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Economic Viability of Coal based Power Generation for Nigeria

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Abstract: - Coal is an abundant and widely spread fossil energy resource in Nigeria that has not been properly harnessed. It has a potential to meet the current and future energy needs of Nigeria if security and diversity of supply remain fundamental. Supercritical Pulverised coal technology is the power plant of choice for most countries in Europe, USA and Asia. This paper examines the economic viability of the deployment of supercritical pulverised coal technology for power generation in Nigeria. The economic viability of the technology was accessed by three major economic parameters; the Net present value (NPV), the levelized generation cost (LGC) and the internal rate of return (IRR). LGC is determined by taking the net sum of expenses and dividing by the discounted value of the electrical energy generated (kWh) throughout the life of the power plant. The NPV is estimated by subtracting the discounted values of the various expenses of the investment from the discounted value of the income generated from the sale of the electricity generated by the plant over its useful life. Company tax of 32% and annual depreciation rate of 33.3% as recommended by Nigeria Electricity Regulatory Council (NERC) were allowed for in the calculation. The results of the study show that supercritical pulverised coal combustion technology is economically, less risk and technically viable option for power generation in Nigeria generating electricity at a levelized cost of 0.045 dollars per kWh at a net present value of $1.13 billion.

***Keywords**: - Coal, SC PCC, Economic analysis, Electricity, kWh, Power Generation*

I. INTRODUCTION

In Nigeria, 93% of electric power generation is provided by fossil fuel (gas), the remainder is from Hydro sources **[1].** There is over 8.6 GW **[2]** of installed capacity of generating plant made of government owned and Independent power plants, details in tables 1.1 and 1.2. Despite the large number of installed power generation capacity, Nigeria could still not meet up with the electricity demand of its populace which is estimated at 10 GW **[3]** because of old age of the power plants and the lack of new generation plants addition. Actual electricity generation is only between 2.5-3.6 GW

Table 1 Installed and Generating capacities of Government owned Power stations in Nigeria **[2]**

S/N	Station name	Type	Year Built	Location	Installed capacity (MW)	Available capacity (MW)
1	Kainji/Jebba	Hydro	1968	Niger state	760	480
2	Shiroro	hydro	1989	Niger state	600	450
3	Kainji/jebba	Hydro	1985	Niger state	540	450
4	Egbin power Plc	Thermal	1986	Egbin, lagos	1320	1100
5	Geregu Power Plc	Thermal	2007	Kogi state	414	276
6	Omotosho Power Plc	Thermal	2007	Ondo state	304	76
7	Delta Power Plc	Thermal	1966	Delta state	900	300
8	Sapele Power Plc	Thermal	1978	Delta State	1020	90
9	Afam (IV-V)	Thermal	1963/01	Rivers state	726	60
10	Calaber Thermal station	Thermal	1934	Cross River state	6.6	nil
11	Oji River	Thermal	1956	Enugu state	10	nil
12	Olorunsago Power Plc	Thermal	2008	Ogun statae	304	76
				Total	**6904.6**	**3558**

Table 2 Installed and Generating capacities of Independent Power projects (IPPs) in Nigeria **[2]**

S/No	Station name	Location	Installed capacity (MW)	Available capacity (MW)
1	AES Power Station	Egbin lagos	224	224
2	SHELL- Afan VI Power station	Rivers state	650	650
3	Agip Okpai Power Station	Delta state	480	650
4	ASG Ibom Power Station	Akwa Ibom	155	76
5	RSG – Trans Amadi Power Station	PH,Rivers State	100	24
6	RSG Omoku Power Station	Omoku, Rivers state	150	30
		Total	**1759**	**1484**

Even if new power plant additions were to be made, it is our concern that the longer term sustainability of fossil fuel-based generation cannot be guaranteed due to the frequent agitation for resource control from the Niger Deltans and vandalism of power plant gas supply infrastructure. More over there is an urgent need for a good energy mix in the nation's energy generation infrastructure due to the so many benefits derivable from it. Globally the energy industry is driving toward sustainable, low carbon emitting, renewable energy sources. However, renewable as at now are still in their infant stage of commercialisation and cannot help to meet Nigeria's base load electricity demand deficit. Coal which is evenly spread across Nigerian states with an estimated reserve of 2.734 billion tonnes **[2]** holds the key to Nigerian's present and even future energy security.

