 times the present electricity supply capacity in the region and about 477×10^5 tons of oil equivalent.

The average annual direct solar radiation in the region is comparable to that of Andasol's CSP site in Spain. Assuming the conditions of the Andasol site, 1% of the region's land area would supply an annual average of 181,303 GWh of electricity if it were used as CSP site. Since CSP is a lower emissions technology, the use of CSP in the Nigerian power sector will reduce the level of carbon emission arising from fossil fuel reliance in the energy sector. Moreover, CSP technology has the potential of improving industrial activities in the region; in addition to power supply, industrial activities which require high temperatures can derive their heat energy from CSP. Industries such as textile, food, metal, plastics, dairy and leather works found in this region can use heat energy from CSP for their industrial operations.

Table 4.1 shows the satellite data of the solar DNI for selected areas in the study region and DNI for some functional CSP locations in Spain and America. The solar energy appropriate for a CSP plant is a measure of the DNI, which is the energy received on a surface tracked perpendicular to the sun's rays (IEA 2010).

4.1 Comparison of DNI for study region and some selected CSP sites

Sites selected in the study region are listed in Table 4.1. The average annual DNI on these sites vary from 2238 KWh /m^2/yr in Kano to 2535 KWh/m^2/yr in Sokoto (Satellite Data).

Table 4.1: DNI for study region

Selected Areas	Longitude (E)	Latitude (N)	Annual Average DNI (KWh/m^2/day)	Annual Average DNI (KWh/m^2/yr)
Katsina	7.6006	12.9894	6.32	2308.4
Kano	8.5138	11.9944	6.13	2238.9
Maiduguri	13.1603	11.8464	6.20	2264.6
Damaturu	11.9608	11.7470	6.31	2304.7
Potiskum	11.0694	11.7091	6.31	2304.7
Gusau	6.6613	12.1628	6.43	2348.6
Sokoto	5.2390	13.0609	6.94	2534.8
Dutse	9.3392	11.7594	6.18	2257.3

Source: NASA Satellite Data

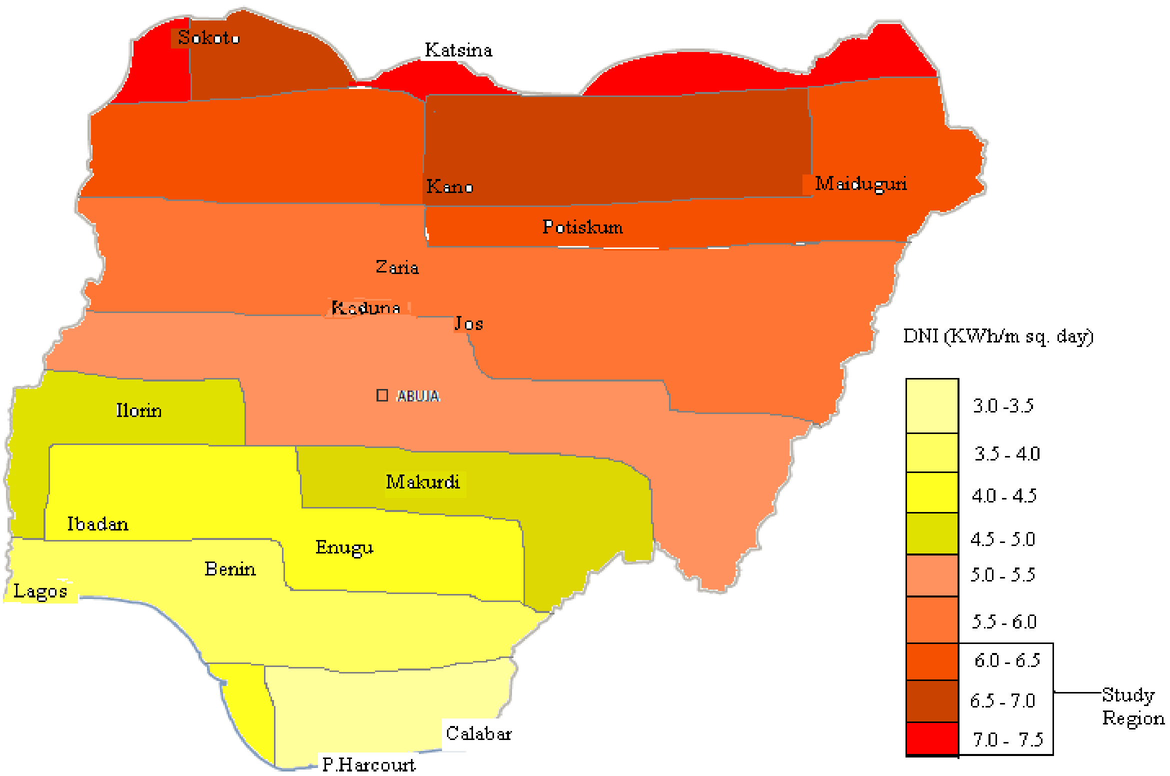


Figure 4.1: Map showing DNI in Nigeria

From Figure 4.1, the study region is areas with DNI between 6.0 $KWh/m^2/day$ to 7.5 $KWh/m^2/day$. Comparing the solar resource in this region to those of some functional solar CSP sites (Figure 4.2) in Spain and America shows that the DNI in the area can support CSP technology. Table 4.2 shows NASA satellite DNI for some functional CSP sites in Spain and America. The DNI (satellite data) recorded on these sites are compared to average DNI (Satellite data) recorded on selected Nigerian sites in Figure 4.2. Details on global CSP installed capacity are described in Table B in appendix B. According to the Andasol power plant's technical report, the ground station annual DNI measurement on the site is 2136 $KWh/m^2/yr$ (Solar millennium 2008:8). Comparing the ground DNI to the satellite data shows an annual DNI difference of 0.018 KWh/day and 6.6 KWh/yr. this result shows that the difference between the ground station and the satellite measurement is not significant.

Table 4.2: DNI for some functional CSP sites

Location	country	Coordinates	Capacity (MW)/ type	Average Daily DNI ($KWh/m^2/day$)	Annual Average DNI ($KWh/m^2/yr$)
Mojave Desert California	USA	35°01′54″N 117°20′53″W	354 (Parabolic trough)	7.10	2593.3
Sanlúcar la Mayor	Spain	37°25′00″N 06°17′20″W	150 (Parabolic trough)	6.18	2257.3
Guadix (Andasol, I, II, III)	Spain	37°13′42.70″N 3°4′6.73″W	150 (Parabolic trough)	5.83	2129.4
Torre de Miguel Sesmero	Spain	38°39′N 6°44′W	100 (Parabolic trough)	6.00	2191.5
Indiantown, Florida	USA	27°03′11″N 80°33′00″W	75 (ISCC)	4.79	1749.6

Source: Greenpeace 2009:82

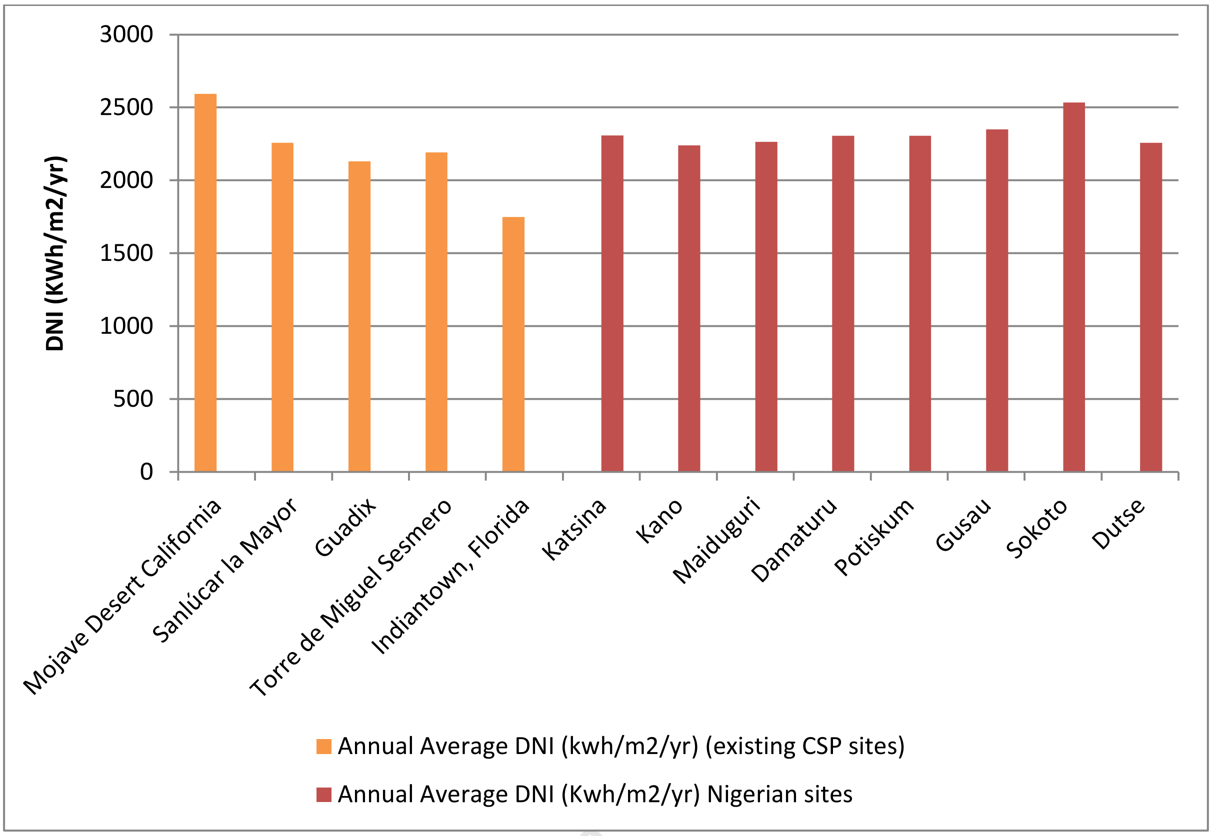


Figure 4.2: Comparison of DNI for study region and some selected CSP sites

An area is deemed appropriate for CSP if the threshold DNI is between 1900 KWh/m^2/year and 2100 KWh/m^2/year (IEA 2010). Below this range, CSP developers suggest the use of solar photovoltaic systems as a better technology because of its economic implications. Areas with low DNI require more investment compared to places with excellent DNI. Another important feature for CSP site is the land slope. Areas with land slope greater than three degrees are considered not suitable for CSP plants (IEA 2005). In a study conducted on eligible areas for CSP in Nigeria, Habib et al (2012) noted that the study region is suitable for CSP because the DNI in the region is above threshold and the terrain is relatively flat.

4.2 Water availability in the study region

Water availability has significant implications for CSP operations. The study region is interspersed by network of rivers and brooks. Major rivers in the region are Rivers Sokoto, Ka and Zamfara which are tributaries of the River Niger. Others are: Hadejia, Rima, Bunzuru, Goma, Gona and Ngadda. The famous Lake Chad is located in the Northeast, close to Madiguri. The Lake Chad alongside River Yobe is a major source of water in the north east region. Because the temperature in the region is relatively high, the rate of evaporation is high and some brooks dry up in dry season (Oyebande 1995:29). However, the major rivers listed above are available throughout the year except when there is severe drought. These rivers serve as sources for dams and irrigation in the region as shown in Figure 4.3 (Oyebande 1995:27, 29). From the map in Figure 4.3, a rough idea of the volume of some of these rivers can be established. For instance, Bakolori Dam constructed on River Sokoto (major tributary of River Rima) has a capacity of about 450 million cubic meters (Yahaya 2002: 420). River Sokoto has a total length of 395 km - it has its source in Funta in Katsina states, and it joins River Rima in Sokoto and flow down to the River Niger.

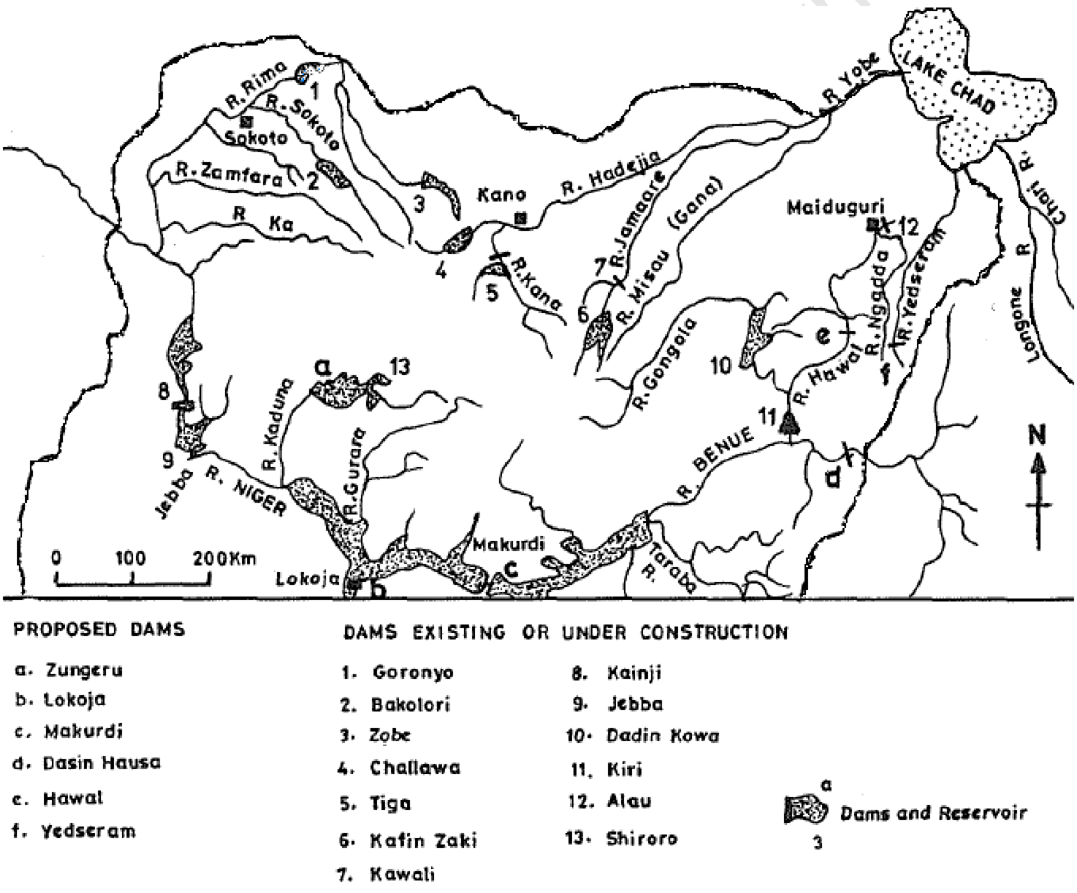


Figure 4.3: Major rivers and Dams in Northern Nigeria Source: Oyebande 1995:27

Other tributaries of River Sokoto are Ka and Zamfara. Goronyo Dam and Jibya Dam have capacities of 976 cubic meters and 142 million cubic meters respectively (Oyebande 1995:29). Data specifying the volume of these rivers are not available at the time of this study. However, using the capacity of dams on some of the rivers, it is assumed that water from these rivers can be utilized in CSP technology but in the dry season when volume of water is expected to decrease, an alternative water supply source might be needed. Sinking boreholes could be an option, as could employing a dry-cooling system in the technology.

4.3 Water usage in CSP technology

Water requirement in CSP technology is relatively high; however, water use in CSP technology is similar to those of conventional power plants. For instance, the same steam cycle principle used in coal and nuclear is used in CSP technology the difference is the energy source employed in converting water to steam (Carter and Campbell 2009). Water serves dual purposes in a steam turbine system; while water is superheated to produce steam to drive the turbines of a power generator, it is also used in the cooling system. In principle, water is assumed to be conserved by condensing steam from the turbine through a closed-loop system and a condenser. However, the condenser needs water to cool down the heat from the steam and water is lost in form of vapour to the atmosphere.

An alternative cooling system is dry-cooling which is expensive and reduces plants efficiency. The cost of dry-cooling in CSP plants can incur an additional 10% to the cost of electricity produced while the efficiency of the plant can also be reduced by about 7%. Water requirement in CSP technology includes mirror cleansing especially in parabolic troughs. Tower CSP plants use less water as surrounding air also help in the cooling system. In comparison to conventional power plants, about 3000 l/MWh are used in both parabolic trough and LFR plants - the water usage is similar to that of nuclear power plant. Water usage in coal and combined cycle natural gas plants are about 2000 and 800 (l/MWh) respectively (OECD and IEA 2010).

