CSP Technology and Its Potential Contribution to Electricity Supply in Northern Nigeria

Olumide Ogunmodimu*, Andrew Marquard*‡

*Energy Research Centre, Department of Mechanical Engineering, University of Cape Town, Private Bag Rondebosch 7701 South Africa

(ognolu006@myuct.ac.za, Andrew.marquard@uct.ac.za)

‡Corresponding Author: Andrew Marquard; Energy Research Centre, Department of Mechanical Engineering University of Cape Town, Tel: +27 (0)21 650 3230, andrew.marquard@uct.ac.za

Received: 26.04.2013 Accepted: 06.06.2013

Abstract- Energy is an essential requirement for socioeconomic development in a country; however, its provision depends on availability of energy sources and the required investment. As Nigeria is experiencing rapid growth in population, adequate energy provision is necessary for corresponding levels 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 fossil fuels. 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 electricity supply in the far northern States of Nigeria. These States are chosen because of the relatively high Direct Normal Irradiance (DNI) in the region. The paper 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.

Keywords- Concentrated solar power, direct normal irradiance, cost of energy, experience curve.

1. Introduction

Energy provision is an essential prerequisite to a nation’s social and economic development. Energy services enable fulfillment of basic human needs such as adequate food supply, lighting, warmth, education and health, which are the objectives of the United Nations (UN) Millennium Development Goals (MDGs) [4]. Access to adequate energy provision remains significant in achieving the MDGs. 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). 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 [6]. Nigeria presently generates about 70% of its electricity from gas thermal plants. This could be attributed to the benefaction of huge natural gas deposit. However, the solar energy potential in the northern region of Nigeria, among other renewable energy sources in the country can contribute significantly to the nation’s energy mix. Other renewable energy sources in Nigeria include biomass, wind, small and large hydropower with potential for hydrogen fuel, geothermal and ocean energies [2]. This paper focuses on the feasibility of an emerging paradigm of renewable energy technology in Nigeria. It examines the potential contribution in selected northern States, and the cost of energy from CSP to that of gas thermal plants in Nigeria. The selected States 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. The estimated land area of the region is approximately 252,102 Square-kilometers. The topography is generally flat, and the region has an average daily solar radiation of 7.0 KWh/m^2 [9].

2. Solar Power Potential in the Study Region

The region in focus in this study is considered most appropriate for CSP technology because of the relatively high DNI recorded from the NASA satellite. 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. 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 [9] over an area of 252,102 km^2. 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). Figure 1 shows the satellite data of the solar DNI for selected areas in the study region and DNI for some different regions in Nigeria. 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 [8].

From Figure 1, the study region is areas with DNI between 6.0 kWh/m^2/day to 7.5 kWh/m^2/day. An area is deemed appropriate for CSP if the threshold DNI is between 1900 kWh/m^2/year and 2100 kWh/m^2/year [8]. 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 of CSP site is the land slope. Areas with land slope greater than three degrees are considered not suitable for CSP plants [7]. 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 the threshold and the terrain is relatively flat.

3. CSP Technology

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 [12]. At present, there are four categories of CSP, with similar modes of operation but different ways of receiving and amplifying the sun's energy. The four categories include; Parabolic Trough, Linear Fresnel Reflector (LFR), Solar Tower or Central Receiver System (CRS) and Parabolic Dish or Dish Stirling systems. The four categories can be divided into two groups based on how they concentrate irradiance on the receiver. LFR and Parabolic trough designs are classified as line focus system. In this design, collectors track the sun and focus irradiance on a linear absorber (usually stainless steel pipes). The absorber moves in tandem with the collector assembly as it tracks the direction of the sun in the parabolic trough design. The LFR uses a fixed linear downward facing receiver positioned at a common focal point of the reflectors. In Dish Stirling and CRS designs, collectors track the sun and focus irradiance at a single point receiver. Higher temperature is achieved in this design and ease of transportation of collected heat to power block.