1.2 Coal use for electric power generation

Coal is an important energy resource for the world, principally for electricity generation. It is the world's most abundant and widely distributed fossil fuel, with global proven reserves totalling nearly 1000 billion tonnes **[4].** Within the last decade, in the global market the demand for coal has grown rapidly, exceeding that for gas, oil, nuclear and renewable energy sources, although this comes at a cost **[4].** On the average, 40% of the world's electricity is generated from coal. Nevertheless this figure is even much greater in many countries, like in South Africa, coal fuels about 93% of their electricity generation; it is 92%, in Poland, 79% in China, 69% in India and 49% in the United States of America just to mention a few **[4].** As can be inferred from the above, most developed and developing countries that have coal deposits meet their energy demands through coal based generation. Nigeria can also bridge its energy demand and supply deficit by leveraging on its abundant coal deposit resource. The potential role coal stands to play in meeting Nigeria energy needs can further be buttressed by the following quotes.... '' The growing energy needs of the developing world are likely to ensure that coal remains a key component of the power generation mix in the foreseeable future, regardless of climate change policy **[4].**'' The onus is now for Nigerian government to find better ways of utilising coal in power generation while causing minimal environmental consequences. A retinue of clean coal technologies (CCTs) have been developed to ensure that **[5].**

Advanced or clean Coal based power generation technologies (CCTs) are technically proven and draws on a cheaply available energy resource. Carbon emissions and greenhouse gas impacts are controlled.

An enormous amount of capital investment will be required to reach the development goals for new electricity capacity investment in Nigeria. It is estimated that Projected Electricity Supply by Fuel Mix (Coal) for 7% growth rate scenario for the years 2015, 2020, 2025 and 2030 are 2393, 6515, 9305 , and 15, 815 mega watt (MW) respectively **[2].** An enormous financial investment will be needed to actualise that and Obtaining the required capital investment from government will be a major problem especially now that government funding of the power sector is becoming more difficult since there is intense competition for funds between different industry sectors. As a result, private participation in power projects is emerging, introducing IPP (independent power producer) projects into the market. For an IPP investor to invest in coal power plant in Nigeria, he needs to be sure he can recoup his investment with some satisfactory interest on time. Another drawback is revealed when it is understood that current low electricity tariffs result in financial shortfalls in the utilities with a consequent lack of capital for new investment.

In order to make a rational decision about choice of an alternative coal fired power plant technology to adopt in Nigeria, there is the need not just for the consideration of the environmental and technical or technological advantage of the alternatives but also the evaluation of the cost and benefits of the technology to know whether it is economically viable. This study therefore examines the economic viability of a Supercritical pulverised coal combustion y (SC PCC) power generation technology option for electricity generation in Nigeria.

1.3 Approach to the study

The economic analysis study investigates clean coal based power generation options, carries out a brief analysis of those that could reasonably be considered suitable for both long and short term commercial power generation in Nigeria and identifies a choice technology for adoption that can be evaluated economically. The evaluation and selection of a favoured technology consist of;

- An assessment of the possible technologies
- Consideration of the level commercialisation of the technologies
- Consideration of the ability or flexibility of the technologies to burn Nigeria coal
- Immediate Nigerian environmental requirements and future stricter emission legislation requirements
- Consideration of costs (both capital, LGC and O&M cost) and efficiency
- Consideration of risks involved.

The economic viability of the technology selected was accessed by three major economic parameters; the NPV, the LGC and the IRR. LGC is determined by taking the net sum of the discounted O&M cost, replacement costs, fuel costs, investment costs, and dividing by the discounted value of the electrical energy generated (kWh) throughout the life of the power plant. The NPV is estimated by subtracting the discounted values of the various expenses of the investment from the discounted value of the income generated from the sale of the electricity generated by the plant over its useful life. Company tax of 32% and annual depreciation rate of 33.3% as recommended by Nigeria Electricity Regulatory Council (NERC) **[6]** were allowed for in the calculation.

II. CLEAN COAL GENERATION TECHNOLOGY (CCT) OPTIONS

The coal based electricity technologies considered for this study; the subcritical pulverised coal combustion (Sub PCC) technology, the supercritical pulverised coal combustion (SC PCC and the circulating fluidised bed combustion (CFBC) technology are presented in this section. Integrated gasification combined cycle (IGCC), Pressurised fluidised bed combustion (PFBC), and ultra supercritical pulverised coal combustion (USC PCC) are clean coal technologies, but were not considered for selection because they are still in their infant stage of commercialisation and development.

2.1 Sub Critical Pulverised coal Technology (Sub PCT)

Subcritical operation refers to steam pressure below 22.0 MPa (critical point of steam) and temperature of about 540^{o}C. Sub PCC is one of the most predominant, conventional and commercialised method of coal conversion to electricity with over 40 years of experience **[7].** Sub critical PCC owes its predominant position to its good all round performance and high availability. It is technically proven and commercially viable. The main barriers to its continued use are its relatively low thermal efficiency and environmental performance.