4.4 Estimated Solar CSP Potential in the study region

Table 4.3: Estimated solar CSP potential in the study region

Study Region	DNI Area	DNI Area with slope< 3%	Eligible (Km^2)	Potential Electricity production (GWh/yr)	Potential CSP capacity (MW)
Borno	100 %	65,490	655	66,941	32,750
Jigawa	60 %	11,239	112	11,446	5,600
Kano	100 %	16,311	163	16,659	8,150
Katsina	90 %	17,151	172	17,578	8,600
Sokoto	50 %	11,251	113	11,549	5,650
Yobe	80 %	32,313	323	33,011	16,150
Zamfara	100 %	23,566	236	24,119	11,800
Total		177,231	1773	181,303	88,700

Source: Adapted by the author from Nigeria Climate assessment preliminary report, as referenced in Habib et al 2012

Eligible land area in Km^2 = 1% of the estimated DNI area

Capacity factor = 40% (Andasol CSP Plant's condition)

Average daily sunshine = 6.5 hours

Heat Storage Capacity = 7.5 hours

Estimated capacity = 50MW/Km^2

4.5 Estimated CSP Capacity

If 1% of the eligible land area in each state is used as CSP sites, 88,700 MW of electricity is achievable in the region. This capacity is over ten times the current national electricity production, and over 200 times electricity supplied to the region in 2007. Moreover, an annual estimated energy of about 181 TWh can be achieved in the region at 40% capacity factor (Andasol CSP plant's capacity factor) in a year. This Figure shows that energy from CSP can contribute significantly to meeting the present and future energy demand in the region.

4.6 Concepts of CSP

The basic concept of CSP technology is relatively simple; it involves the concentration of the sun's Direct Normal Irradiation (DNI), using lenses or mirrors. The sun's energy is amplified to temperatures in the range of 400-1000^{0}C. This heat is first transformed to mechanical energy (by conventional steam cycle, Stirling engines or combined cycle engines) then to electrical energy (OECD/IEA 2009). At present, there are four categories of CSP, with similar modes of operation but different ways of receiving and amplifying the sun's energy.

4.6.1 Parabolic Trough

This technology uses curved parabolic shaped mirrors to concentrate incident DNI from the sun on an absorber made of stainless steel pipes. The pipes, which are coated and positioned in an evacuated glass tube, are placed at the focal line of the trough to enable it receive high concentrated heat energy from the trough. The coat and the glass tube help it absorb high levels of radiation while preventing heat lost by convention. Figure 4.4 shows the components of the collection assembly of a parabolic trough (Nafisa and Sadid 2010**)**.

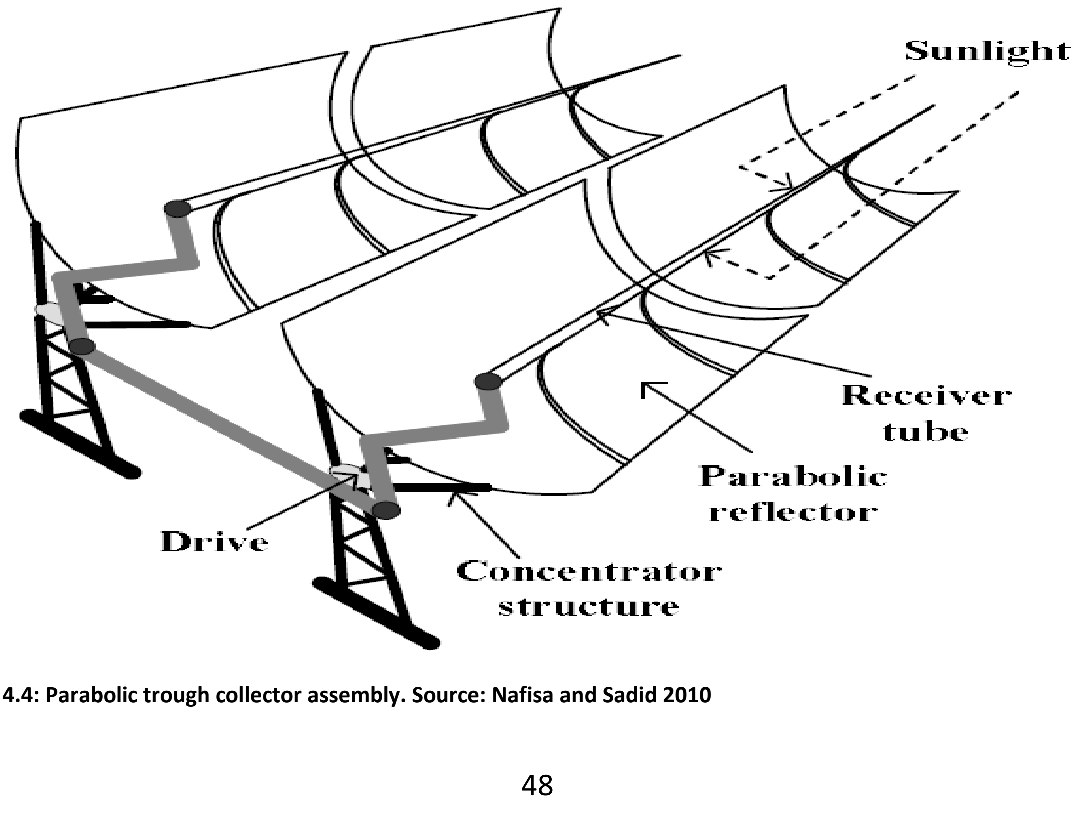


Figure 4.4: Parabolic trough collector assembly. Source: Nafisa and Sadid 2010

Evacuated Receiver Tube (Schott Solar 2011)

A Typical Parabolic trough CSP installation (Ben Backwell 2009)

The parabolic reflector is an array of curved mirrors, which can be more than 100 m long with curved surface of about 5 m to 6 m. The mirror is about 0.85 mm thick with a selective silver coat at the back. The receiver tube is an evacuated glass tube of about 115 mm in diameter, which encloses a stainless steel pipe of 70 mm diameter (Nafisa and Sadid 2010). The concentrator structure gives the mirror and receiver tube firm support, while a drive attached to it makes it flexible when moving in the direction of the sun. The collector assembly is designed with a tracker, which enables it to track the path of the sun (Leitner and Owens 2003).

A heat transfer fluid such as synthetic oil is heated up to 400^0 C as it passes through the receiver tube. The heated fluid (thermal oil) transfers heat from receiver tube to heat exchanger where water is pre heated and the evaporated steam super-heated before being used to run the turbines of a power generator to produce electricity. The process of producing electricity from solar parabolic trough is delineated in Figure 4.5. Due to the intermittent nature of solar radiation, a backup arrangement may be required, especially at night and on cloudy days. The system can be designed as an integrated solar combined cycle system (ISCC), or solar power plant with storage system. In ISCC, there is conventional power input and solar input. The combination is usually solar and gas systems; however, it can be used in coal, and diesel power plants. Combining conventional power plant with solar field will reduce the quantity of fossil fuel required and hence, reduces the quantity of GHG emitted from a specific installed capacity (Shuba et al 2010).

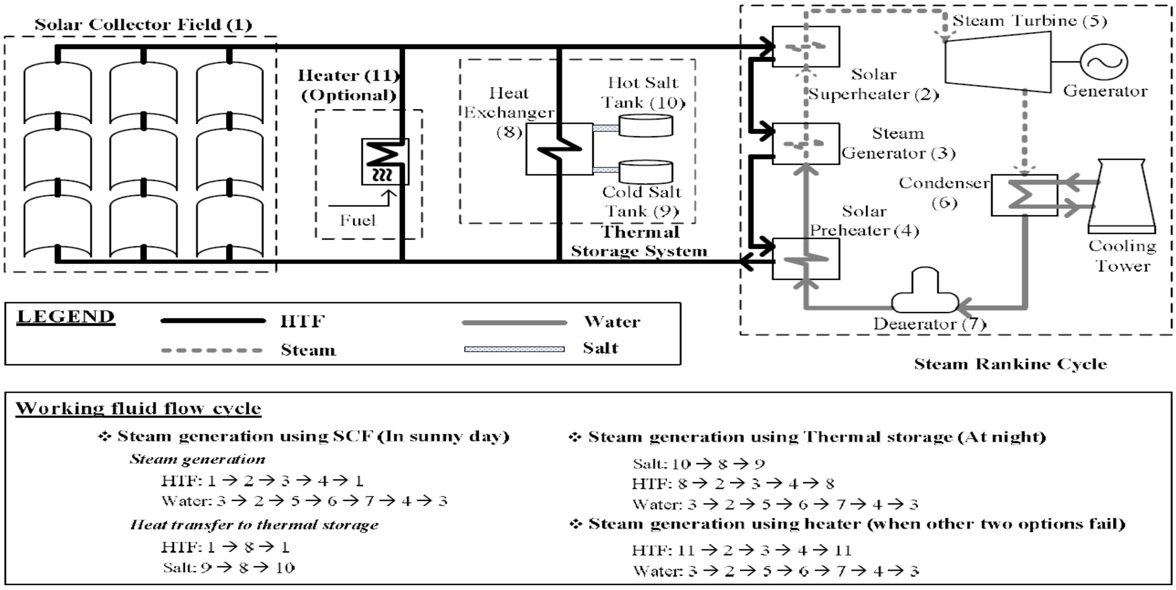


Figure 4.5: Parabolic trough plant with thermal storage. Source: Nafisa and Sadid 2010

Moreover, when the system is not an ISCC, a heat storage system is designed to support power production at night and on cloudy days. During peak sunshine periods, heat energy is stored in a thermal storage system. The thermal oil from the solar collector field is made to pass through a heat exchanger positioned in between two storage tanks. While the thermal oil is passing through the heat exchanger, cold molten salt is pumped through it to absorb heat energy and stored in another tank as hot salt. The process is reversed at night or on cloudy days as hot molten salt heats up the thermal oil instead of the solar field. Plants with thermal storage systems can achieve an annual capacity factor of over 70% (Denholm and Mehos 2011). This is a significant advantage over other renewable energy technologies as it addresses the problem of intermittency of power supply and can therefore provide base load.

4.6.2 Linear Fresnel Reflectors (LFR)

This technology is similar to parabolic trough system but uses fixed linear downward facing receiver positioned at common focal point of the reflectors as shown in the Figure 4.6 below. A row of slightly curved mirrors is used to focus sun's rays onto the fixed receiver. Compared to parabolic system, this design is more flexible and does not require as large a capital investment. The facility uses direct steam generation thus, eliminating the use of thermal oil and heat exchanger. However, in relation to parabolic trough design, the system is less efficient and it is difficult to incorporate thermal storage capacity into it (OECD/ IEA 2010). Despite its less efficient cycle and the corresponding larger field collector requirement, LRF uses less land area compared to parabolic trough and central receiver technologies because of its compact nature.

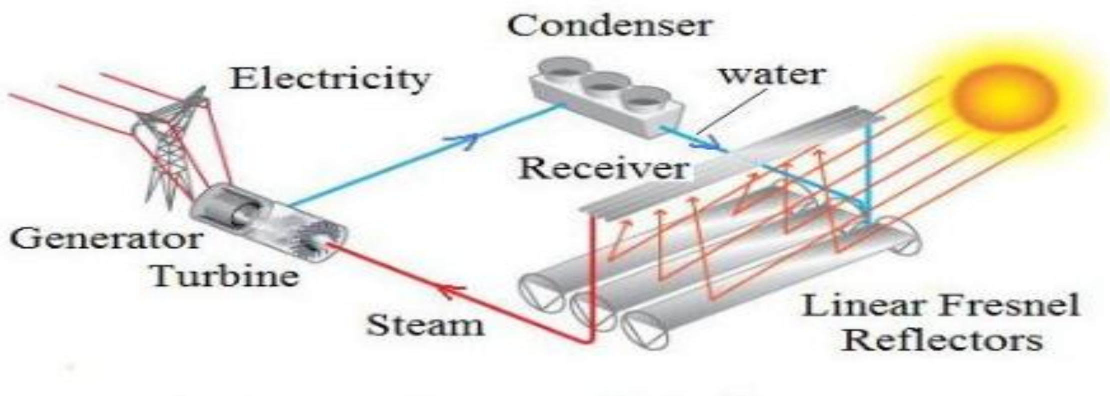


Figure 4.6: Linear Fresnel Reflectors (LFR) solar power plant. Source: Brighthub.com

4.6.3 Solar Tower or Central Receiver Systems (CRS)

The Central Receiver System (CRS) is a type of solar furnace using hundreds of small reflective mirrors called heliostats to concentrate the sun's rays on a central receiver placed on top of a fixed tower (Figure 4.7). The concept allows the receiver to reach extremely high temperatures, which is used to heat the Heat Transfer Fluid (HTF) (usually molten nitrate salt) to a temperature of up to 1000^0 C. The salt can serve as both heat transfer fluid and storage medium (OECD/ IEA 2010). The thermal energy absorbed by the HTF is transferred into steam cycle, where it generates superheated steam for the turbine.

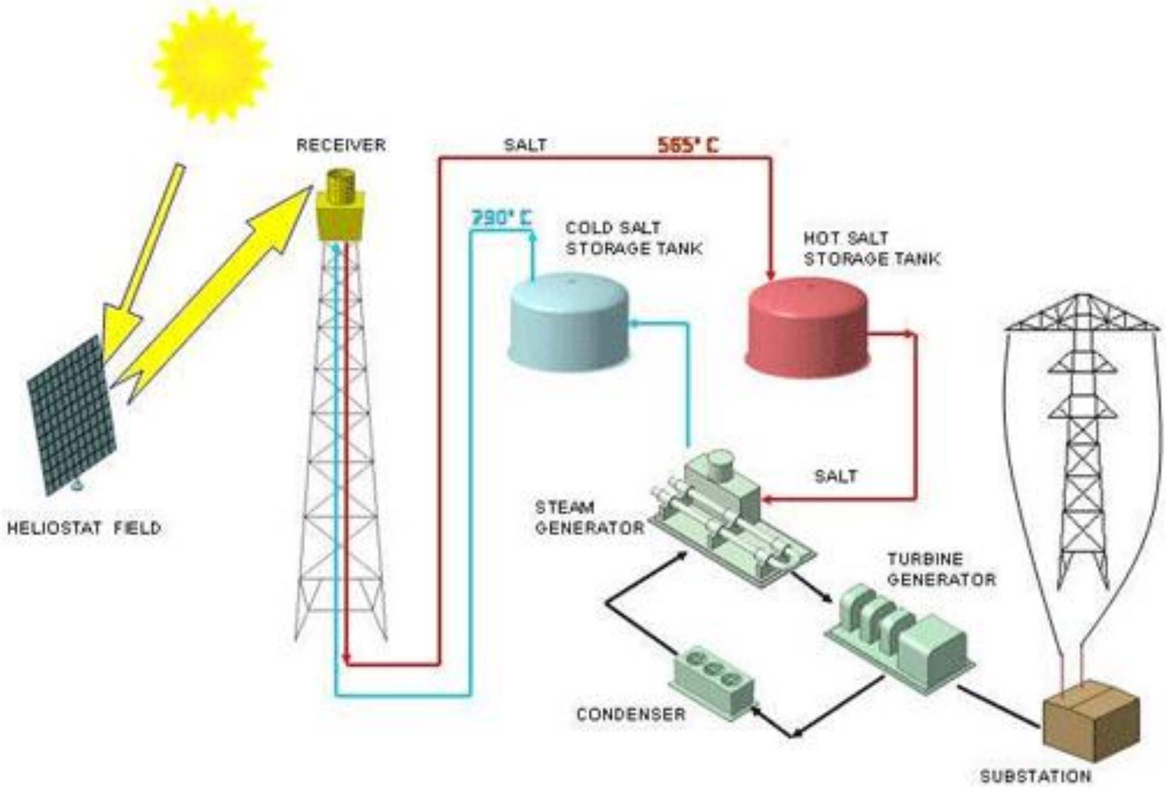


Figure 4.7: Solar Tower or Central Receiver Systems (CRS)

Abengoa's PS-10 project in Seville Spain (Rafael Osuna 2007)

The Abengoa PS-10 solar thermal power plant in Spain is the first commercial central receiver plants in the world. It has an electrical output of about 11 MW_e produced with 624 large movable mirrors (Heliostats) and 100 m high tower (ENS 2007).

4.6.4 Parabolic Dish or Dish Stirling

Parabolic dishes are used to concentrate solar radiation onto a receiver propped at the focal point of the dish. The heat generated at the receiver is used to power an independent generator such as Stirling machines or small turbine systems. The movement of the apparatus in tandem with the sun's direction allows high concentration of solar radiation on the receiver. This temperature can be as high as 750^0 C depending on the thermal property of the heat transfer medium (Greenpeace 2009). Hydrogen or helium gas is usually used as working gas in Stirling engines (Nafisa and Sadid 2010). The Stirling engine in the PCU operates on hot air expansion principle. The heat energy in the working gas is first transformed to mechanical energy and latter to electrical energy.