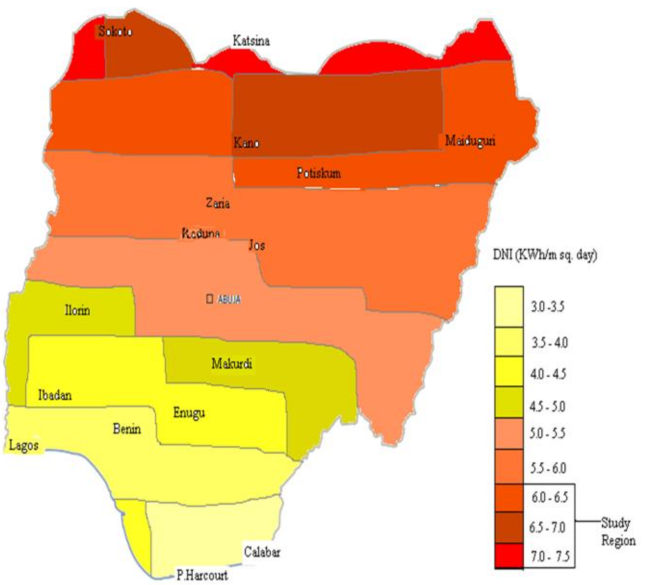

Fig. 1. Map showing DNI in Nigeria. Source: Adapted by the author from NASA satellite data base [10]

4. 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 the parabolic dish system may produce better capacity, and allow them to compete with larger systems [12]. 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% [11]. CSP technology is projected to make a significant contribution to the future renewable energy development according to the global CSP outlook (2009). Based on an 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 [5].

5. Site Selection and Land Requirement

Apart from strong DNI, other important factors to be considered while selecting a CSP site are land slope, proximity to the power grid, access to water and proximity to backup file (if applicable). Flat land with a slope between 1^0 – 3^0 is considered ideal for CSP site. 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. 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

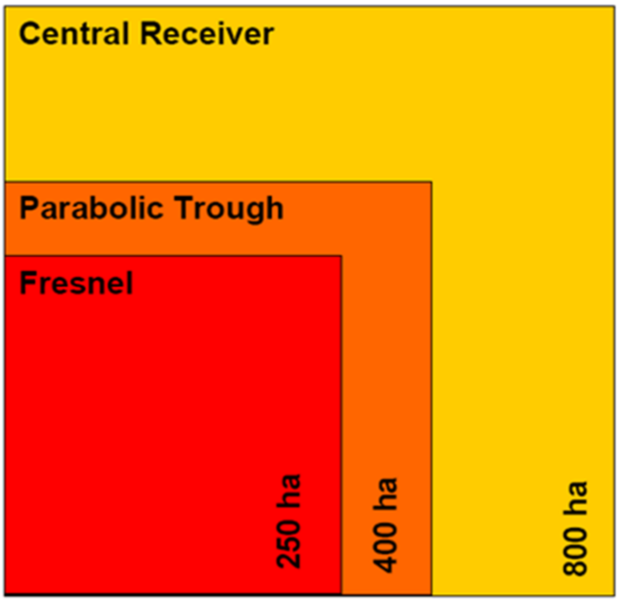

Fig. 2. Land use for 100 MW plant by the three technologies. [15]

collector field so also is the storage size. However, sites with strong DNI require smaller collector field. Comparing the three technologies shown in Figure 2 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.

6. Overview of Andasol Solar Pwer Station and Potential Site in the Study Region

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. It has a 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 an estimated life span of 40 years [14]. The plant is located close to the Mediterranean Sea at 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 a collector surface of about 510,120 m^2 each. (Solar millennium 2010) Andasol plant uses a 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 a heat storage medium; the set comprises of 40% sodium nitrate ($NaNO_3$) and 60% potassium nitrate ($KaNO_3$). 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 [14]. The longer hours achieved by the introduction of heat storage system has helped the plant achieve an average annual efficiency of about 14.7%.

The average annual direct solar radiation in the study 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. This is about 10 times the present electricity supply capacity in the region and about 159×10^5 tons of oil equivalent. 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 higher 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. 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. Table 1 shows estimated solar CSP potential in the study region.

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

Table 1. 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 [14]

Heat Storage Capacity = 7.5 hours

Estimated capacity = 50MW/Km^2

From Table 2, If 1% of the eligible land area in each State is used as CSP sites, 88,700 MW capacity 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.

7. 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 cost of energy. A linear relationship occurs between the 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 develops resistance to the flow of current [3] 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 the CSP site below which solar PV technology will be advisable [8]. 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 Levelised Cost of Electricity (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 [16][13]:

$$CoE\ (Nigeria) = CoE\ (Spain) * \frac{DNI\ (Spain)}{DNI\ (Nigeria)} \times {}^{\$}/_{€} \qquad (1)$$

The LCoE from a CSP plant varies with the 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 2 and Figure 3.