2.2 Supper Critical (SC) Pulverised Coal Technology (SC PCT)

This is an improvement over the conventional sub critical pulverised coal combustion. Cycle generating efficiency is improved beyond that of sub critical PCC power plants by modifying the unit to operate at higher (above critical) steam temperature and pressure. Higher efficiency means less emission for every MWh of electricity generated by burning coal **[7].** It is reported than more than 400 SC PCT plants are in operation globally **[8; 9]**

2.3 Circulating Fluidised Bed Combustion (CFBC)

The CFB is a variant of the PCT plant. It is environmentally friendly, flexible to burn a wide spectrum of coals including blends of coal and coke. CFBC is efficient and one of the promising CCTs. The technology is proven in small capacity. Good technical and superb environmental performance without the aid of complex flue gas treatment units is responsible for its rapid development. Take up of CFBC at utility scale has been limited but this is mostly due to the fact that the technology is new and the largest single capacity boiler in operation is 460 MWe, although other high capacity plants are being commissioned **[9].**

2.4 Comparison of coal based generation options

A summary of comparison of the options at 500 MWh is presented in Table 3. This shows Sub PCT to have the lowest total plant cost (TPC) price option with a levelized electricity cost of $47.7/kWh. It represents the lowest risk of the options because of its maturity and long years of experience. SC PCC is marginally more expensive than Sub PCC in this assessment, but with better efficiency and environmental performance. However less mature, there is a high potential that it will be more cost competitive in the long run.

III. SELECTION OF APPROPRIATE TECHNOLOGY

In an earlier work by the authors, Super critical pulverised coal combustion (SC PCC) technology is identified as the appropriate technology for Nigeria. This is because of its more advanced commercial status compared with other options, and its significantly lower levelized generation cost and O&M cost compared to sub PCC technology. Additionally there is known commercial experience of generating power using SC PCC in some African countries like South Africa; this confers on SC PCC the best technology of choice in Nigeria.

This technology continues to be selected as a power plant of choice in China, India, Japan and Europe by commercial investors ahead of other CCTs **[4].** Being a highly efficient technology, it can meet the current short term Nigerian electricity requirements with minimal emissions and it has a great potential to meet whatever future long term policy of emission legislation that Nigeria may become obliged to tomorrow like Carbon capture and storage (CCS).

Table 3 Summary of the clean Coal technologies based on a 500 MWe capacity Plant burning Sub-Bituminous coal **[10, 11]**

Parameter	Sub critical PCC	Super-Critical PCC	CFBC
Maturity	Completely mature	Substantially mature	Proven at small scale(<200 MWe)
Range of Unit size	50-1000 MW	250-1000 MW	40-400 MW
Fuel flexibility	Burns wide range of coals but less better than AFBC at extreme moisture/ash	Burns wide range of coals but less better than AFBC at extreme moisture/ash	Burns practically any fuel
Thermal efficiency	Lowest (33-37%) HHV	High (37-42%) HHV	Low (35%)
Environmental performance	Low efficiency and FGD solids disposal problem	Better than sub-PCC because of higher efficiency	Low efficiency and large volume of solids
Availability	Excellent (85%)	Good (85%)	Limited experience
Capacity factor (%)	80	80	80
TPC ($/kW) HHV	1266	1306	1386
Capital cost ($/kWh)	25.7	26.5	28.1
O&M Cost ($/kWh)	8	8	10.4
Fuel Cost ($/kWh)	14	13	9.5
LGC ($/kWh)	47.7	47.5	48

CFBC is a good and competitive option for low calorific value fuels but its capacity and the type of coal in Nigeria limits its selection. The highest commercial capacity of a CFB plant in operation is approximately 460 MWe Lagisza plant in Poland **[12]** which is less than the capacity of 500 MW being proposed. Installation of multiple boilers of CFB to make up the capacity of 500 MW would make the LGC and capital and O&M cost higher by about 50-70%. USC PCC and IGCC were screened out and not considered for selection because they were judged not to have been proven commercial for a cost effective, competitive and reliable power generation in Nigeria within the next ten years. Besides, there is no technological knowhow in Nigeria to operate those kinds of high tech power plants. There is also greater potential for this technology's costs to be driven down over time and performance improved as a result of the developments in new boiler materials now under way.

3.1 Economic viability of SC PCC power plant

Although diverse ways exist for checking economic viability, the most often and commonly applied methodology in the electricity industry for this purpose is employed below, i.e., the estimation of the levelized generation cost (LGC) , the internal rate of return (IRR) and the net present value (NPV) of the investment.