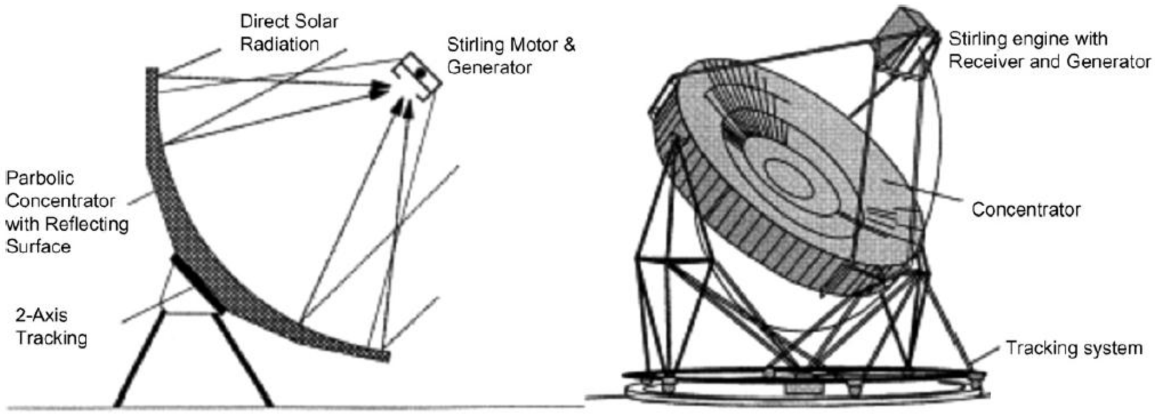
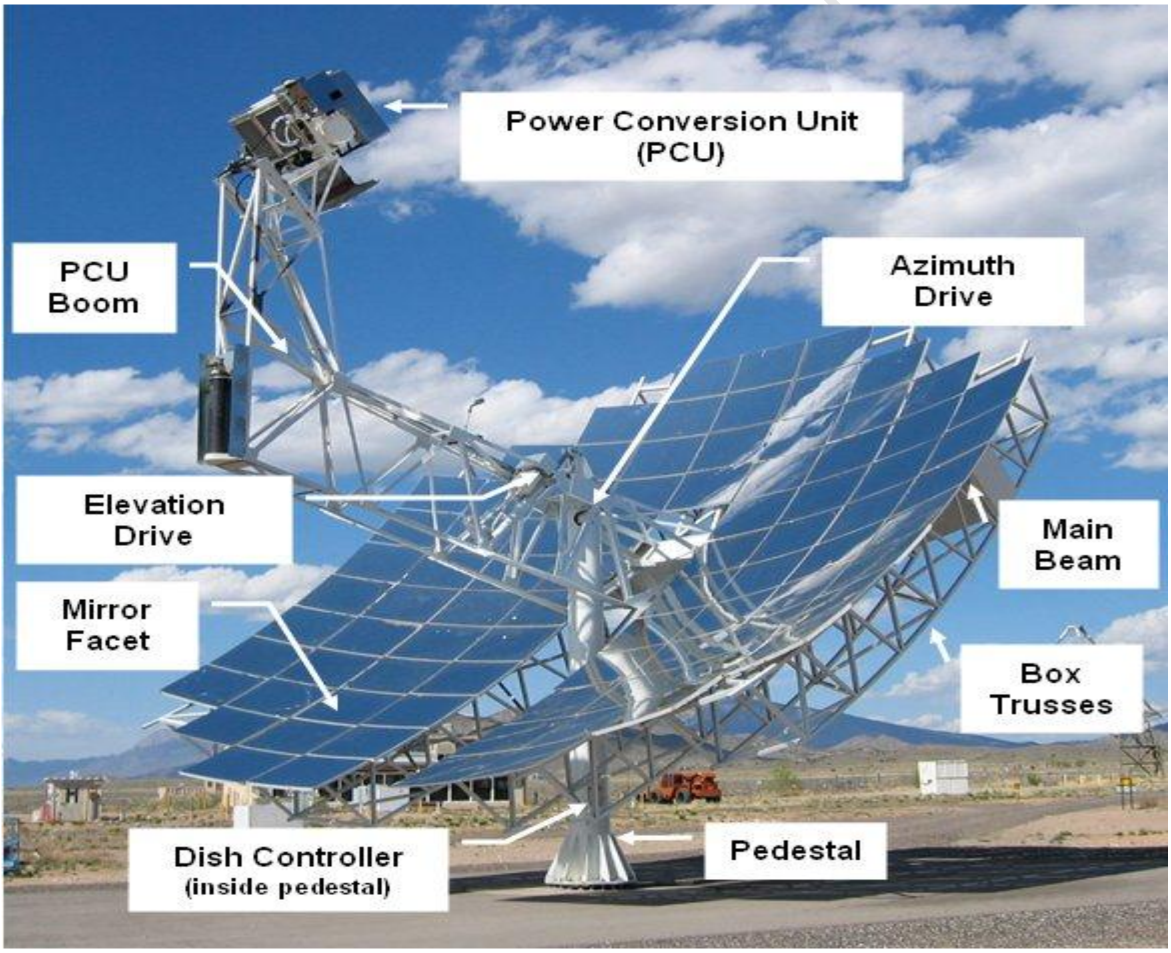


Figure 4.8: Schematic view of parabolic dish with Stirling engine. Source: Pavlovi'c et al 2012



Source: stirlingenergy.com

4.7 Comparison of different CSP technologies

Parabolic dish has a higher annual solar- to- electric efficiency (31.25%) compared to other systems because of its high temperature though, with limited capacity due to the independent power production in each of the dishes. However, mass production of parabolic dish system may produce better capacity, and allow them to compete with larger systems (OECD/IEA, 2009). Parabolic trough system on the other hand, has a higher capacity but with lower efficiency. The operating temperature of the working fluid is about 400^0 C, bringing its annual solar- to- electric efficiency to about 14% (Nafisa and Sadid 2010). Table 4.4 shows some characteristics and performance indicator of CSP technologies. CSP technology is projected to make a significant contribution to the future renewable energy development according to the global CSP outlook (Greenpeace 2009). Based on advanced growth scenario, a higher capacity factor is projected from the technology leading to a significant global power contribution of 7% and 25% in 2030 and 2050 respectively. As at the time of this study, CSP is contributing about 1700 MW of electricity to global electricity generation (Greenpeace 2009).

Table 4.4: characteristics and performance indicator of CSP technologies

System	Concentrator Technology	Power Conversion	Capacity Unit in MW	Concentration (Kw/m^2)	Annual Solar Efficiency	Capacity Factor (solar)	Land Use m^2/MWh/y
Trough	Parabolic Trough	Rankine Cycle	10-200	70-80	10-15% (D) 17-18% (P)	24 %(D) 25-90%(P)	6-8.0
LFR	Linear Fresnel Reflector	Rankine Cycle	10-200	25-100	9-11% (P)	25-90% (P)	4-6.0
Tower	Heliostat Solar Field	Rankine/Brayton Cycle	10-150	300-1000	8-10 %(D) 15-25%(P)	25-90% (P)	8.0-12
Dish-Engine	Parabolic Dish	Stirling/Brayton Engine	0.01-0.4	1000-3000	16-18% (D) 18-23%(P)	25% (P)	8.0-12

Source: Kamil 2011:811

(D) = demonstrated (P) = projected

4.8 Site Selection

Apart from strong DNI, other important factors to be considered while selecting a CSP site are land slope, proximity to power grid, access to water and proximity to backup fuel (if applicable). Flat land with slope between 1^0 – 3^0 is considered ideal for CSP site (Schlecht 2011:9). Water usage is high in CSP technologies (except for parabolic dish) because it is used both in the condenser and mirror cleaning. Dry cooling could be an option especially in arid areas where there is limited access to water – this will however, reduce the efficiency of the plant and raise the capital cost of the plant. Sites closer to the grid will not bear the cost of building transmission lines over long distances.

4.9 Land Requirement

Land requirements in CSP technology vary with a number of factors such as; electrical output, storage size, solar radiation and cycle efficiency. A larger electrical output requires a larger collector field so also is the storage size. However, sites with strong DNI require smaller collector field. Comparing the three technologies shown in Figure 4.9, under similar conditions, production of 100 MW will require different land areas. While the central receiver requires double of the size of parabolic trough plant to produce the same capacity, the LFR requires lesser land space because of its compact nature.

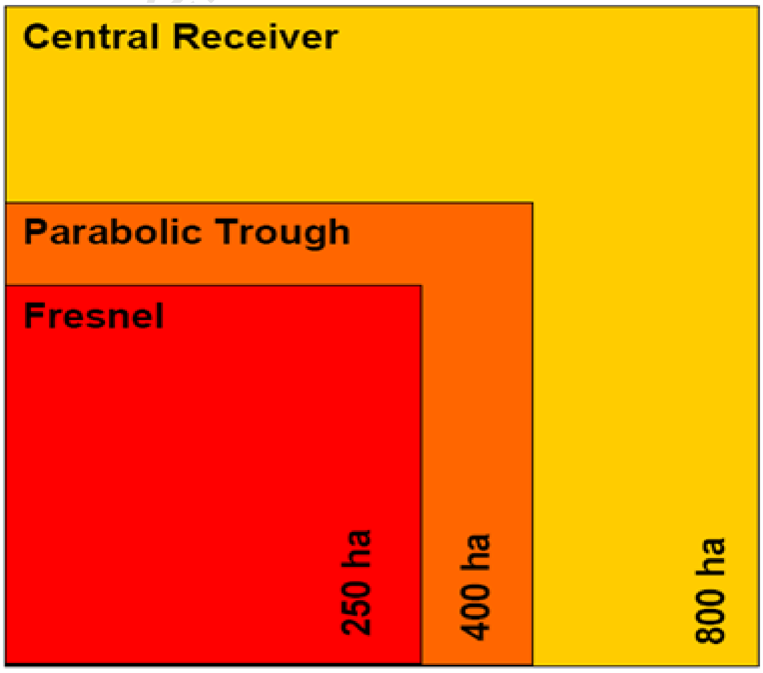


Figure 4.9: Land use for 100 MW plant by the three technologies. Source: Brent 2012

4.10 Overview of Andasol solar power station

Andasol solar power plant is located in the Southern Spanish province of Andalusia in Spain; it is the first commercial parabolic trough solar thermal plant in Europe and the first with heat storage in the world (Pavlovic et al 2012). It has total electricity producing capacity of 150 MW and annual energy production of 540 GWh from a three unit of 50 MW each. The plant went online in 2009 with estimated life span of 40 years (Solar millennium 2008). The plant is located close to the Mediterranean Sea on an elevation of about 1100 meters above the sea level. Its location gives it access to strong DNI and water; the average annual DNI on the site is 2136 KWh/m^2 and the plant uses about 870, 000 m^3 of water annually basically for cooling. The plant occupies about 2,000,000 m^2 of land with collector surface of about 510,120 m^2 each. (Solar millennium 2010) Like the technical mode of operation of a parabolic trough plant discussed above, Andasol plant uses heat transfer fluid, superheated steam and thermal storage system for its operation.

The thermal storage backup system is designed to keep the plant running at overcast periods and at night. It uses a molten salt as heat storage medium; the salt comprises of 40% sodium nitrate ($NaNO_3$) and 60% potassium nitrate (KNO_3). A share of heat from the solar field is used to heat the molten salt from a temperature of 291^0 C to about 390^0 C. The salt is transferred between two tanks (cold and hot tanks): the movement of the heated salt between these two tanks allows it to supply the required heat for electricity production in the absence of solar energy. The heat energy capacity of the system is about 1010 MWh, this energy can enable the plant to function for about 7.5 hours at night (Pavlovic et al 2012). The longer hours achieved by the introduction of heat storage system has helped the plant achieve an average annual efficiency of about 14.7%.

4.11 Andasol Power Station and a Potential site in the study region

The average annual DNI in the study region is comparable to that of Andasol's CSP site in Spain. Considering the conditions of the Andasol site, similar electricity output can be achieved from a potential site in the region. As shown in Figure 4.2, the average annual DNI in some places in the study region is higher than those of functional commercial CSP sites in Spain. Cost of energy from areas with high DNI will reduce due to better efficiency expected from CSP plants in such areas (IEA 2010). A mathematical relationship comparing the cost of energy from Andasol plant to its DNI can be used to determine the likely cost of energy from a similar plant (or potential plant) with different DNI (Franz Trieb et al 2011: 309). In subsequent chapter, the condition of Andasol plant will be used to determine the likely cost of energy from a potential CSP plant on a site in the study region.

4.12 Potential Contribution of CSP to the Study Area

Adopting CSP technology in the study region will reduce dependence on conventional fossil fuel in the country since CSP is a lower emissions technology. As discussed above, the solar potential in the region can meet its power demand if 1% of the eligible land is used in CSP technology. Generating power in the region will reduce the cost of building infrastructure to transmit power from power stations in the South. Since drawing power over long distances makes transmission lines susceptible to transmission loss, generating power in the study region will reduce such loss. Another benefit of CSP in the region is provision of heat energy for industrial activities. The use of heat energy from CSP in industrial operations is suggested by IEA as a way of reducing dependence on fossil fuel for such operations (CSP-Global outlook 2009:35).

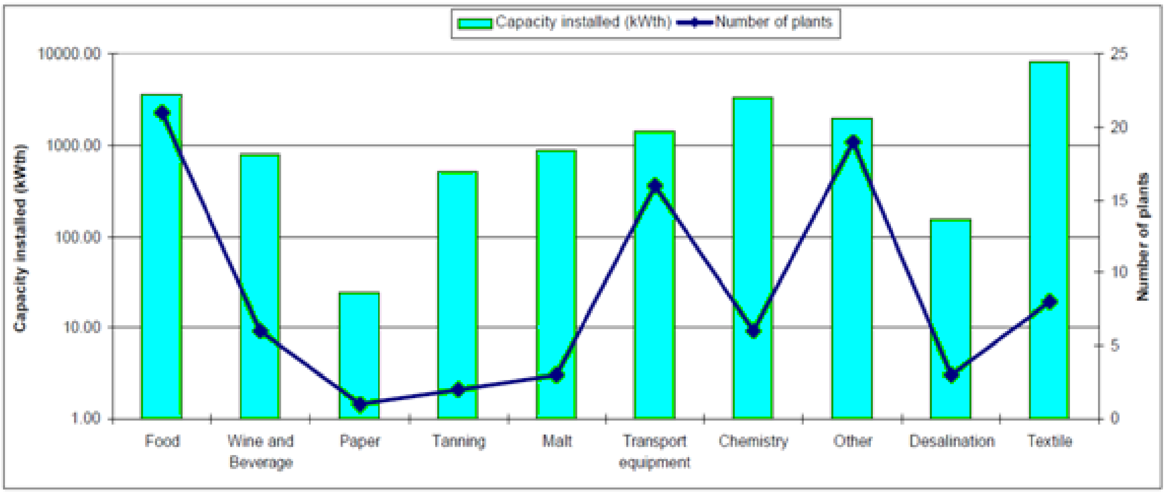


Figure 4.10: Solar industrial process heat plants by industries. Source (Claudia et al 2008): IEA report on about 90 operating solar thermal plants for process heat in 21 countries. The survey shows a total installed capacity of 25 MW with total land coverage of about 35,000 m^2 for industries meeting their heat requirement via solar energy. The operating capacity of the solar thermal plants in industry represents about 0.02% of the total global solar thermal capacity which is 118 GW.

Considering the nature of industrial activities in this region, adoption of CSP technology has the potentials of resuscitating moribund industries in the region. Industries such as textile, food, metal, plastics, dairy and leather works found in this region can use heat energy from CSP for their industrial operations. According to an IEA commissioned study on 'Potential for Solar Heat in Industrial Processes', Claudia et al (2008) noted that heat required for industrial operations such as those found in the study region ranges between 100 – 400^0 C. Such temperature can be generated from parabolic trough plants. A number of industries across the globe are using solar process heat for their operations. Figure 4.10 shows the result of an IEA survey conducted in 2007 on solar heat processes and the global installed capacity. The result shows that some industries manufacturing similar products to those found in the region are meeting their heat energy demand with solar thermal technology.

Chapter 5

Cost of Energy from CSP and Conventional Power

As discussed in previous chapters, economic growth requires an increase in energy production. According to the electricity supply projection done by the Energy Commission of Nigeria (ECN) (ECN 2011:67, 71), the nation is expected to start harnessing its solar energy potentials in solar thermal technology as from the year 2020. However, since the solar energy resource is abundant in the northern region, power generation in the study region will reduce transmission losses associated with sourcing power from gas thermal power plants in the southern region. Consequently the cost of building the necessary infrastructure would be reduced. CSP technology to-date has its commercial market in Spain and the United States only (Franz Trieb et al 2011: 307), probably due to the market competition with conventional power and high investment cost required. If the cost of energy from CSP is too high and public utilities are not willing to charge their customers higher electricity tariffs, government would have to create incentives that will encourage investors to invest in CSP technologies. However, countries where CSP have been introduced to the commercial market have been able to develop policies that encourage its usage alongside conventional source of power. For example, Spain has been able to set the same tariff for electricity supply from both CSP and conventional energy sources (Solar Millennium 2008:5).