Table 2. Model parameters

[1]Also in Nigeria for DNI 2535 kWh/m^2/yr is 0.26 \$/kWh
[2]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

[1]Highest DNI in the study region, [2]Average DNI in the study region

8. CSP Experience Curve

CSP experience curve describes unit cost decrease with increase in cumulative production, the cost declines by a constant percentage as the number of unit product doubles. The constant percentage is otherwise called Progressive Ratio (PR). The CSP cumulative capacity projection selected for this study is the moderate growth scenario projection assumed by Greenpeace CSP global outlook [6]. This report

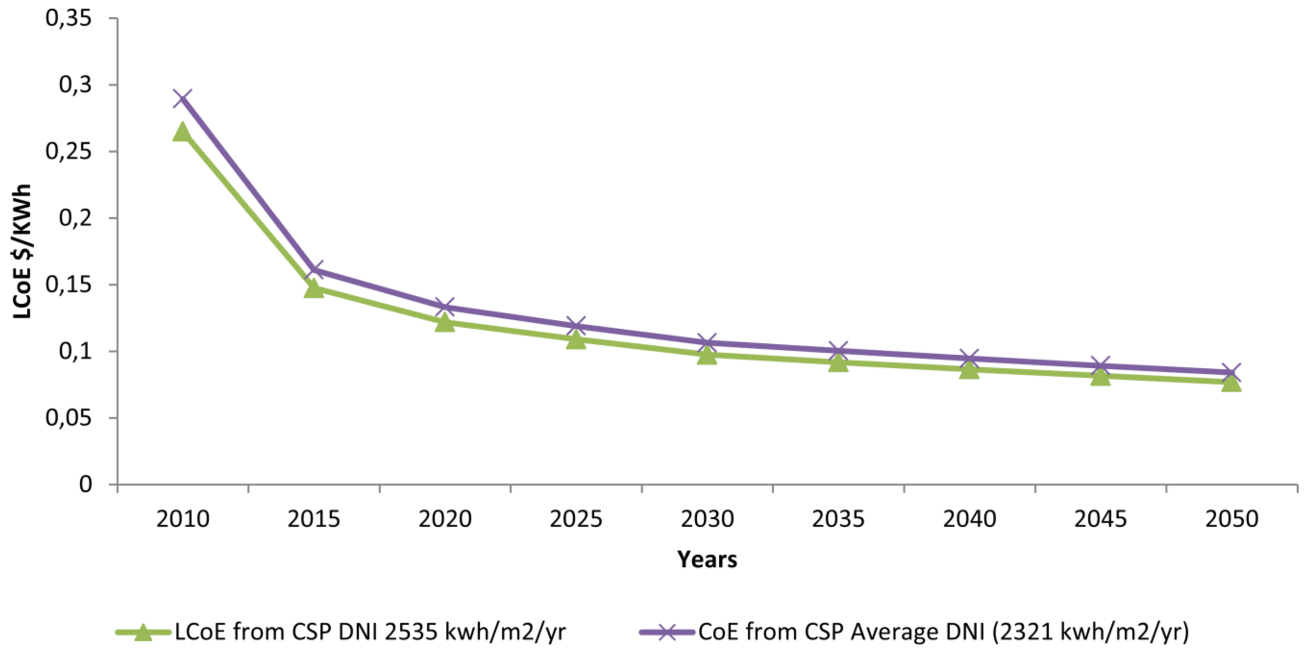

Fig. 3. CSP experience curve for study region with average DNI of 2321 kWh/m^2/yr and highest DNI of 2535 kWh/m^2/yr (PR 0.88)

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 policy measures around the world aimed at supporting CSP technology. This scenario assumes these measures either planned or underway is 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 the cost of energy in the study model. Details on global CSP moderate capacity growth and corresponding levelised cost under the Nigerian condition are discussed in Figure 4-9.

$$CoE = CoE^{\circ} \times (\Delta Q)^{b} \quad (2)\ [17]$$

$$b = Log_2\,(PR) \quad (3)\ [17]$$

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

b – Experience index

Figure 3 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 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.

9. 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 the 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. 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 subsidized by the government. In 2010, government sets the price of gas in Nigeria at 1$/mBtu and the transport cost of gas to power stations was 0.30$/mBtu. In the case of gas supply to power generating stations, government waives its own share of the Product Sharing Contract (PSC) as subsidy on electricity production. The international market price of gas is however different from the domestic market price. The government uses international gas price trend to sell gas in the international market while local consumers enjoy an indirect subsidy in the form of a reduced price. Though, government plan to review the domestic price of gas by proposing a new gas price of 2 $/mBtu starting from the year 2013[1], the international gas price for the same year is projected at 5.3$/mBtu according to the IEA (2010). This study employs different domestic gas prices and the international gas price scenarios in the model used for projecting the cost of energy from gas thermal plants in Nigeria. The domestic gas prices include the present subsidized gas price to power stations and the proposed domestic gas price slated for the year 2013. 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