In any given electricity generation project, the levelized generation costs (LGC) represents the constant stream of costs or electricity price (usually in dollars) over the life of the plant, which is needed to cover all operating expenses, payment of debts and accumulated interests on expenses made by the project initially, and the payment of an acceptable return to the investors.

Levelized cost is estimated by converting the net cash flows of the project to the equivalent net present value costs at the first year the plant commenced operation and dividing the result by the yearly revenue of electricity sales over the project life time. The levelized cost of electricity is made up of three basic components; total capital requirement also called the investment cost, operation and maintenance cost and cost of fuel.

3.2 Investment cost (I) or total plant cost (TCR)

TCR as used here is the sum of all the costs incurred in buying, supplying and building the plant including the cost of land accounted for as if they were spent instantaneously TCR consists of costs as: the PC boiler and accessories cost, cost of flue gas clean up systems, cost of ducting and stack, steam T-G plant, including cooling water system, accessory electric plant, and cost of balance of plant, engineering services, and some allowance for uncertainty **[9].** TCR is usually provided by a mixture of loans, that is, debt contribution through bonds, and equity contribution. In calculating LGC, provision is made so that these costs are paid back with some interests to the owners and lenders over the useful life of the project. TPC are added and divided over the yearly generated output to get the average cost per kWh. Total plant costs of coal fired power plants vary depending on location, supplier, type of plant and type of fuel burnt and environmental requirements. The variation is however less than 10 % as observed in MIT cost estimates **[10].**

3.3 Bond and Equity

A bond is an interest-carrying instrument or discounted government or corporate security that compels the user to pay the bondholder a specific sum of interest. However, equity financing is contributed by the owners of the project and usually paid back from the remaining revenues left after meeting all other obligations and, hence, posses a higher risk of not being completely recouped in comparison to the debt proportion. In LGC estimation investigation, it is assumed that the bond and equity contributions are recouped on a fixed yearly basis irrespective of the quantity of generated output.

3.4 Annual operations and maintenance (O&M) costs

As the name suggests, O&M costs represent the costs incurred in operating and maintaining the plant annually throughout its useful life. These costs are dependent on operation of the plant but are not essentially in direct proportion with the quantity of output, but will stop if plant stops operation. Operational costs include labour and management costs, insurance and other services, and certain types of consumables. Maintenance costs include cost of scheduled overhauls and periodic upkeep. As with TCR, these costs are summed and divided by the yearly generated output to come at the mean cost per kWh. However, unlike Investment costs that are relatively independent of mode of operation, the operating mode significantly influence these types of costs. For instance much less labour will be needed for a power plant that generates electricity only during peak periods of the season, as opposed to one that is used as a base-load power plant. Nevertheless, the condition of power plant working seasonally will not arise in Nigeria any sooner as the demand for power has continuously increased for some years now and is expected to go on in coming years. Moreover, O&M costs naturally rise after some time as the plant ages, as against the investment costs that are presumed steady and fixed as soon as the initial investment is made.

3.5 Fuel and other variable and costs (F)

Fuel cost is the cost of coal, and depends on the plant loading and calorific value. Variable costs are estimated from fuel consumption, maintenance expenditures for forced outages, and other input costs driven directly by hourly plant operations.

IV. FINANCIAL MODELLING

The financial evaluation used discounted cash flow (DCF) to calculate a levelized cost of generation and a net present value (NPV) analysis to assist in the economic analysis of the preferred coal based generation technology. Key project assumptions on which the study was based are:

- The Nigerian average rate of inflation (consumer prices) within the last eight years is 12%. This inflation rate will be used for O&M escalation to protect the investors against future uncertainties in price escalation.
- The price of Nigeria coal was $40 per tonne in 2005 and was forecasted to be $42 per tonne in 2010 **[13].** Annual coal price of $42 forecasted above is assumed and fuel escalation rate equivalent of the inflation rate of 12% was used in fuel price escalation.
- The capital financing for the project was assumed to be 70% borrowed through bonds at a cost of 19.29% and 30% owners equities at a cost of 20.9% and a company tax rate of 32% as recommended by NERC in multi tariff order for the determination of charges **[6]** for power generation in Nigeria.

- Although the average life of a coal power plant is between 30-40 years, a conservative economic life of 30 years was assumed for the coal power plant so the investors can recoup their investment on time.
- The estimation did not account for site specific factors like transmission line additions, transformer or fuel delivery
- The investment cost is escalated at 3% to reflect the forecasts by power plants/equipment cost index **[14].**
- Since money has time value, and the plant will come online in 2016, all currencies are expressed in 2016 $.