An additional benefit is the development of a local energy industry. Spain for instance, imports most of its energy fuel especially fossil fuels. Dependence on imported fuels makes the country's energy security fragile. Due to the volatility of the international oil market, countries reliant on oil imports can encounter supply problems. This can result in interruptions in energy supply (Franz Trieb et al 2011: 310). In order to improve energy security, Spain is looking to improve its local energy supply by utilizing its solar energy resource. Not only will this improve the energy security of the country but will also improve the emissions profile of the country's energy sector. (Franz Trieb et al 2011: 310)

In Nigeria, government pays subsidies on the price of gas supply to power stations in order to encourage a boost in power supply. However, government admits that such an arrangement is not sustainable (Michael et al 2004: 135). In this study, the international gas price is assumed to be the realistic market price from the opportunity cost perspective because the gas consumed locally could have otherwise been sold at the international gas price. The domestic and international prices of gas were used to compute a model for the levelised Cost of Energy (LCoE) for power supply from conventional gas power station under the IEA new and current policies scenarios (IEA 2010: 71). Moreover, the LCoE of energy from CSP was calculated using the highest DNI recorded in the study region[3] and the average DNI for all the sites considered in the study.

The IEA current and new policies scenarios reflect assumed future government policies regarding the energy market. The new policies scenario takes account of existing energy policies and declared intentions while current policies scenario assumed no change in government policies. The IEA study does not state specifically the degree of certainty of future energy market. It however based its projection on already adopted policies in the energy market as baseline for current policies scenario. In the new policies scenario, energy market projection is based on implementation of announced energy policy objectives. These objectives include national pledges to reduce greenhouse gas emissions and plans to phase out subsidy by some countries.
The following sections analyse the results from the model used for this study.

5.1 LCoE from Conventional gas-Thermal Power Plant in Nigeria

The LCoE is an analytical tool used to determine the generating cost of electricity without including transmission cost and externalities such as environmental and health impact. Input parameters include investment cost, discount rate, fuel cost, operation and maintenance cost. In this study, LCoE is used to compare cost of energy generated from gas thermal plant and CSP technology in Nigeria. LCoE is calculated by adding the annual levelised cash flow in a generating plant and dividing it by the total annual energy produced. The levelised cash flow includes fuel cost, operation and maintenance cost, and the initial capital cost. Table 5.1 shows input parameters for LCoE of a gas thermal power plant.

[3] The study region is the region with the highest DNI in the country according to data from NASA satellite.

$$LCoE = LevCap + LevO\&M + LevFuel \ldots\ldots\ldots\ldots\ldots\ldots 5.1$$

$$CRF = \frac{1 * (1+i)^n}{((1+i)^n - 1)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5.2$$

$$ICC = Invetment \left({}^{\$}/_{kw} \right) * capacity\ (kw) \ldots\ldots\ldots\ldots\ldots 5.3$$

$$LevCap = \frac{CRF * ICC}{8760 * availability * capacity} \ldots\ldots\ldots\ldots\ldots\ldots 5.4$$

Table 5.1: Input Parameters

		References
Discount Rate	12%[4]	CBN
Life Time (n)	30 years	IEA 2009
ICC is initial capital cost (total debt)	$ 3989556000	Appendix C
Availability	69.4%	Appendix C
LevO&M (fixed & variable)	0.0004 $/KWh	WADE & ICEED 2009: 31
Capacity	5.904 GW	WADE & ICEED 2009:28
CRF	0.124143658	Appendix C
LevCap	0.013792 $/KWh	Appendix C
Investment cost	675.74 $/KWh	Appendix C
Levfuel	0.046628 $/KWh	Appendix C

[4] Decisions on interest rate are taken by the Central Bank of Nigeria (CBN) and the benchmark interest rate is set at 12%. The decision according to the CBN was informed by the nature of the Nigerian economy and the global economic environment. The Nigerian economy is highly dependent on crude oil market which can be influenced by global market condition. The CBN says the 12% benchmark will help mitigate against any negative impact of the global oil market on the nation's economy (James 2012).

5.2 Levelised cost of fuel (LevFuel) - Domestic and International cost of fuel in Nigeria

Price of fuel in Nigeria is determined through a product sharing contract (PSC) between the international oil companies and the federal government. Under the PSC policy, the NNPC which is government's representative engages the service of a competent contractor to carry out oil production. The contractor bears the initial cost but the government reimburse him after oil discovery and production. The contractor is allowed to market the product at a price set by the NNPC (Nkay 2011). The domestic price of oil and gas in Nigeria is however different from the international market. For instance, in 2010 while the price of gas was about 4.1$/MMBtu at the international market (IEA 2010), the domestic price of gas in Nigeria was 1$/MMBtu (Aderibigbe 2010). Despite the domestic price of gas in Nigeria is comparatively cheap, government still waive its own share of the PSC on gas supply to power stations. However, gas supply to power stations include a transport charge of 0.30 $/MMBtu (Tallapragada 2009:32) (Adribigbe 2010: 42).

The equation below is used to determine the price of gas to power stations

Price of gas to power stations (P) = Aggregate price (P_a) + Transport charge (T_c)………5.6 (Aderigbe 2010: 41)

Aggregate price P_a is determined by the product sharing contract (PSC) between the government and international oil companies in Nigeria (IOC).

$P_a = P_{IOC} + P_{FGN}$ …. 5.7

P_{IOC} is the share for International Oil Companies

P_{FGN} is the share of gas revenue for the government

According to the NNPC stake holder workshop as referenced in (Adribigbe 2010: 42), the PSC is in ratio 51% to 49% respectively between the government and the IOC.

P_{IOC} = 49% of P_a, P_{FGN} = 51% of P_a (in case of subsidy, the government's share = 0)

In 2010, government set the price of gas in Nigeria at 1$/MMBtu and the transport cost of gas to power stations was 0.30$/MMBtu. In the case of gas supply to power generating stations, government waive its own share of the PSC as subsidy on electricity production. The international market price of gas is however different from the domestic market price. Government uses international gas price to sell gas in the international market while local consumers enjoy an indirect subsidy in form of a reduced price. Though, government plan to review the domestic price of gas by proposing a new gas price of 2 $/MMBtu starting from the year 2013, the international gas price for the same year is projected at 5.3$/MMBtu according to the IEA (2010). Applying the above equations, in year 2010, the subsidised cost of gas to power station was 0.79$/MMBtu.

$$0.49 + 0.30 = 0.79 \text{ \$/MMBtu}$$

The fuel price used in this study assumes the two scenarios of subsidised fuel price and non-subsidised fuel price. The subsidy on gas according to the government is aimed at encouraging adequate gas supply to power stations. However, government claim the system is not sustainable and it plans to withdraw the subsidy sometimes in the future (NERC 2008). The rate of increase in fuel price in this study was based on the IEA, (2010) natural gas price projection scenarios. The new Policy and current policy scenarios were considered using the real value import price of gas into the United States. This price is otherwise referred to as the international gas price in the IEA (2010) report.

Nigerian government plans a new price of 2$/MMBtu for domestic gas starting from year 2013(Aderibigbe 2010:39), this new price is also included in the model. Details of the projection for the four different scenarios for the domestic gas price increase under IEA's new and current policies scenarios for gas increase are shown in the table 5.2. Using different domestic gas prices and the international gas price, a comparison can be drawn between the costs of energy from gas thermal plant and that of CSP. The cheap price of gas in Nigeria (both the present cost and the propose cost) has created a significant margin between it and the international price, likewise the cost of energy in both scenarios. These disparities in prices have different implications on the cost of energy from a potential CSP plant in Nigeria. The following sections analyse the competitiveness of the cost of energy from CSP in relation to the cost of energy from gas thermal plant using both domestic and international gas price scenarios.

Table 5.2: IEA natural gas price increase rate – Real terms

New policies scenario	
Year ranges	% rate of increase
2009-2015	9.33
2015-2020	2.90
2020-2025	2.34
2025-2030	1.70
2030-2050	0.99
Current Policies Scenario	
2009-2015	9.33
2015-2020	3.20
2020-2025	2.60
2025-2030	2.30
2030-2050	1.50

(Sorce: IEA, 2010: 71)

Applying equation 5.1 and the IEA gas price increase scenarios shown in table 5.2, the following results were obtained for LCoE for the domestic gas price.

New Policies Scenario

Year	2010	2015	2020	2025	2030	2035	2040	2045	2050
LCoE 1 ($/KWh)	0.023	0.028	0.030	0.032	0.034	0.035	0.036	0.037	0.038
LCoE 2 ($/KWh)	0.029	0.037	0.041	0.044	0.047	0.048	0.050	0.052	0.054
LCoE 3 ($/KWh)	New Price of fuel from 2013	0.033	0.036	0.039	0.041	0.042	0.044	0.045	0.047
LCoE 4 ($/KWh)		0.048	0.054	0.058	0.062	0.065	0.067	0.070	0.073

Current Policies Scenario									
Year	2010	2015	2020	2025	2030	2035	2040	2045	2050
LCoE 1 ($/KWh)	0.023	0.028	0.031	0.031	0.033	0.035	0.036	0.038	0.040
LCoE 2 ($/KWh)	0.029	0.037	0.041	0.045	0.049	0.051	0.054	0.057	0.061
LCoE 3 ($/KWh)	New Price of fuel from 2013	0.033	0.036	0.040	0.043	0.045	0.047	0.050	0.052
LCoE 4 ($/KWh)		0.048	0.054	0.060	0.065	0.069	0.073	0.078	0.083

LCoE 1 – is the subsidised cost of energy in the business as usual scenario

LCoE 2 – is the cost of energy assuming there were no subsidy

LCoE 3 – is the subsidised cost of energy in the new[5] price scenario

LCoE 4 – is the cost of energy without subsidy in the new price scenario

Figures 5.1 and 5.2 show the cost of energy from domestic gas price for the current and new policy scenarios, two of the prices were based on the subsidised and non- subsidised cost domestic cost of gas in 2010. The result shows that the cost of energy from gas thermal stations in 2010 was 0.023 $/KWh in case of subsidy and 0.028 $/KWh if subsidy were withdrawn. Though, the domestic price of gas is cheap compared to the international gas price, the non-subsidised gas price scenario shows a significant margin between it and subsidised price. In the second case of the proposed new domestic price of gas, two possible scenarios were assumed in the projection: a case where the price of gas to power station is being subsidised and if subsidy is removed. The non-subsidised new price projection shows a significant high cost of energy in both current and new policies scenarios. The proposed new price projection is most likely to be the future ideal domestic gas price based on the non-sustainability of subsidy on gas price and the determination of government to review the domestic price of gas.

[5] New price of natural gas is scheduled to take off in 2013 (Aderibigbe 2010: 42)

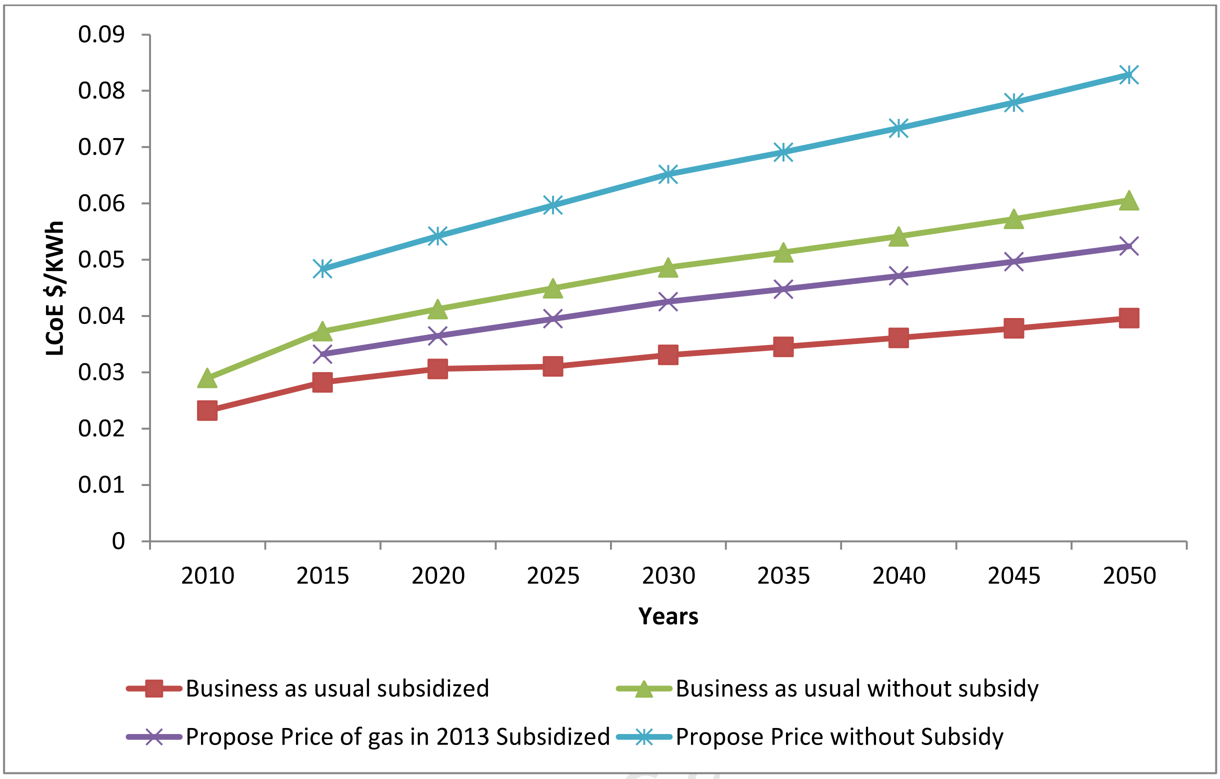


Figure 5.1: LCoE for gas thermal Power in Nigeria – IEA current Policy Scenario

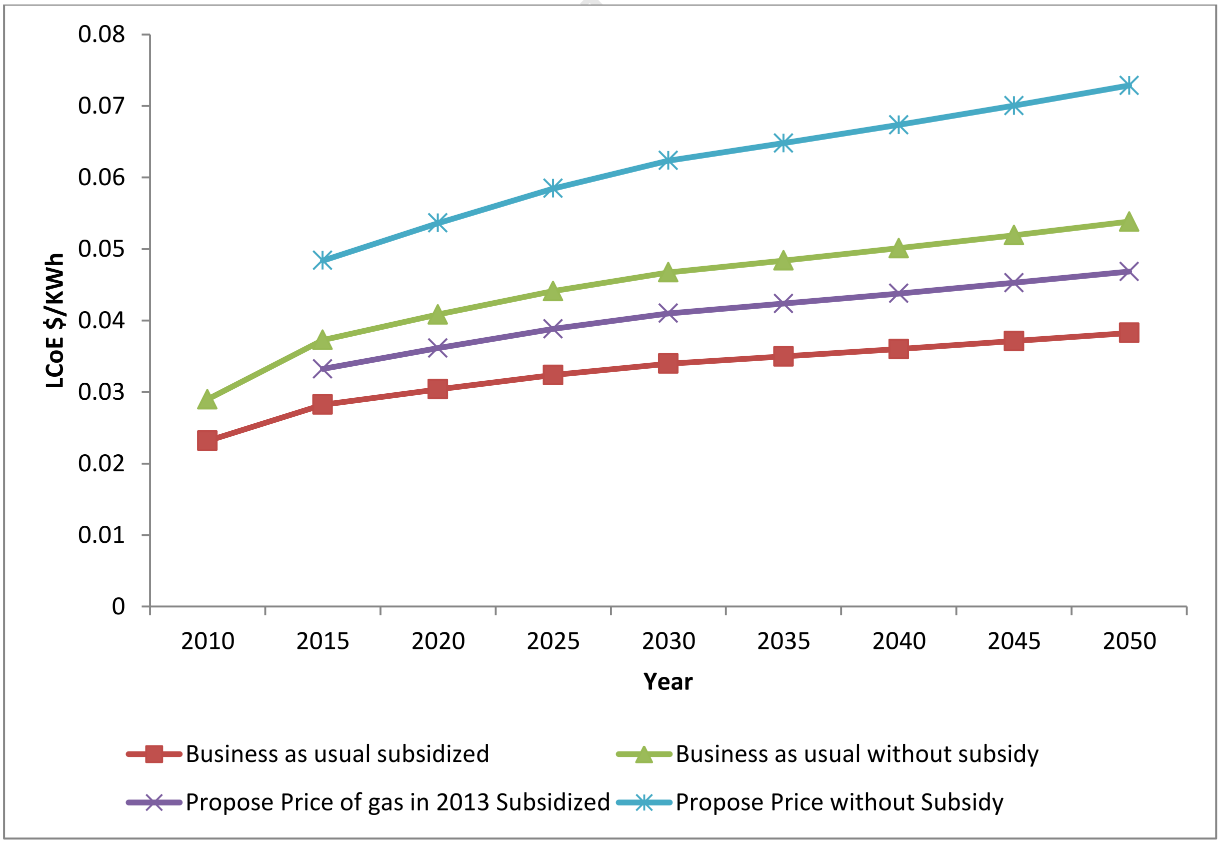


Figure 5.2: LCoE for gas thermal Power in Nigeria – IEA New policy scenario

The result based on the new and current policy scenarios shows a slight difference in the cost of energy as from year 2025. This implies that a possible decrease in the cost of energy from natural gas is possible under the new policy scenario. Comparing the results of international gas price projection in Figure 5.3 to the domestic gas price projections in Figure 5.1 and 5.2, the cost of energy using international gas price is relatively high compared to the domestic market. The likely achievable cost of energy in year 2050 under the domestic gas projection is 0.082 $/KWh while that of international gas price is 0.174$/KWh. However, the LCoE under the international fuel price scenario is considered in this study as the realistic market for natural gas in Nigeria from the opportunity cost perspective. The gas that is consumed locally at cheap or subsidised price could have been otherwise sold at international gas price.