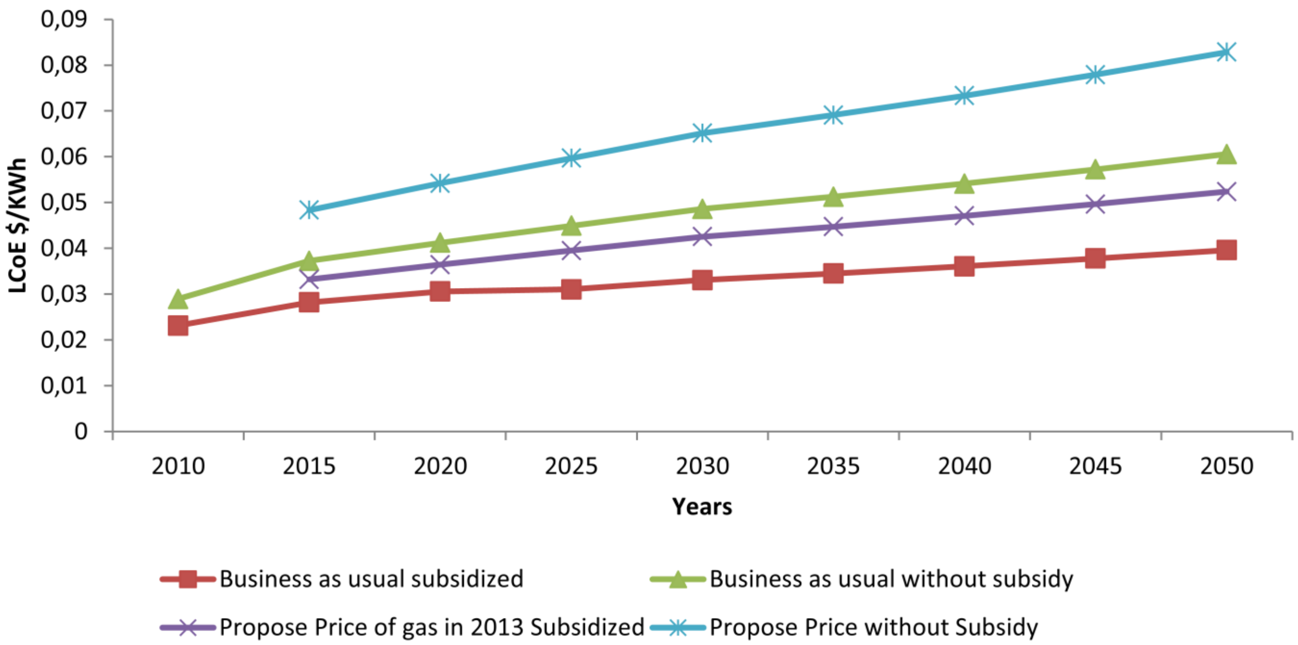

Fig. 4. LCoE for gas thermal power in Nigeria – IEA current policy scenario

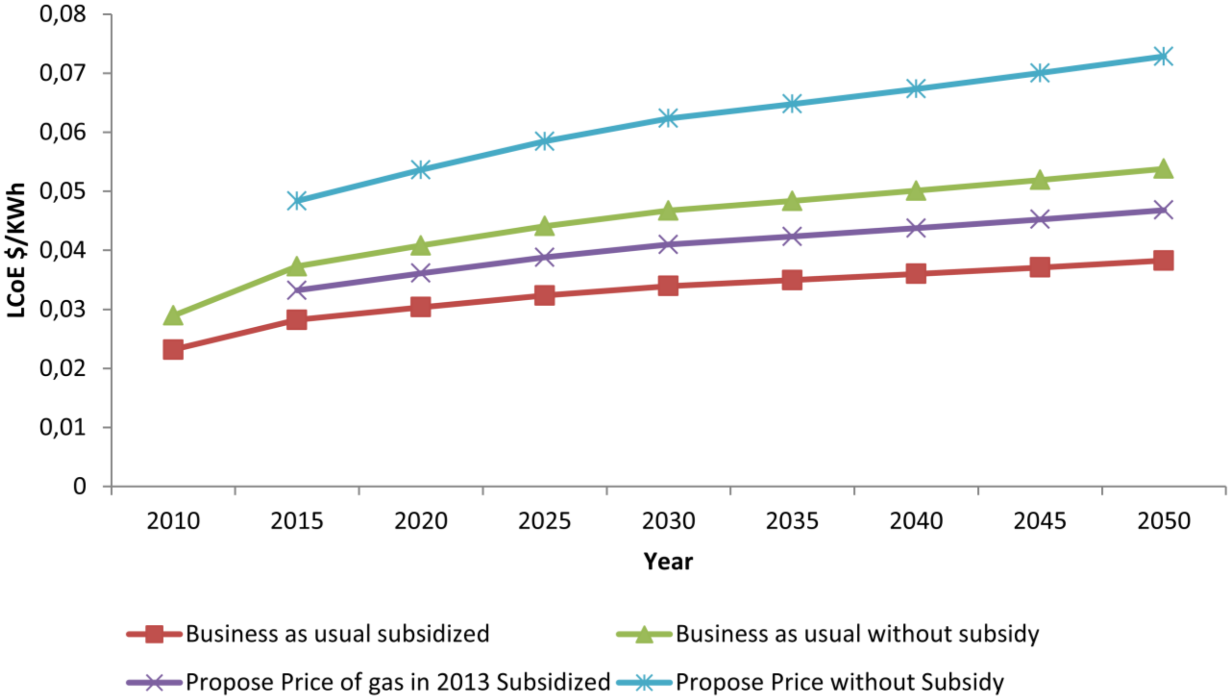

Fig. 5. LCoE for gas thermal power in Nigeria – IEA new policy scenario

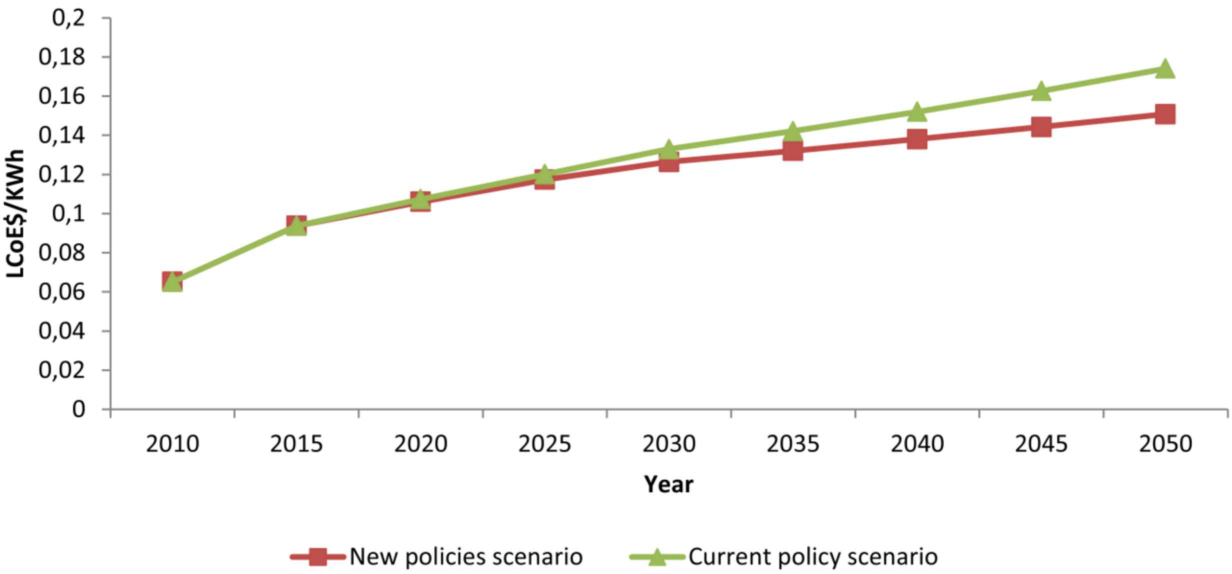

Fig. 6. LCoE for gas thermal power in Nigeria IEA international gas price

price is otherwise referred to as the international gas price in the IEA (2010) report. Applying the different gas price scenarios, the following results were obtained from the model.

Figures 4 and 5 show the cost of energy from domestic gas price for the current and new policy scenarios, two of the prices were based on the subsidized and non- subsidized 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-subsidized gas price scenario shows a significant margin between it and subsidized 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 subsidized and if subsidy is removed. The non-subsidized new price projection shows a significant high cost of energy in both current and new policy scenarios.