4.1 Analysis of costs

Levelized generation cost (LGC). The cash flow diagram for the project throughout its 35 years life cycle is shown in figure 4.2. The levelized generation cost is estimated using equation 1 **[9, 15],** adapted to model the various inputs and assumptions

$$LGC = \frac{Total\ life\ cycle\ cost}{total\ life\ energy\ production}$$

$$LGC = \frac{I + (1-T)\{O + R + F\} - TD}{(1-T).G_{1\circ}C \sum_{t=1}^{k} \left\{\frac{1+h}{1+i}\right\}^{t}} \left[\frac{\$}{kWh}\right] \quad (1)$$

Discounted cost of investment (I).The relationship between the present (I_t) and (I) future value of income at discount rate i, is given by

$$\frac{I}{I_t} = (1+i)^{-N} \quad (2)$$

Accommodating the rate of cost escalation as a result of inflation (h) into equation (2),
The discounted value of I after N years becomes **[16].**

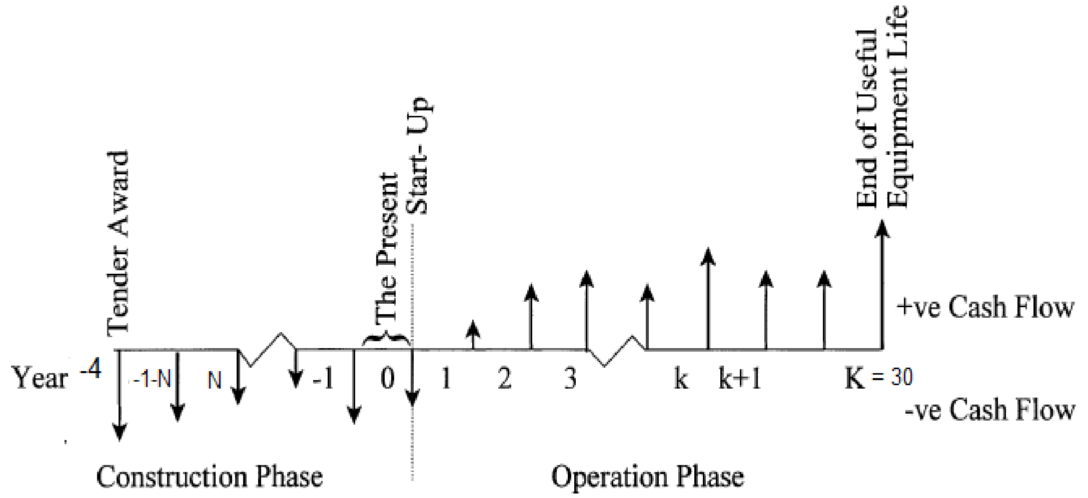

Figure.1 Investment and economic life cycle for the power plant

$$I = \sum_{t=1-N}^{0} I_t \left\{\frac{1+h}{1+i}\right\}^{N} = I_o + I_1\left\{\frac{1+h}{1+i}\right\}^{1} + I_2\left\{\frac{1+h}{1+i}\right\}^{2} + . \ . \ . \ . + I_N\left\{\frac{1+h}{1+i}\right\}^{N} \quad (3)$$

Similarly discounted O&M is calculated using the expression

$$O = \sum_{t=1}^{k} O_{annual} \left\{\frac{1+h}{1+i}\right\}^{t} \quad (4)$$

and discounted fuel cost (F) is given by

$$F = \sum_{t=1}^{k} F_t \left\{\frac{1+h}{1+i}\right\}^{t} \quad (5)$$

Discounted revenue (E) from electricity generated (G_A) is

$$E = G_A.C + G_A.C\left\{\frac{1+h}{1+i}\right\}^1 + G_A.C\left\{\frac{1+h}{1+i}\right\}^2 + \cdots + G_A.C\left\{\frac{1+h}{1+i}\right\}^k \quad (6)$$

Discounted replacement cost R is;

$$R = \sum_{t=1}^{k} R_{1^\circ annual}\left\{\frac{1+h}{1+i}\right\}^t \quad (7)$$

Discounted depreciation (D) is given by;

$$D = D_A\sum_{t=1}^{k}\left\{\frac{1+h}{1+i}\right\}^t \quad (8)$$

The discount rate (i) also called the post tax weighted average cost of capital is calculated from equation (9) **[17]**

$$i = WACC = \frac{E_C \times C_E}{E_C + D_C} + \frac{D_C \times C_D}{E_C + D_C}(1-T) \quad (9)$$

where,

$$C_E = R_F + \beta\{R_M - R_F\} \quad (10)$$

4.2 Plant input data calculation.

The specification of the plant and the method for calculating some of the plant input data used in the financial model are summarised in table 4