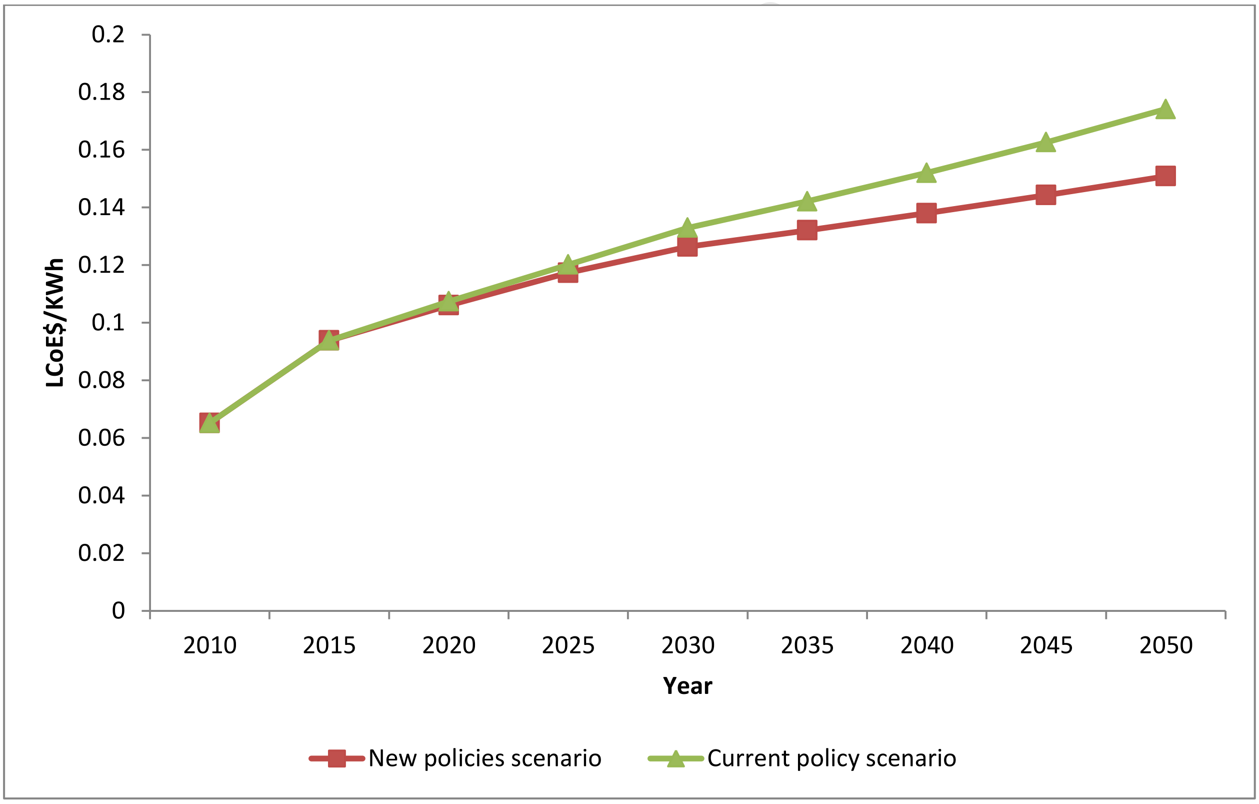


Figure 5.3: LCoE for gas thermal power in Nigeria – IEA international gas price[6]

[6] Adapted by the author from the IEA US real gas price import projection (IEA 2010: 71)

5.3 Cost of Energy from CSP

Key element which determines the cost of energy from a CSP site is its capacity factor which is influenced by the quality of the DNI on the site. High DNI intensity will produce higher capacity factor and lower LCoE. A linear relationship occurs between capacity factor of a CSP plant and the DNI intensity on the CSP site. Unlike CSP, at high DNI, the efficiency of solar PV module decreases because high temperature develop resistance to the flow of current (Vittorio and Valerio 2011). Due to the difference in response to temperature changes in the two technologies, CSP developers suggest a threshold DNI of 1900 KWh/m^2/year for CSP site below which solar PV technology will be advisable (IEA 2010). Apart from capacity factor, the cost of energy from a CSP plant is influenced by cash flow which includes the investment cost, discount rate, operation and maintenance cost. The LCoE for CSP in the study region can be calculated by comparing its DNI to that of a functional commercial CSP plant. In this study, the DNI and the cost of energy for the Andasol plant in Spain is used for the calculation. Though, there were no CSP plants in Nigeria at the time of this study, assuming a similar condition to that of Andasol plant, the following equations can be used to calculate the potential cost of energy from CSP under Nigerian conditions:

$$CoE\ (Nigeria) = CoE\ (Spain) * \frac{DNI\ (Spain)}{DNI\ (Nigeria)} \times {}^{\$}/_{€}$$ (Franz Trieb et al 2011: 309),

(Rawya Mostafa Elshazly 2011: 90) … 5.8

The LCoE from a CSP plant varies with DNI, the higher the DNI in a particular site the lower the LCoE. The result from the study model shows a difference of 0.02 $/KWh between the highest DNI in the study region and the average DNI in the study region. However, the average DNI for the study region will be considered in this study. Detailed results of the average DNI and the peak DNI LCoE are shown in Table 5.3 and Figure 5.4.

Model Parameter

[7]LCoE in Nigeria for DNI 2535 KWh/m^2/yr is 0.26 \$/KWh
[8]LCoE in Nigeria for DNI 2321 KWh/m^2/yr is 0.28 \$/KWh
LCoE in Spain (DNI 2090 KWh/m^2/yr) is 0.27 €/KWh (0.32 \$/KWh)
LCoE – Cost of Energy from CSP
\$/€ - 1.19 (exchange rate for Euro to dollar)
PR 0.88

5.4 CSP Experience Curve

CSP experience curve describes unit cost decrease with increase in cumulative production, the cost declines by a constant percentage as number of unit product doubles. The constant percentage is otherwise called Progressive Ratio (PR) (Neiji 1997:1099). The CSP cumulative capacity projection selected for this study is the moderate growth scenario projection assumed by Greenpeace CSP global outlook (2009: 55). This report was chosen because it is a joint publication by the Greenpeace International, the European Solar Thermal Electricity Association (ESTELA) and IEA SolarPACES. The scenario takes into account all policies measures around the world aimed at supporting CSP technology. This scenario assumes these measures either planned or underway are fully implemented. Starting from CSP global installed capacity of 1020 MW in 2010, the moderate scenario assumes an annual growth rate scenario of 17% and 27% for 2011 and 2015 respectively. Subsequently the capacity will decrease significantly by 7% and 2% in 2030 and to 2050 respectively. The following equations were used to estimate the decrease in cost of energy in the study model. Details on global CSP moderate capacity growth and corresponding levelised cost under Nigerian condition is shown in Table 5.3.

$CoE = CoE° \times (\Delta Q)^b$ (Price & Carpenter 1999:6)

$b = Log_2\,(PR)$

CoE – cost of energy at a particular year x

$CoE°$ - Initial cost of energy for the base year

ΔQ – Change in cumulative capacity with respect to capacity for the base year

PR – Progressive Ratio

[7] Highest DNI in the study region
[8] Average DNI in the study region

Table 5.3

Years	2010	2015	2020	2025	2030	2035	2040	2045	2050
Capacity (MW)	1020	24468	68584	125959	231332	318448.2	438371	603454.9	830707
LCoE[9] ($/KWh)	0.265	0.147	0.122	0.109	0.097	0.092	0.087	0.082	0.077
LCoE[10] ($/KWh)	0.289	0.161	0.133	0.119	0.106	0.100	0.095	0.089	0.084

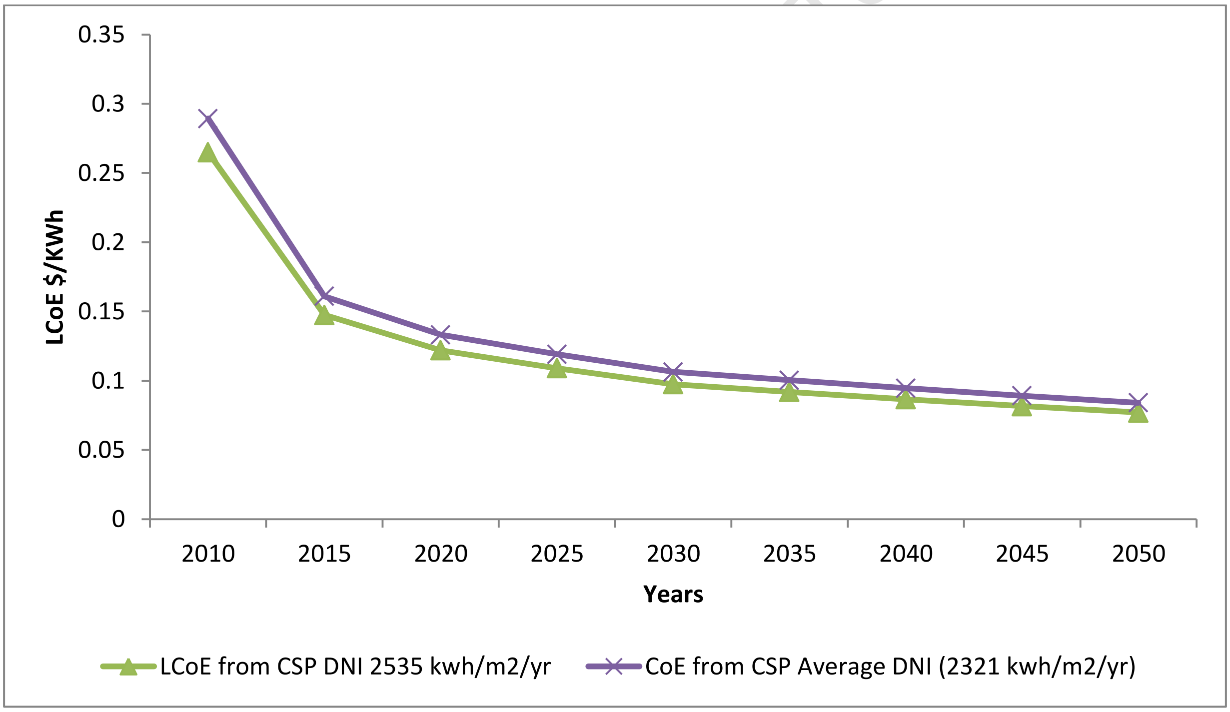


Figure 5.4: CSP Experience Curve for study region with average DNI of 2321 KWh/m^2/yr and Highest DNI of 2535 KWh/m^2/yr (PR 0.88)

Figure 5.4 shows the learning curves for CSP under Nigerian condition, using peak DNI and average DNI. It illustrates a lower cost of energy for higher DNI; this further confirms that

9 LCoE for CSP with highest DNI (2535 KWh/m^2/yr) in the study region
10 LCoE for CSP with average DNI (2321 KWh/m^2/yr) in the study region

areas with high DNI will have better efficiency. However, the average DNI in the region can be assumed to be the least possible DNI on a potential CSP site in the region.

Comparing the results of different possible LCoE from conventional plants to the experience curve from CSP under the domestic gas prices scenarios, the cost of energy from CSP can be considered relatively high until year 2050. In case of subsidised and low domestic gas price, LCoE from conventional plants will be cheaper compared to that of CSP. Taking in to consideration the cost spent on subsidy or the gain that would have come from a higher cost of gas, a competitive cost of energy from CSP can be assumed. Figure 5.5 and 5.6 show the LCoE based on different domestic gas price projections under IEA current and new policies scenarios. The two scenarios show that the LCoE from CSP will become competitive with LCoE from conventional gas thermal plants in 2050 only for the proposed new gas price, at CSP PR of 0.88. For the business as usual projection both for the subsidised and non-subsidised situations, the LCoE will become competitive sometimes beyond year 2050 under the same condition

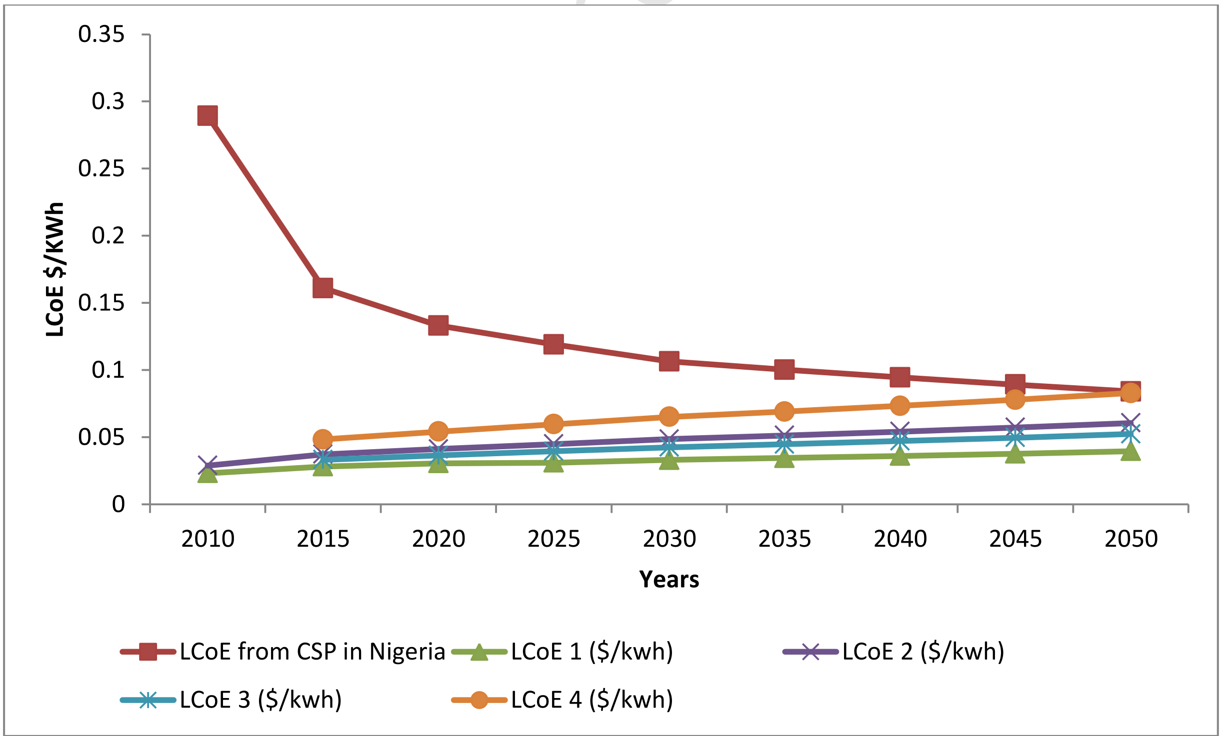


Figure 5.5: CSP experience curve and LCoE for gas thermal power plant – Domestic gas Price projections (IEA current policies scenario)