Comparing the results of the international gas price projection in Figure 6 to the domestic gas price projections in Figure 4 and 5, the cost of energy using international gas price is relatively high compared to the domestic market. The likely achievable cost of energy in the year 2050 under the domestic gas projection is 0.082 $/kWh while that of international gas price is 0.174$/kWh. However, the LCoE

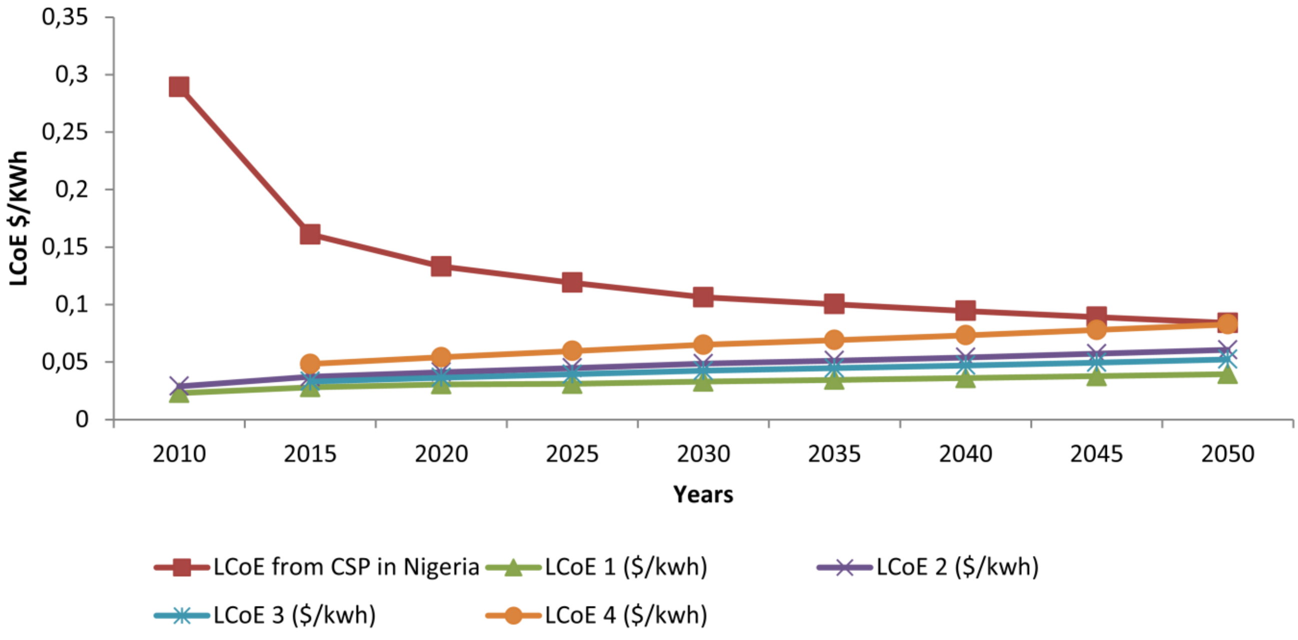

Fig. 7. CSP experience curve and LCoE for gas thermal power plant – Domestic gas price projections (IEA current policies scenario)