Table 4 Plant input data used in excel calculation

S/No	Calculation input data	Unit	Value	remarks
1a	Construction period	years	5	
b	Project economic life	years	30	
2a	Generation capacity	MW	500	
b	Efficiency (HHV)	%	37.5	
3	Capacity factor	%	85	
4	Availability	%	90	
5a	Investment cost	\$/kW	1800	
b	Total investment cost	\$ million	900	2ax5a
6	One yr calendar period	hr	8760	
7a	Annual gen. output	kWh/yr	3350700000	2ax3x4x6
b	Electricity tariff	\$/kWh	0.07	[6]
c	Annual revenues	\$ million	234.54	7ax7b
8	Calorific value of fuel	kJ/kg	31600	
9	Coal feed	tonne/hr	152	(2ax3600)/(8x2b)
10	Annual fuel use	tonne/yr	1,131,792	3x6x9
11	Coal price	\$/tonne	42	
12	Annual fuel cost	\$ million	47.5	10x11
13	O&M cost	\$/kWe	15.6	[18]
14	Annual O&M cost	\$ million	7.8	7x13
15	Capital from Debt (D)	%	70	[6]
16	Capital from equity	%	30	[6]
17	Cost of debt (R_D)	%	19.29	[6]
18	Asset beta (β)	%	50	[6]
19	Risk free rate (R_F)	%	14.8	[6]
20	Market return or ROR (R_M)	%	27	[6]
21	Cost of equity (R_E)	%	20.9	$R_F - \beta(R_M - R_F)$
22	WACC (i)	%	15.34	See Eqn. 9
23	Inflation rate (h)	%	12	[6]
24	Company tax rate (T)	%	32	[6]

4.3 Discounted Cost of investment (I).

The investment cost (I) of the coal fired power plant with NO_x combustion controls (low NO_x burner & OFA) and without SO_2 is estimated to be \$1,800 per kW. Construction time for coal power plants is usually 4 or 5 years **[18]**. Since there is no coal fired power plant construction experience in Nigeria, the schedule for construction of coal fired power plant in South Africa as shown in table 5 is applied here. The discounted cost of total plant investment (I) as determined from equation (3) using excel model, adapted to model the various inputs and assumptions is \$1344.97 million

Table **5** Economic requirements for generation in Nigeria (NERC, 2008)

Project economy		
▪	Construction time:	5 years
▪	Economic life:	30 years
▪	Company Tax rate:	32%
▪	Financing policy:	Equity and debt (30:70%)
▪	Asset beta (β)	0.5
▪	Risk free rate (R_F)	14.8%
▪	Cost of debt (R_D)	19.29%
▪	Market return (R_M)	27%

4.4 Discounted value of O&M Cost (O).

Annual O&M cost for coal fired power plant of capacity 500 MWe in South Africa for the year 2010 was estimated as $17.38 per kWe (2007 $) [18] which is $19.56 in 2016 $. In Nigeria, cost of labour is assumed to be cheaper due to disparity in the economy of South Africa and Nigeria. The annual O&M cost in Nigeria is assumed to be 80% of South Africans' O&M (i.e. 20% less). Therefore the annual O&M cost in Nigeria at the first year of plant operation is

O_{annual} = 0.8 x $19.56 = $15.64 per kWe.

O_{annua}l = $15.64 x 500000 million = $7.82 million.

Applying equation (4) in the excel model, the discounted value of O&M is

O = $157.74 million

4.5 Discounted fuel cost (F). Annual fuel cost (F_A) as estimated in the cost input data estimation in table 4 is $47.54 million. Applying equation (5), Discounted fuel cost over the 30 years life of the power plant (as in table 4) is F = $961.3 million

4.6 Discounted value of the revenue from electricity produced annually.

At a capacity factor of 85% and availability of 90%, the coal fired power plant will generate an annual net output of 3.3507 GWh. From table 6, the average electricity tariff in Nigeria per kWh is ₦8.95 ($0.07 per kWh) at an exchange rate of 1$ for N135.

Therefore, $E_{annual=}$ G_A.C= 3.3507x10^3x0.07 = $234.55 million

Applying equation (6) in the Excel model,

Discounted value of E_{annual}=$4743.3 million

4.7 Replacement cost (R).

The power plant will definitely need some of its major parts changed or refurbished during its life time. . Assuming 15% of the total plant investment is used for the replacement. We also assume that this is evenly spaced over 28 years of its life time. Hence, annual replacement cost (R_A) is

$$R_A = 0.15 \times \frac{900}{30} = \$4.5\ million$$

Using equation (7), discounted replacement cost R is $87.11 million

Table 6 Nigeria electricity tariffs Schedule for 2010 (NERC, 2008)