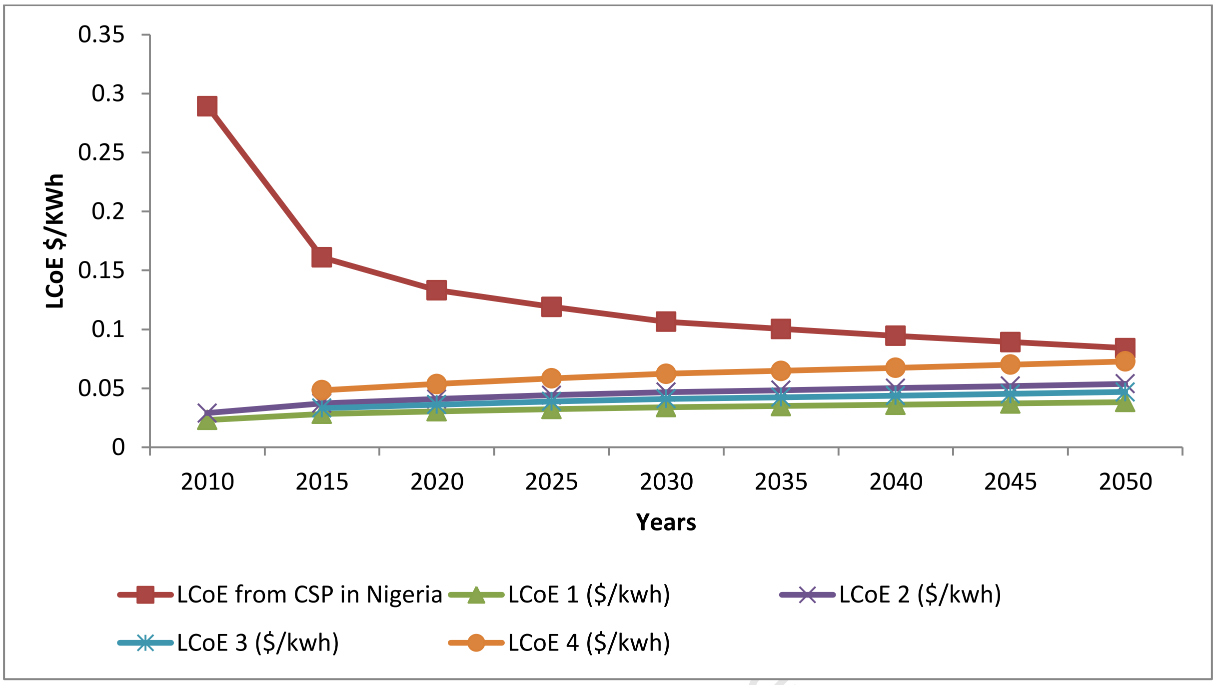


Figure 5.6: CSP experience curve and LCoE for gas thermal power- Domestic gas price projections (IEA New Policies Scenario)

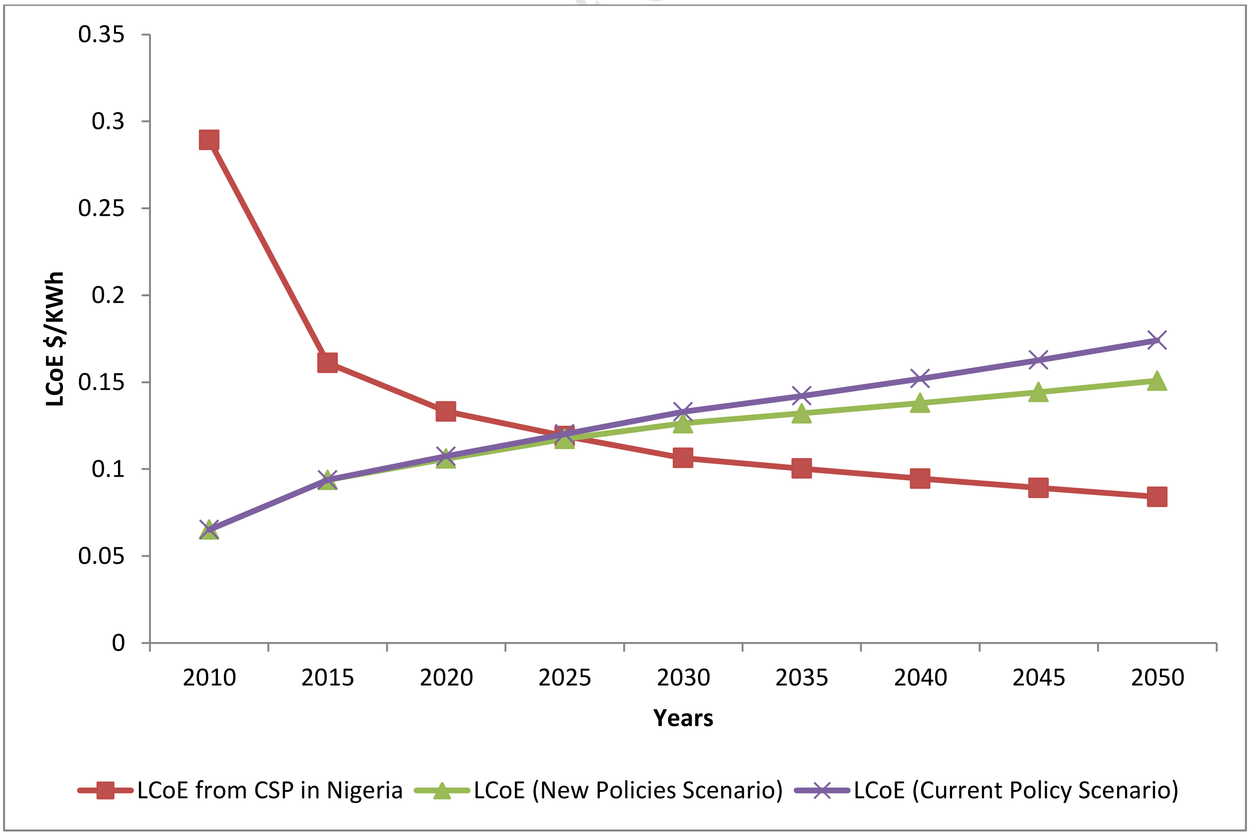


Figure 5.7: CSP experience curve and LCoE for gas thermal power (gas thermal plant) – International gas price projection

Applying the international gas price into the model shows a different LCoE growth pattern for the two IEA scenarios (New Policies and Current Policies scenarios). The result shown in Figure 5.7 predicts a promising and economical market for CSP (LCoE perspective) by year 2025. The international gas price scenario is however different as it becomes competitive with LCoE from CSP as from year 2025 for the two different scenarios (both current and new policies scenarios). Subsequently, LCoE from CSP will decrease as that of conventional gas thermal plants increases. Relating this result to the ECN energy supply model discussed in chapter 3, the model predicts year 2020 as when CSP will start contributing to the nation's power demand (ECN 2011: 67). According to this study, for Progressive Ratio (PR) 0.88, the LCoE for CSP will be 0.03$/KWh higher than the LCoE from conventional gas thermal plants in year 2020. Afterwards, from year 2025 onward, CSP market will be feasible from the economic perspectives.

5.5 Sensitivity Analysis

There is prospect for possible reduction in the global cost of energy from CSP. In cases where there is massive deployment of CSP in global market, there will be reduction in Progressive Ratio (PR) for CSP learning curves. Figure 5.8 shows model results for likely reduction trends in Cost of energy from CSP should massive boost arise in global CSP market. The results for different PRs indicate that the LCoE for CSP decreases with decrease in PR. Assuming a lesser PR for the CSP experience curve, implies a lesser LCoE which will create a more competitive market between LCoE for CSP and conventional gas thermal power plants in the country.

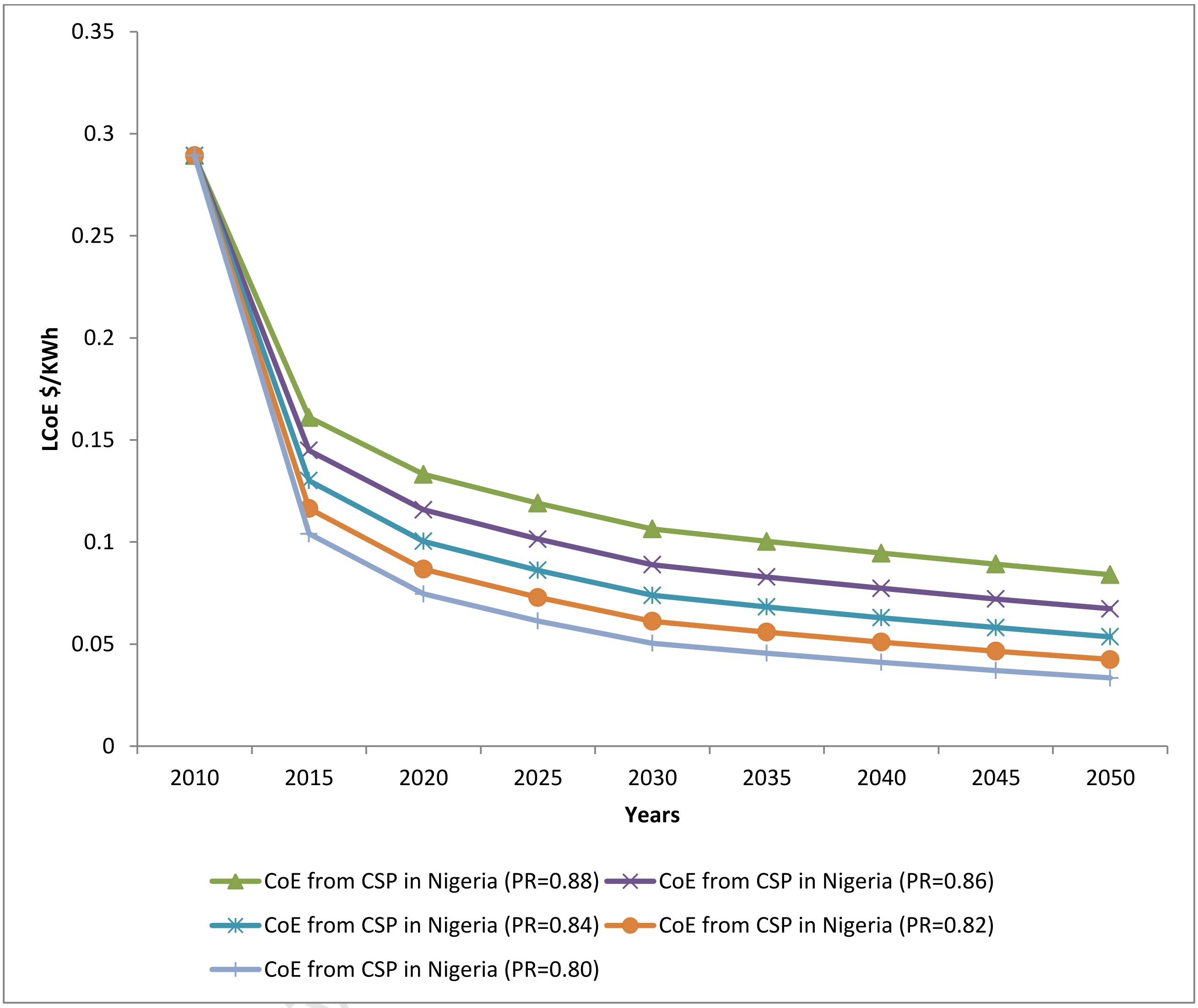


Figure 5.8: CSP experience curve with different Progressive Ratios

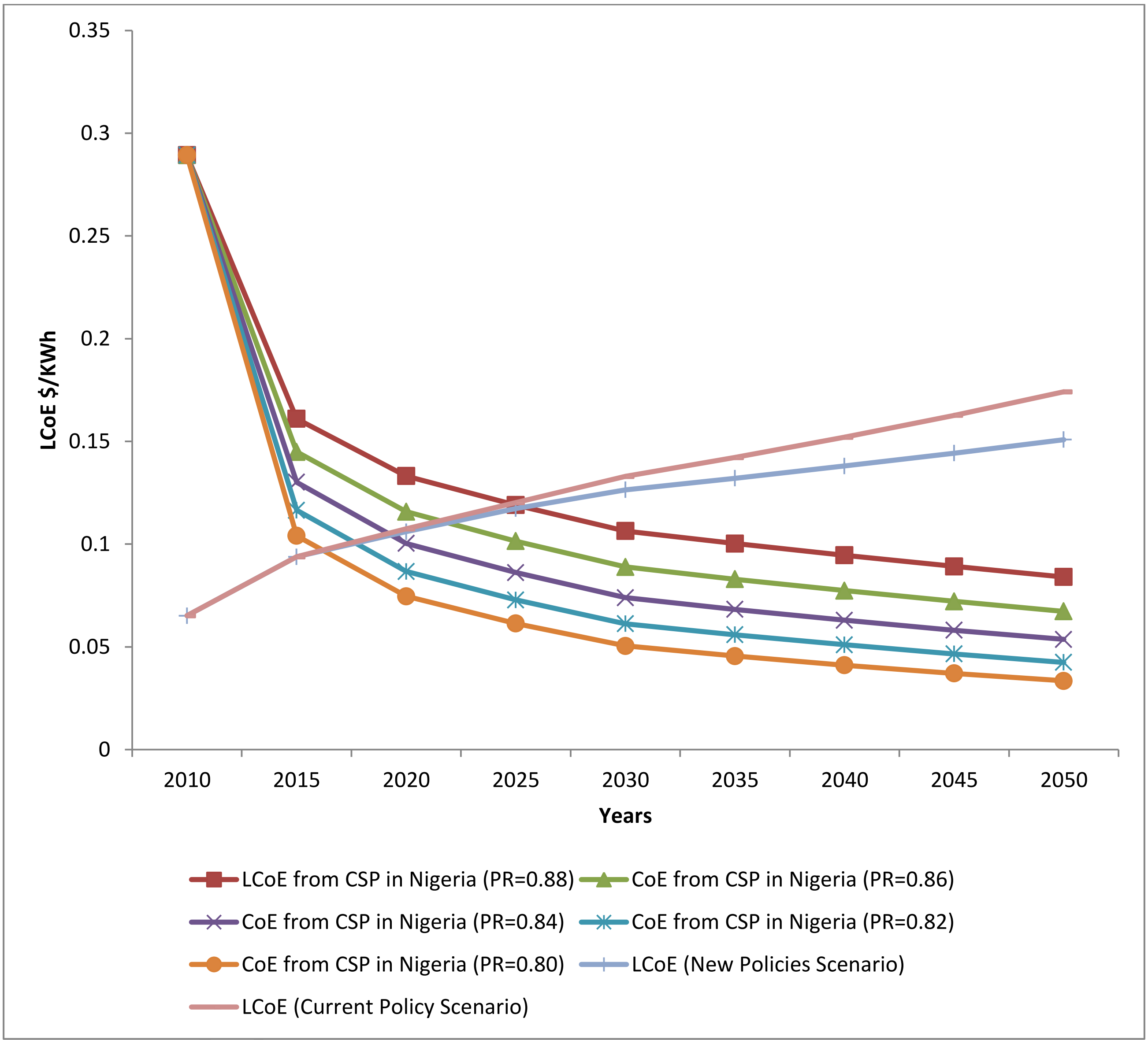


Figure 5.9: CSP experience curve and LCoE for gas thermal power plant and international gas price

Matching likely decrease in LCoE from CSP (owing to possible reductions in PR) with LCoE from gas thermal power plant using the international gas price, the results shows different points of interceptions. However, the various points of interceptions show a competitive cost of energy from CSP as from year 2015 under the Nigerian energy condition.