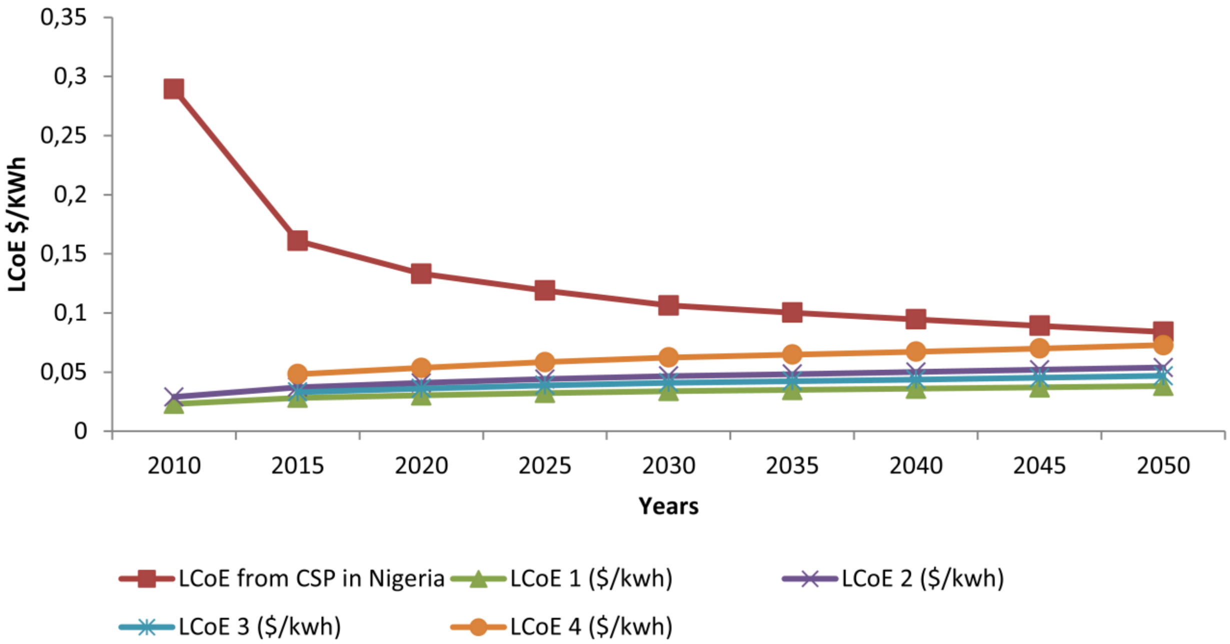

Fig. 8. CSP experience curve and LCoE for gas thermal power- Domestic gas price projections (IEA new policies scenario)

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 a cheap or subsidized price could have been otherwise sold at international gas price.

10. Cost of Energy from Conventional Gas Thermal Plants and Potential CSP Plant in Nigeria

Comparing the results of different possible LCoE from conventional plants to the experience curve from CSP under the domestic gas price scenarios.

The cost of energy from CSP can be considered relatively high until the year 2050. In case of subsidized and low domestic gas price, LCoE from conventional plants will be cheaper compared to that of CSP. Taking into 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 7 and 8 show the LCoE based on different domestic gas price projections under IEA current and new policy 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

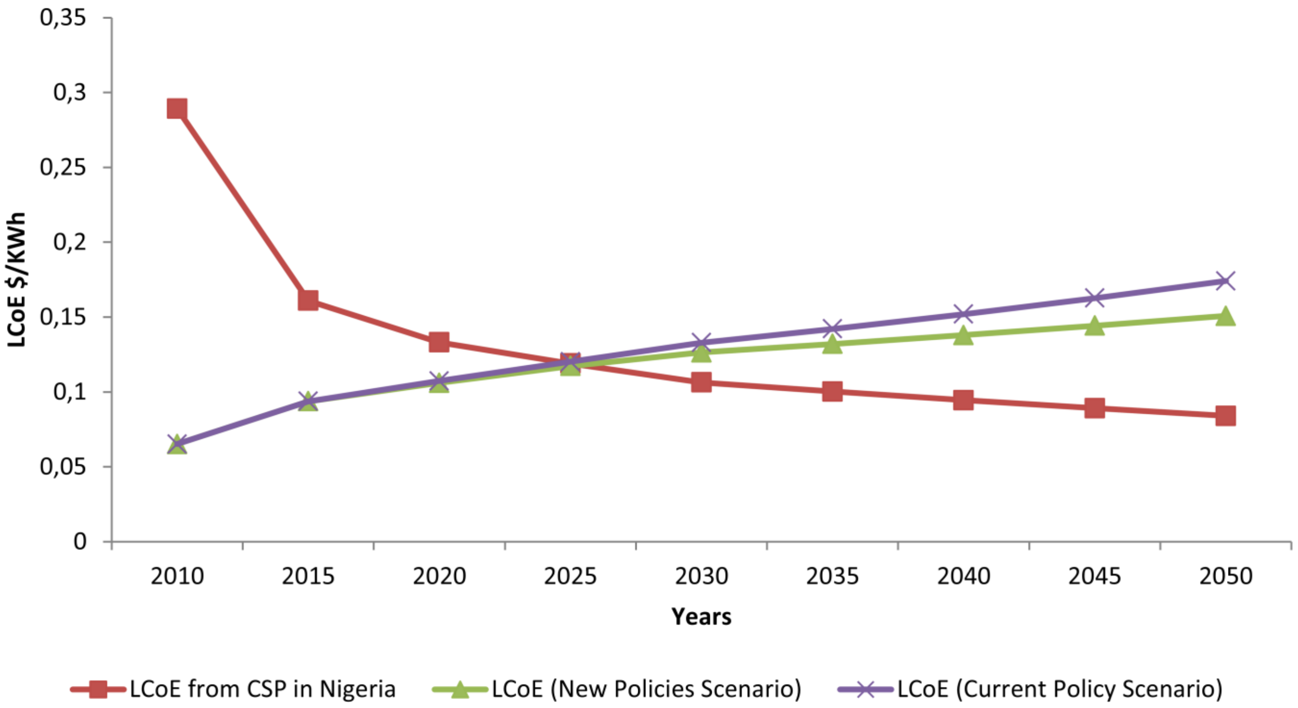

Fig. 9. CSP experience curve and LCoE for gas thermal power (gas thermal plant) – International gas price projection

0.88. For the business as usual projection both for the subsidized and non-subsidized situations, the LCoE will become competitive sometimes beyond the year 2050 under the same condition.