Type of load	Tariff code	categories	Energy charge (₦:K/kWh)
Residential	R1-R5 (MD)	<5kVA to < 20 MVA	1.80-12.50
Commercial	C1-C4 (MD)	<5kVA to < 20 MVA	9.40-12.30
Industrial	D1-D5	<5 kVA to > 20 MVA	9.80-12.90
Special tariff class	A1-A6	<15 kVA to < 20 MVA	8.60
Street lightening	SI	1ph, 3ph	6.60
		Average	7.28-10.62($0.07)

Exchange rate used: $1 = ₦135

4.8 Discounted value of depreciation expense (D).

The power plant will depreciate in value with use. Hence a depreciation allowance is usually allowed for the replacement of the plant at the end of its economic life. Annual depreciation expense D_A is given by

$$D_A = \frac{total\ plant\ cost}{depreciation\ period} = \frac{900}{30} = \$30\ million$$

Applying equation (8),

Discounted depreciation cost (D) is D = $222.4 million.

4.9 Net Present value (NPV).
This is the net cash flow throughout the life of the power plant. It is the difference between benefits accruing from the investment and costs or expenses incurred in running the business.
NPV after tax is calculated by the expression **[15]**

$$NPV\ after\ tax\ at\ T\% = (1-T)\{E-(F+O+R)\}+T\times D-I \qquad (11)$$

Applying equation (11) in Excel model adapted
NPV at a tax of 32% is 1131.44 million dollars.

4.10 Levelized generation cost (LGC).
Applying equation 1 in the excel model, the levelized generation cost of the power plant is estimated thus,
LGC= $0.045 per kWh (₦6.1 per kWh)
Allowing 30% for profit, the tariff for power from the power plant will be $0.059 per kWh (₦7.8 per kWh).

4.11 Pay back period (PB) and Internal rate of return (IRR).
The payback period is 19 years while internal rate of return of the project is 20.8%

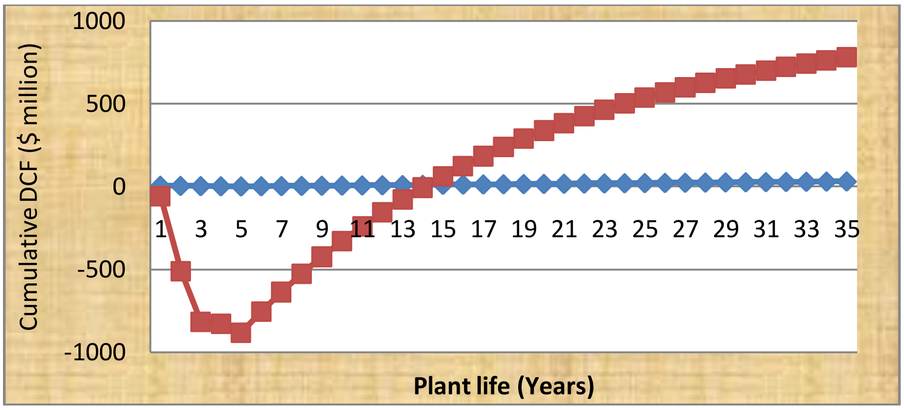

Figure 2 Graph of Plant life VS cumulative DCF

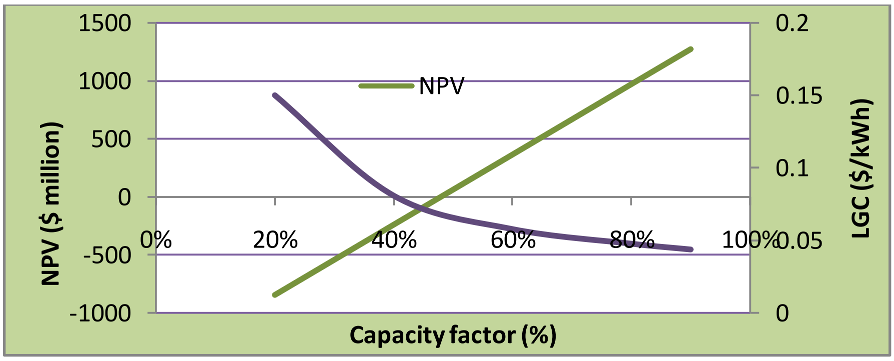

Figure 3 Sensitivity of NPVand LGC on Capacity factor

4.12 Sensitivity/Risk Analysis: Impacts of Major Factors on LGC.

The LGC and other economic performance indicators (NPV, IRR, PB) estimated are determined majorly by four cost parameters; the investment cost, the O&M cost, the capacity factor and the cost of fuel. Since some of these cost are estimated and assumptions in future values are difficult to predict accurately, there would always be some uncertainty about the projects results. To reveal the potential risks that may be associated with the input factors and proffer solutions, the SC PCC study was subjected to further sensitivity analysis of the plant capital, O&M and capacity factor. Three alternative scenarios were created, one being the original plant capital of $1800/kW (Identified as the base case) and the other two scenarios. For each scenario the plant cost, O&M cost and capacity factor were further increased by a percentage until the NPV becomes negative and that point becomes the switching value of the project. The other scenario is cost reduction by 10% and then 15% to demonstrate the effect of a 10% and 15% subsidy of plant capital cost, O&M cost, and fuel cost. The main inputs and results for the sensitivity analysis are shown in table 7.