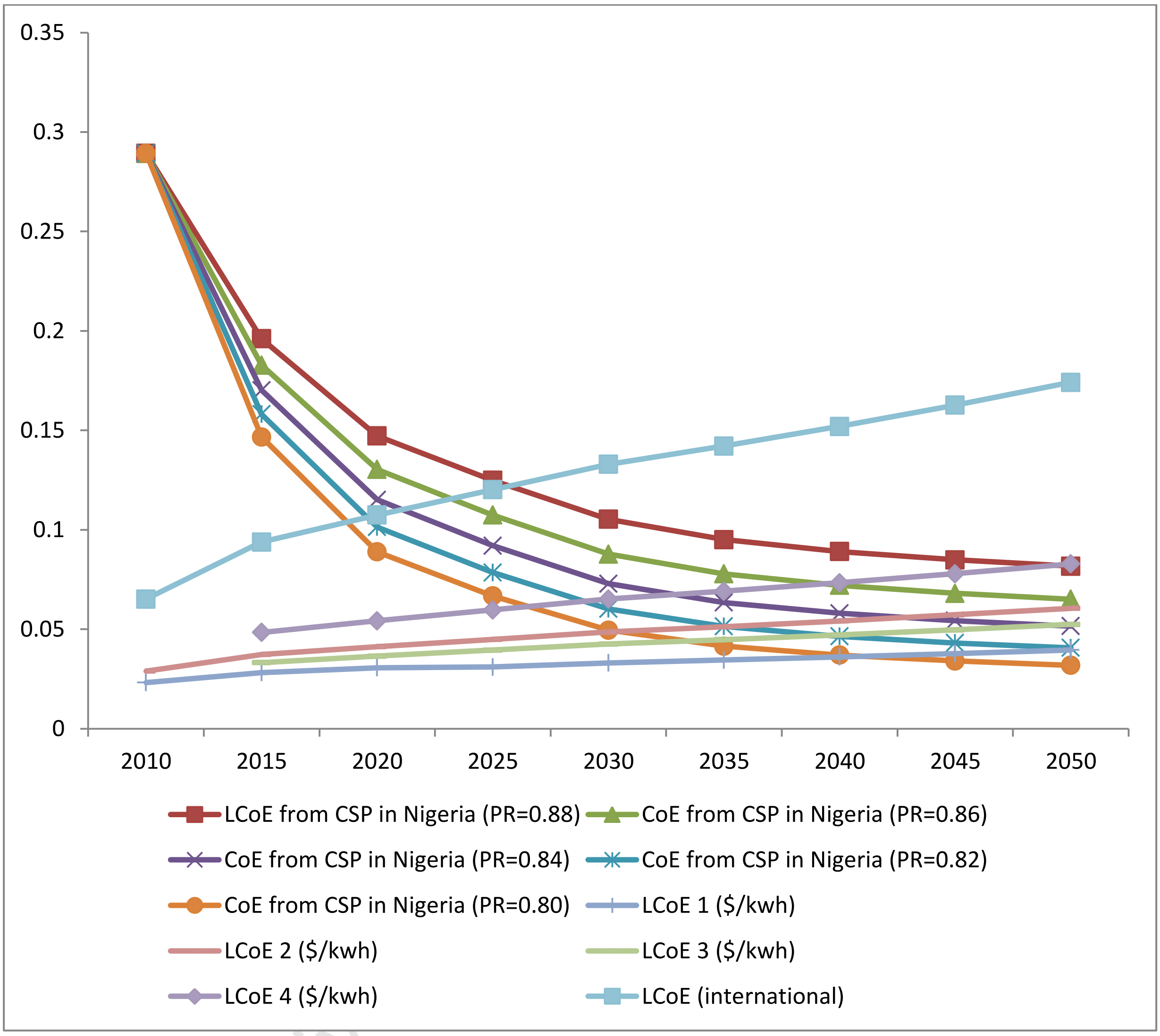


Figure 5.10: Experience curve with different PRs and different LCoE for different domestic gas price projection – (IEA current policies scenario)

The results projects possible competitive cost of energy between LCoE from CSP and LCoE from conventional gas power plants for the business as usual low cost of gas and the international gas price scenarios. The LCoE from the international gas price is more reasonable compared to the domestic gas price. Under the international gas price, LCoE from CSP becomes comparatively cheap as from year 2030 for different PRs.

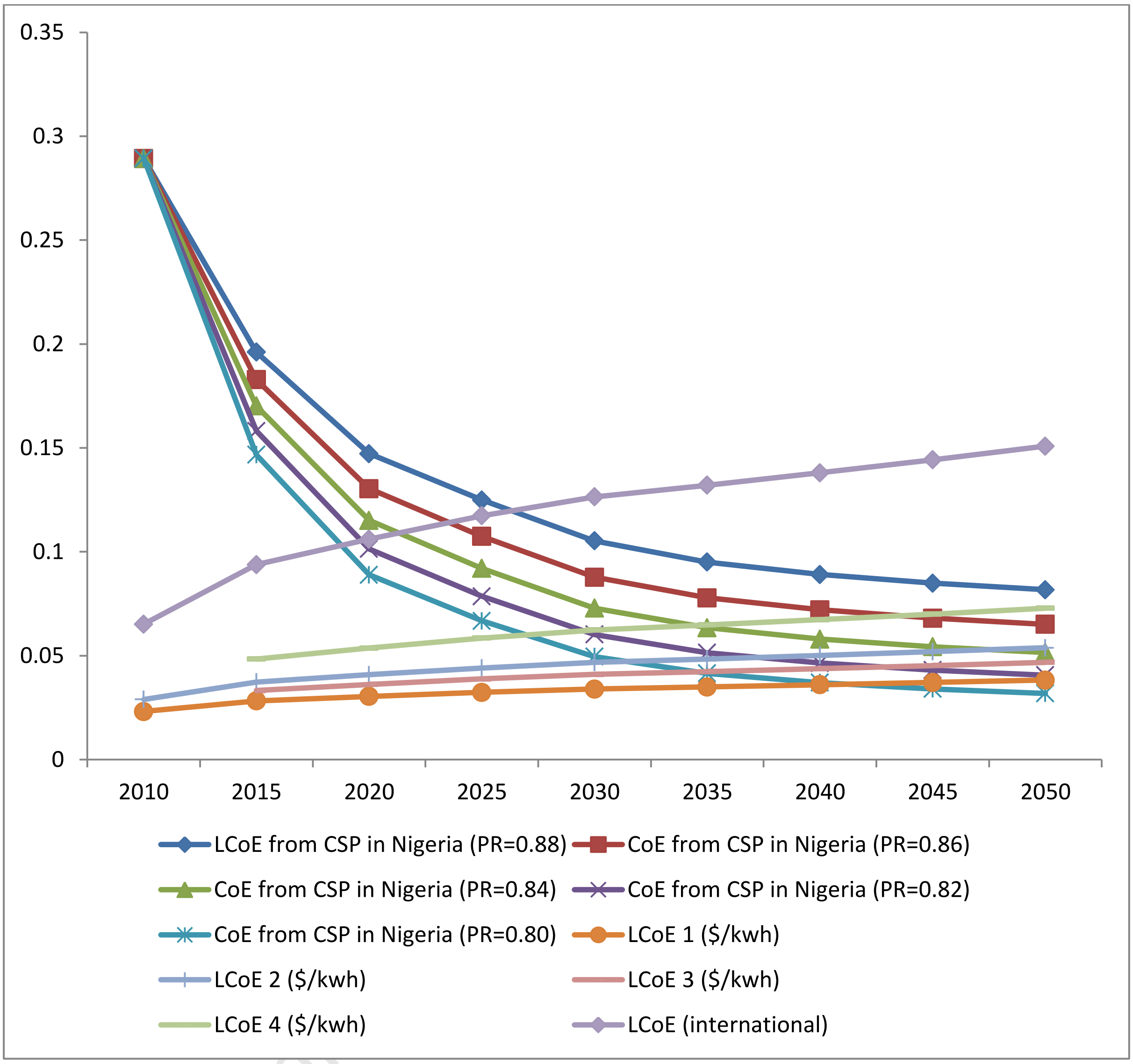


Figure 5.11: Experience curve with different PRs and LCoE for different domestic gas price projection- New policies scenario

Figures 5.9 to 5.11 show different CSP experience curve with different PRs in relation to LCoE of gas thermal power using domestic and the international gas price projections. The result shows that if the PR is reduced from 0.88 to 0.80, the LCoE for CSP will become competitive with cost of energy from conventional power as from year 2030 for business as usual gas price without subsidy. However, in case where the subsidy continues, it will become competitive with conventional power in year 2035 for both scenarios (IEA current and new polices scenarios). However, the international gas price is different for both scenarios as it becomes competitive as from year 2020. Considering the non-sustainability of subsidy on price of natural gas in Nigeria, and the opportunity cost in case of international market, the LCoE for international fuel price is more realistic. Moreover, the experience curve where a PR of 0.88 is assumed is more realistic if compared with the trend assumed in a similar study done for the MENA region (Franz Trieb et al 2011: 309). Based on this result analysis, the cost of energy from CSP in Nigeria will become competitive with conventional energy cost as from year 2025.

Chapter 6

General Conclusion and Recommendations

6.1 Summary

This study has investigated the energy situation in far northern Nigeria and the feasibility of adopting Concentrated Solar Power (CSP) technology in the region. The States in this region are Borno, Jigawa, Kano, Katsina, Sokoto, Yobe and Zamfara, all spread across the open Sahel-Savannah terrain of the country. These States are chosen because of the similarities in their energy potentials and the economic activities, which are similar to other Nigerian northern States. Access to modern energy services in this region is very low, compared to other parts of the country despite the energy potential in the region. Inadequate energy provision has hindered the economic development of the region especially among the rural communities since a greater percentage of the population resides in rural and semi urban settlements.

The inability to provide basic energy services to larger portion of the population has made the region's energy consumption subsistence among small percentage of the population. The energy demand outstrips the supply and the supply cannot meet the domestic needs let alone the industrial and commercial activities. The residential sector and the industrial sector are worst hit by the poor power delivery. Over 3 million households in this region lack access to electricity while the remaining households receive supply between two to seven hours in every 24 hours. This situation has made majority of households in this region to either complement power supply from the grid with supply from private generators or depend on supply from private generators only. Industrial activities in the region had suffered a major setback since 1999 when Kano State (industrial centre of the northern region) lost about 498 industries to poor power supply (Karofi 2007). Agriculture is the mainstay of the region's economy and many of its mineral resources remained unexploited.

However, the region lies within a high sunshine belt and thus having a daily average DNI of 6.2 KWh/m^2 / day and an annual average of 2320 $KWh/m^2/yr$. The annual average DNI in the region is a bit higher than that of the Andasol CSP plant in Spain which is 2090 $KWh/m^2/yr$. As discussed in this study, the region has the potentials to support CSP technology. Employing the use of CSP technology in the region will contribute substantially to the present and future energy demand of the region. Meeting the future energy demand as projected based on three economic growth scenarios (reference (7%), high (10%) and optimistic (13%) economic growth scenarios) requires adoption of indigenous energy resource. This is necessary because of the cost of building infrastructure to transmit power from gas thermal power stations in the Southern region to the study region. Moreover, building a power plant in the region will reduce transmission loses associated with transmitting power over long distances.

Results from the afore mentioned projection shows that at reference and high growth scenarios, energy demand of 1344 GWh and 1925 GWh respectively will be needed in year 2020. In the study done by ECN on national energy supply by fuel projection, energy production from CSP is projected to start in year 2020 with annual capacity of 1000 MW and 3200 MW for both reference and high growth scenarios. Hypothetically, adoption of CSP technology in the region will reduce emissions associated with conventional fossil fuel plants. About 1% of the areas eligible for CSP technology in the region can supply the present energy demand of the region. Other potential benefit of the technology to the region is its industrial applications. Industries such as food, textile, plastics, metal, dairy and leather works found in the region can use heat energy from CSP for their operations. The adoption of heat energy from CSP in industrial operations is in accordance with IEA’s recommendation on reduction of fossil fuel consumption in industrial sector (Greenpeace 2009:35).

Moreover, electricity production from an indigenous energy resource in the study region has the potentials of producing adequate power for commercial and household electricity demand in the region. Complementing power generation with power supply from CSP will make significant contribution to day time power demand. For instance, daily commercial activities by mini traders and artisans need electricity for their operations. Most of these people as discussed above depend on personal generators for their businesses. The major reason for the adoption of personal generators in both households and commercial sectors is the inadequate supply of power. Production of more power from CSP technology has the potential of increasing the number of households that will have access to electricity in the region. Further to this, many households connected to electricity but do not have steady power supply or complement supply with generators will no longer bear the cost of running generators. Improved power supply to the region will alleviate energy poverty among women and children; time spent on sourcing for alternative provisions for their energy demand would be spent in a more productive way.

The study confirms a relationship between energy supply and productivity. In order for the country to achieve its economic objectives, the role of adequate energy provisions is indispensable. Despite the potential benefits of adopting this technology, an important observation in the study is the feasibility of the technology from the perspective of cost of energy. At present, the country generates about 70% of its energy from gas thermal power plants and the cost of energy from these plants is considerably low owing to the fact that the cost of gas for power generation is being subsidised by the government. The government however acknowledged that this arrangement is not sustainable, and it plans to withdraw it sometimes in the future (Michael et al 2004: 135). From opportunity cost perspective, the gas being consumed locally for power generation can otherwise be sold at international market price.

The following observations were made from the sensitivity analysis of the results of different scenarios used in the study:

- If the international trend of deployment of CSP market has a Progressive Ratio (PR) of 0.88 at moderate growth scenario (as projected by by green peace CSP global outlook (2009: 55) the cost of energy from CSP under Nigerian condition will decrease as follows:
  i) At average DNI of 2321 $KWh/m^2/yr$, the cost of energy will reduce from 0.28$/KWh in year 2010 to 0.08 $/KWh in year 2050
  ii) At peak DNI of 2535 $KWh/m^2/yr$, the cost of energy will reduce from 0.26 $/KWh in year 2010 to 0.07 $/KWh in year 2050
- The cost of energy from gas thermal power stations was observed under **two** gas price scenarios – 'business as usual scenarios' and ' new price scenarios'. In both cases,

subsidy on gas was considered, should government decide to continue subsidizing the cost of gas to power stations or should government remove the subsidy. The result shows that for either case, the domestic price of gas is low and consequently the cost of energy from power plants. The cost of gas projection were modelled for the two cases under the IEA's 'current and new policies price increase scenarios' the results show that:

i) The cost of energy using the domestic price of gas will become competitive with that of CSP in year 2050 under IEA current policies scenarios, if the government will initiate the propose price of 2 $/MMBtu of gas in 2013. Should government continue to subsidize the cost of gas to power stations, the competition will be beyond 2050.

ii) The cost of energy using the international gas price will become competitive with that of CSP as from year 2025. The result shows that the LCoE of both technologies intercept in year 2025 and subsequently, the LCoE from CSP becomes cheaper.

iii) The results from the sensitivity analysis shows that if the Progressive Ratio (PR) is reduced from 0.88 to 0.80 (implies reduction in price as global installed capacity increases). The LCoE from using different gas prices intercepted at various point as from year 2025 to 2050.

6.2 Energy Security and Environmental Concern

As discussed, the nation's natural gas reserve as well as other fossil fuels can meet its energy demand. However, from the energy security perspective, it is important for Nigeria to diversify its energy supply mix. Presently, hydropower constitutes about 30% of the nation's electricity supply (Akinbami 2001). While the use of hydropower can be referred to as a renewable source of energy, it is vulnerable to climate change. A decrease in water level associated with drought is a major constraint to hydropower generation. Adoption of CSP technology will complement for possible interruption from hydropower stations. Natural gas as discussed is a major energy fuel in Nigerian power generation so also a major energy fuel globally. Due to its prominent role in global energy supply, its price is determined by the international market trend. When there is increase in demand for gas in the international market, there is tendency for increase in price and consequently affects the cost of energy. In case of Nigerian domestic market, cheap cost of gas is an opportunity lost. Unlike fossil fuel-based energy, CSP does not incur a fuel cost. Therefore it is not as susceptible to price changes during its operation lifetime. Further to this, as CSP does not require a fuel besides from the sun, it will not encounter supply shortages in the years to come. Contrastingly fossil fuel reserves globally are being put under increasing pressure, creating the risk of supply shortages in the future (Kjell et al 2010). If invested in, CSP could contribute to creating a more resilient energy supply mix in Nigeria given the renewable nature of its fuel source and its independence of fossil fuel price volatility.

Another major concern is the environmental issues associated with energy production. As the world is clamouring for GHGs emission mitigation, it is important for Nigeria to consider investing in lower emissions technology such as CSP. This study shows that CSP under Nigerian condition is feasible as from year 2025 from the international gas price perspective. Risks associated with fossil fuel consumption include environmental degradation, environmental pollution, GHGs emissions, and possible interruption in fuel supply. Instances of these effects in Nigeria include the Niger-Delta oil spillage and gas flaring (Greg 2001). Shortage in supply of gas to power stations arising from militant activities in the Niger-Delta region has often times affected the operations of many power plants (Obioh and Fagbenle 2009). The cost of environmental externalities arising from the use of fossil fuel makes CSP advantageous in the long run. It is therefore worthwhile investing in CSP technology from both energy security and environmental perspective.

6.4 Impact of Subsidy on Power Production

As discussed, government is paying subsidy on the price of gas supply to power stations in Nigeria. This arrangement was designed to encourage adequate power supply in the country. However, the effect of this blanket subsidy is evident on the economy. The subsidy could have been structured in a way to alleviate energy poverty through provision of affordable electricity for the poor. The amount being paid on subsidy could have contributed substantially to developing the power sector through building of necessary infrastructure for power generation and transmission. Contrastingly, the subsidy aimed at improving power supply in the country seems to be retarding the possible development that would have been recorded in the sector. The renewable energy master plan discussed in chapter 2, envisions the exploitation of renewable energy resources at price which promotes realisation of equitable and sustainable development. The results obtained in this study shows that subsidy will not encourage the development of renewable energy technologies. As long as subsidy is being paid on price of domestic gas in Nigeria, the cost of energy from gas thermal plants will remain ridiculously low. Subsidy is distorting energy market in Nigeria and also creating a barrier to renewable energy development. In order to encourage renewable energy technologies such as CSP, strategies to face out subsidy on domestic price of gas must be put in place. Continuous payment of subsidy will make the economy to run at loss as it does not allow return on investment. Blanket subsidy is too expensive as the evidence is shown in the level of electricity generation and infrastructural development in the power sector. If subsidy will exist, the beneficiaries should be the poor. Consequently, money spent on subsidy could be invested in meeting the energy needs of the poor by setting up for instance, mini hydro plants and solar-based village pilot scheme.