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 9 predicts a promising and economical market for CSP (LCoE perspective) by year 2025. The international gas price scenario 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.

11. Conclusion

The results analyzed in this study show that subsidy on gas price will not encourage the development of CSP technology. As long as subsidy is being paid on price of domestic gas in Nigeria, the cost of energy from gas thermal plants will remain comparatively low. The subsidy and low domestic price of gas are distorting the 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 phase out subsidy and review the domestic price of gas must be put in place. If Nigeria will start harnessing its solar thermal potentials, the current price of gas must be reviewed. Preferably, government should remove blanket subsidy on gas supplied to power plants. Instead of subsidy payment, government should facilitate the expansion of renewable energy technologies by providing investor friendly incentives. Relying mainly on a particular source of power supply can cause national power outage should there be interruption in gas supply. Hence, diversifying the utilization of the nation's energy sources will encourage security of supply.

References

[1] A. Sambo. The place of Renewable Energy in the Nigerian Electricity Sector .Energy Commission of Nigeria Abuja. 2009.

[2] D. Aderibigbe, "Power Supply To Industries - Pros and Cons of Available Options", Nigerian Society of Chemical Engineers 2010 .

[3] F. Vittorio, and M. Valerio, An evaluation of thermodynamic solar plants with cylindrical paprabolic collectors and air turbine engines with open Joule-Brayton cycle. Jounal of Energy. 2011. Vol. 44, No. 1, pp 862-869

[4] Global Network on Energy for Sustainable Development (GNESD). Reaching the Millennium Development Goals and beyond Access to modern forms of energy as a prerequisite Global Network. UNEP Roskilde Demark. 2007.

[5] Greenpeace, Concentrating Solar Power Global Outlook 09; Why Renewable Energy is Hot 2009 [Online]. Available :http://www.greenpeace.org/international/Global/international/planet-2/report/2009/5/concentrating-solar-power-2009.pdf [2012, 07/05].

[6] Intergovernmental Panel on Climate Change. Fourth Assessment Report: Climate Change. IPCC, Geneva, Switzerland. 2007.

[7] International Energy Agency. Renewable Energy Essentials: Concentrating Solar Thermal Power. 2009. [Homepage of IEA], [Online]. Available: http://www.iea.org/papers/2009/CSP_Essentials.pdf [2012, 06/22].

[8] International Energy Agency. World Energy Outlook 2010. IEA Paris, France.

[9] M. Usman, rural solar electrification in nigeria: renewable energy potentials and distribution for rural development 2012. [Online]. Available: http://ases.conferenceservices.net/resources/252/2859/pdf/SOLAR2012_0232_full%20paper.pdf [2012, June/ 19].

[10] NASA. NASA Surface meteorology and Solar Energy - Location. http://eosweb.larc.nasa.gov/cgi-bin/sse/grid.cgi?email=na Ed:NASA. 2011.

[11] N. Nafisa, and M. Sadid . Concentrating Solar Power (CSP) and Its Prospect in Bangladesh. Dhaka, Bangladesh. 2010.

[12] OECD and IEA. Renewable Energy Essentials: concentrated Solar Thermal Power. IEA Paris, France. 2009.

[13] R. Mostafa. Feasibility of Concentrated Solar Power under Egyptian Conditions. 2011

[14] S. Habib, N. Idris, M. Ladan, and A. Mohammad. Unlocking Nigeria's Solar PV and CSP Potentials for Sustainable Electricity Development. International Journal of Scientific & Engineering Researc. 2012, Vol. 3, No. 5, pp. 1-8.

[15] Solar Millenium AG . The parabolic trough power plants Andasol 1 to 3: The largest solar power plants in the world – Technology premiere in Europe Solar Millennium Erlangen, Germany.

[16] T. Franz, M. Hans, & K. Jurgen, 2011. Financing concentrating solar power in the Middle East and North Africa—Subsidy or investment? Journal of Energy Policy. 2011, Vol. 39, No 1, pp. 307-17.

[17] W. Price, and S. Carpenter, "The Potential for Low-Cost Concentrating Solar Power Systems", Intersociety Energy Conversion Engineering Conference National Renewable Energy Laboratory. NREL/cp 550-26649, August 1-5, 1999.