6.3 Policy Implications

a) If Nigeria will start harnessing its solar thermal potentials as from year 2020, the current price of gas must be reviewed. Preferably, government should remove blanket subsidy on gas supplied to power plants.
b) Low cost of energy from gas thermal power plants will not encourage investors to invest in renewable technologies such as CSP. Instead of subsidy payment, government should facilitate the expansion of renewable energy technologies by providing investor friendly incentives.
c) Relying mainly on a particular source of power supply can cause national power outage should there be interruption in gas supply. Hence, diversifying the utilisation of the nation's energy sources will encourage security of supply.

General Recommendations

1. It is important for government to establish meteorological centres across the country. These centres will help researchers to get adequate and precise data on solar radiation measurement on a particular site.
2. The national meteorological centre should develop a data base where maps showing ground station measurements of solar irradiance for different locations across the country can be access.
3. The renewable energy master plan should be instituted by an Act of parliament, this will enable proper implementation.
4. There is need for government to encourage the use of CSP technology in areas identified eligible in this study. As discussed, such initiative will increase the GDP of the region.
5. Generation of energy in the study region will save the cost involved in building infrastructure to draw power lines over long distances, and also prevent possible power loss in transmission.

Possible areas of further research as identified in the study:

- More comprehensive study on specific engineering requirement for a CSP site in the study region
- Exhaustive study on availability of water for CSP location in the region
- The socio economic contribution of CSP technology to the study region and the nation at large
- The use of heat energy from CSP technologies for industrial operations in the region

In conclusion, readers should note that data used in this study are taken from NASA satellite database as meteorological data on ground station measurements were not available as at the time of this study. Therefore, there is tendency for variations in results if ground station data were used.

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Appendix A

Table A1: IEA 2009 Energy Balance for Nigeria

2009

SUPPLY AND CONSUMPTION	Coal & peat	Crude oil	Oil products	Natural Gas	Nuclear	Hydro	Geotherm. solar etc.	Biofuels & waste	Electricity	Heat	Total
Production	5	117470	-	18950	-	389	-	91907	-	-	228722
Imports	-	-	7677	-	-	-	-	-	-	-	7677
Exports	-	-115951	-678	-13058	-	-	-	-	-	-	-129687
Intl. marine bunkers	-	-	-621	-	-	-	-	-	-	-	-621
Intl. aviation bunkers	-	-	-673	-	-	-	-	-	-	-	-673
Stock changes	-	897	1937	-	-	-	-	-	-	-	2834
TPES	**5**	**2416**	**7642**	**5893**	**-**	**389**	**-**	**91907**	**-**	**-**	**108252**
Electricity and CHP plants	-	-	-586	-2732	-	-389	-	-	1701	-	-2007
Oil refineries	-	-2592	2427	-	-	-	-	-	-	-	-166
Other transformation*	-	177	-388	-2169	-	-	-	-2443	-148	-	-4971
TFC	**5**	**-**	**9094**	**992**	**-**	**-**	**-**	**89464**	**1552**	**-**	**101108**
INDUSTRY	**5**	**-**	**193**	**992**	**-**	**-**	**-**	**9055**	**279**	**-**	**10524**
Iron and steel	-	-	-	75	-	-	-	-	-	-	75
Chemical and petrochemical	-	-	-	401	-	-	-	-	-	-	401
Non-metallic minerals	5	-	-	-	-	-	-	-	-	-	5
Other/non-specified	-	-	193	516	-	-	-	9055	279	-	10043
TRANSPORT	**-**	**-**	**8152**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**8152**
Domestic aviation	-	-	-	-	-	-	-	-	-	-	-
Road	-	-	8126	-	-	-	-	-	-	-	8126
Other/non-specified	-	-	27	-	-	-	-	-	-	-	27
OTHER	**-**	**-**	**620**	**-**	**-**	**-**	**-**	**80409**	**1273**	**-**	**82302**
Residential	-	-	620	-	-	-	-	80409	874	-	81903
Comm. and public services	-	-	-	-	-	-	-	-	399	-	399
Agriculture/forestry	-	-	-	-	-	-	-	-	-	-	-
Other/non-specified	-	-	-	-	-	-	-	-	-	-	-
NON-ENERGY USE	**-**	**-**	**129**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**129**
Electricity and Heat Output											
Electricity generated - GWh	-	-	2533	12715	-	4529	-	-	-	-	19777
Heat generated - TJ	-	-	-	-	-	-	-	-	-	-	-

Source: IEA 2010

Table A2: Existing and potential power stations in Nigeria

s/n	Power Station	Type	State	Capacity (MW)	Status
1	Egbin	Thermal	**Lagos**	**1320.00**	**Existing**
2	**Afam**	**Thermal**	**Rivers**	**969.60**	**Existing**
3	**Sapele**	**Thermal**	**Delta**	**1020.00**	**Existing**
4	**Ijora**	**Thermal**	**Lagos**	**40.00**	**Existing**
5	**Kainji**		**Niger**	**760.00**	**Existing**
6	**Jebba**		**Niger**	**578.40**	**Existing**
7	**Shiroro**		**Niger**	**600.00**	**Existing**
8	**Delta**	**Thermal**	**Delta**	**912.00**	**Existing**
9	**Orji**		**Rivers**	**20.00**	**Existing**
10	**Geregu**	**Thermal**	**Kogi**	**414.00**	**Ongoing**
11	**Omotosho**	**Thermal**	**Ondo**	**335.00**	**Ongoing**
12	**Papalanto**	**Thermal**	**Ogun**	**335.00**	**Ongoing**
13	**Alaoji**	**Thermal**	**Abia**	**504.00**	**Ongoing**
14	**Omoku**	**Thermal**	**Rivers**	**230.00**	**New IPP**
15	**Rain/Ube**	**Thermal**	**Bayelsa**	**225.00**	**New IPP**
16	**Sapele**	**Thermal**	**Delta**	**451.00**	**New IPP**
17	**Eyaen**	**Thermal**	**Edo**	**451.00**	**New IPP**
18	**Egbema**	**Thermal**	**Imo**	**338.00**	**New IPP**
19	**Caliber**	**Thermal**	**Cross River**	**561.00**	**New IPP**
20	**Mambilla**		**Taraba**	**2600.00**	**New**
21	**Zungeru**		**Niger**	**950.00**	**New**
22	**AES**	**Thermal**	**Lagos**	**300.00**	**Commissioned IPP**
23	**AGIP Okpai**	**Thermal**	**Delta**	**480.00**	**Commissioned IPP**
24	**Omoku**	**Thermal**	**Rivers**	**150.00**	**Approved IPP**
25	**Obajana**	**Thermal**	**Kogi**	**350.00**	**Approved IPP**
26	**Ibom Power**	**Thermal**	**Akwa Ibom**	**188.00**	**Approved IPP**
27	**Ethiope Energy Ltd**			**2800.00**	**Approved Licenses IPP**
28	**Farm Electric Supply**			**150.00**	**Approved Licenses IPP**
29	**ICS Power**			**624.00**	**Approved Licenses IPP**
30	**Supertek Ltd**			**1000.00**	**Approved Licenses IPP**
31	**Mabon Ltd**			**39.00**	**Approved Licenses IPP**
32	**Geometric Ltd**			**140.00**	**Approved Licenses IPP**
33	**Aba Power Ltd**			**0.00**	**Licensed Distributor**
34	**Westcom Tech & Energy Service Ltd**			**1000.00**	**License Granted IPP**
35	**Lontus & Bresson Nig Ltd**			**60.00**	**License Granted IPP**
36	**Anita Energy Ltd**			**136.00**	**License Granted IPP**
37	**First Independent Power Co Ltd**			**95.00**	**License Granted IPP**

38	**First Independent Power Co Ltd**	**150.00**	**License Granted IPP**
39	**Hudson Power Station**	**200.00**	**License Granted IPP**
40	**Ibafo Power Station**	**640.00**	**License Granted IPP**
41	**Shell Distribution Coy Ltd**	**100.00**	**License Granted IPP**
42	**Agbara Shoeline Power Ltd**	**1800.00**	**License Granted IPP**
43	**Index thermal Power Ltd**	**1800.00**	**License Granted IPP**
	Total	**24,106.00**	

Source: Sambo et al 2010

Table A3: Estimated per capita annual supply capacity and hours of public power supply

States		Estimated Supply capacity (KW)	Per capita supply capacity (KW)	Hours of Public Power Supply in / 24 hrs
1	Borno	13,041.25	0.0031	2-7
2	Jigawa	43,610.02	0.01	2-7
3	Kano	59,865.49	0.006	2-7
4	Katsina	52,301.03	0.01	2-7
5	Sokoto	35,612.63	0.01	2-7
6	Yobe	11,152.44	0.005	2-7
7	Zamfara	39,006.30	0.012	2-7
	Total	254,589.16	0.007706*	N/A

Source: BECANS States reports 2007

Appendix B

Table B: Global CSP installed capacity, operational and announced CSP Plants

S/n	Name	Country	Location	Technology type	Capacity (MW)
1	Solar Energy Generating Systems	USA	Mojave Desert, California	parabolic trough	354
2	Solnova Solar Power Station	Spain	Sanlúcar la Mayor	parabolic trough	150
3	Andasol solar power station	Spain	Guadix	parabolic trough	150
4	Extresol Solar Power Station	Spain	Torre de Miguel Sesmero	parabolic trough	100
5	Palma del Rio Solar Power Station	Spain	Palma del Río	parabolic trough	100
6	Manchasol Power Station	Spain	Alcázar de San Juan	parabolic trough	100
7	Valle Solar Power Station	Spain	San José del Valle	parabolic trough	100
8	Martin Next Generation Solar Energy Center	USA	Indiantown, Florida	ISCC	75
9	Nevada Solar One	USA	Boulder City, Nevada	parabolic trough	64
10	Ibersol Ciudad Real	Spain	Puertollano, Ciudad Real	parabolic trough	50
11	Alvarado I	Spain	Badajoz	parabolic trough	50
12	La Florida	Spain	Alvarado (Badajoz)	parabolic trough	50

13	Majadas de Tiétar	Spain	Caceres	parabolic trough	50
14	La Dehesa	Spain	La Garrovilla (Badajoz)	parabolic trough	50
15	Helioenergy 1	Spain	Ecija	parabolic trough	50
16	Lebrija-1	Spain	Lebrija	parabolic trough	50
17	Solacor 1	Spain	El Carpio	parabolic trough	50
18	Solacor 2	Spain	El Carpio	parabolic trough	50
19	Puerto Errado 1+2	Spain	Murcia	fresnel reflector	31.4
20	Hassi R'mel integrated solar combined cycle power station	Algeria	Hassi R'mel	ISCC	25
21	PS20 solar power tower	Spain	Seville	solar power tower	20
22	Kuraymat Plant	Egypt	Kuraymat	ISCC	20
23	Beni Mathar Plant	Morocco	Ain Bni Mathar	ISCC	20
24	Yazd integrated solar combined cycle power station	Iran	Yazd	parabolic trough	17
25	Gemasolar	Spain	Fuentes de Andalucia (Seville)	solar power tower	19.9
26	PS10 solar power tower	Spain	Seville	solar power tower	11
27	Kimberlina Solar Thermal Energy Plant	USA	Bakersfield, California	fresnel reflector	5
28	Sierra Sun Tower	USA	Lancaster	solar power tower	5
29	Archimede solar power plant	Italy	Syracuse, Sicily	parabolic	5

				trough	
30	Thai Solar Energy (TSE) 1	Thailand	Huaykrachao	parabolic trough	5
31	Liddell Power Station Solar Steam Generator	Australia	New South Wales	fresnel reflector	2
32	Keahole Solar Power	USA	Hawaii	parabolic trough	2
33	Maricopa Solar	USA	Peoria, Arizona	dish stirling	1.5
34	Jülich Solar Tower	Germany	Jülich	solar power tower	1.5
35	Saguaro Solar Power Station	USA	Red Rock	parabolic trough	1
36	Shiraz solar power plant	Iran	Shiraz	parabolic trough	0.25
	Overall operational capacity				**1702.65**

s/n	**Name**	**Country**	**Location**	**Expected completion**	**Technology**	**Capacity (MW)**
1	Ivanpah Solar Power Facility	USA	San Bernardino County, California	2013	solar power tower	370
2	Solana Generating Station	USA	West of Gila Bend, AZ	2013	parabolic trough	280
3	Mojave Solar Park	USA	San Bernardino County, California	2014	parabolic trough	250
4	Ashalim power station	Israel	Negev desert	2013	parabolic trough	250
5	Crescent Dunes Solar Energy Project	USA	Nye County, Nevada	2013/14	power tower	110

6	Solaben 2, 3	Spain	Logrosan	2012	parabolic trough	100
7	Helios 1+2	Spain	Ciudad Real	2012	parabolic trough	100
8	Shams	UAE	Abu Dhabi Madinat Zayad	2012	parabolic trough	100
9	Termosol 1+2	Spain	Navalvillar de Pela (Badajoz)	2013	parabolic trough	100
10	Helioenergy 2	Spain	Ecija	2012	parabolic trough	50
11	Extresol 3	Spain	Torre de Miguel Sesmero (Badajoz)	2012	parabolic trough	50
12	Astexol 2	Spain	Badajoz	2011	parabolic trough	50
13	Arenales PS	Spain	Moron de la Frontera (Seville)	2013	parabolic trough	50
14	Cargo Solar Power (Guj) P. Ltd.	india	KUTCH (Gujarat)	2013	parabolic trough	50
15	Shriram EPC	india	BAAP (Rajasthan)	2013	parabolic trough	50
16	El Reboso 2	Spain	El Puebla del Rio (Seville)	2012	parabolic trough	50
17	Morón	Spain	Moron de la Frontera (Sevilla)	2012	parabolic trough	50
18	Olivenza 1	Spain	Olivenza (Badajoz)	2012	parabolic trough	50
19	La Africana	Spain	Posada	2012	parabolic trough	50
20	Guzman	Spain	Palma del Río	2012	parabolic	50

					trough	
21	Orellana	Spain	Orellana	2012	parabolic trough	50
22	Casablanca	Spain	Cáceres	2013	parabolic trough	50
23	Enerstar Villena Power Plant	Spain	Villena	2013	parabolic trough	50
24	Aste 1A	Spain	Alcázar de San Juan	2012	parabolic trough	50
25	Aste 1B	Spain	Alcázar de San Juan	2012	parabolic trough	50
26	Jinshawan	China	China		solar updraft tower	27.5
27	Termosolar Borges	Spain	Borges Blanques (Lleida)	2012	parabolic trough	25
28	Alba Nova 1	France	Corsica	2013	Fresnel	12
29	THEMIS Solar Power Tower	France	Pyrénées-Orientales		solar power tower	1.4
30	Renovalia	Spain	Albacete		dish	1
	Overall capacity under construction					**2106.9**

Source: Adapted by the author from (Ucilia Wang 2011) and (Mosta Elshazly 2011)

An additional capacity of about 2000 MW is expected from CSP when the various projects under construction are completed. The increasing capacity in CSP global installation as discussed in table 8, is an indication for possible decrease in cost of energy from CSP according to CSP developers (Trieb etal 2011: 309)

Appendix C

Levelized cost of Electricity from gas thermal plants in Nigeria

Table C: Input parameters for LCoE from gas thermal plants in Nigeria

Technology	Capacity (1) (GW)	Load Factor (2)	Generation TWh	Actual Capital Cost (US$/KW) (3)	Actual Cost ($)	Average Cost($/kw)
Gas Turbine	3.804	0.66	21.87	669	2544876000	
Gas ST	1.32	0.73	8.47	669	883080000	
CCGT	0.78	0.82	5.57	720	561600000	
Total	5.904		35.91		3989556000	675.7378

(1) PHCN, IPP, Joint Venture (JV), and private sector databases

(2) Source: National control centre, Oshogbo, Osun State Nigeria

(3) The 25-year Nigerian power development plan, 2006

(As referenced in WADE & ICEED, 2009 and power sector reform committee report, 2008)

Availability = Total Elect Production / (8760* Total Installed Capacity)

Generation TWh = capacity (GW)* load factor (%) * 8760/1000

Discount Rate	0.12
Life time of plant	30 years
CRF	0.124143658
ICC	3989556000
Availability	0.694328433
LevO&M (both Fix &Var) $/KWh	0.0004

LCoE = LevCap+LevO&M+LevFuel

CRF = 1*(1+i)^life)/((1+i)^life - 1)

LevCap= CRF*ICC/(8760*availability*Capacity)

Where ICC = Initial Capital Cost (total debt), $

ICC=investment ($/kW)*Capacity (kW)