Table 7: Sensitivity analysis inputs and results

Item	Unit	Base case	Switching value/Bad trend	Favourable trend	
				Good	Better
Installation cost	$/kW	1800	Up by 85%	Down by 10%	Down by 15%
			3328	1620	1530
Installation cost	$ million	900	1664	810	765
LGC NPV	$/kWh/$ $ million	0.045 1131.4	0.07 -0.16	0.042 1264.8	0.041 1331.4
Fuel cost	$/tonne	42	Up by 173.1%	Down by 10%	Down by 15%
			114.7	37.8	35.7
Fuel cost	$ million/year	47.54	129.8	42.79	48.91
LGC NPV	$/kWh $ million	0.045 1131.4	0.070 -0.06	0.044 1196.8	0.043 1229.5
Capacity factor	%	85%	47.6%	Up by 5.9%	Up by 11.8%
				90	95
Impacted fuel cost	$million/year	47.54	26.62	50.33	53.13
LGC NPV	$/kWh $ million	0.045 1131.4	0.071 -0.012	0.044 1282	0.042 1434

An investment cost of $1800 per kWe at a tax rate of 32% and discount rate of 15.4% translates in the analysis of this study to LGC of $0.045 per kWh which is very well below the tariff benchmark of $0.07 per kWh set by the Nigeria electricity regulation council (NERC, 2008). With all other factors remaining constant, a capital cost increase by about 50-65% will still give good returns on investment. However, cost above $3327 per kWh (i.e. increase above 65%) will change the Npv to a negative value.

The discount rate is the interest rate used to determine the present value of the future streams of income from the project. The relationship between discount rate and LGC or NPV will reveal to investors what range of discount rates will produce a positive cash flow and hence electricity tariff below the benchmark of $0.07 per kWe. A discount rate below 20% will give a positive NPV and electricity with tariff rate within the limits set by NERC. However, a discount rate of above 20.7% is the switching value and will change the project to a non profitable one.

The capacity factor is another important factor in the analysis of a power plant performance economically. The NPV drops progressively as the capacity factor is decreased from 85 through 70 t0 65% and becomes negative at a capacity factor of 47.6%.

An increase in fuel cost to about 150-165% of the base fuel cost will l not change the NPV of the project to a negative value, but the lower the fuel cost, the lesser the cost of electricity. However, fuel cost increase to about 170% will switch the NPV of the project to negative.

V. SUMMARY OF MODELLING

A summary of a levelized unit cost of generation and NPV cost analysis performed, using a DCF model, adapted to model the various inputs and assumptions attributable to the selected alternative is shown in table 8.

Table 8 Summary of computed results for 500 MWe net coal power plant

Variable	Discounted value	LGC ($/kWh)	% of total
Investment cost (I)	$1344.97 million	0.0290	64%
O&M cost (O)	$157.74 million	0.0023	5%
Fuel cost (F)	$961.30 million	0.0142	31%
Replacement cost (R)	$87.11 million	0.0011	2%
LGC		0.045	100%
Sale price of a kWh of electricity (30% profit)		0.059 USD/kWh	
Sum of discounted revenue over 30 years.		$4,743.28 million	
NPV		$782.09 million	
PBT		19 years	
IRR		20.8%	

VI. CONCLUSIONS

Coal based electricity has been a major source of power in so many countries especially those that have coal deposits. It is a major contributor of the power sectors of USA, China, South Africa, Australia to mention just a few. Nigeria has plentiful coal deposits but cannot meet its power needs presently because it has been depending solely on oil and hydro sources for its power needs. The gap between Nigeria's electricity demand and supply continues to widen, reinforcing the rising pace of economic and social development.

The integration of coal power generation in the Nigeria electricity mix will not only guarantee the steady and interruptible power supply that has eluded it for centuries, but will ensure security of energy supply, stability in

prices of electricity by removing unnecessary monopoly in the electricity sector and also ensure survival and continued operation of companies in the Nigerian environment while also attracting new ones. This will have a general multiplier effect of creating additional employment opportunities for the teeming unemployed youths while also setting the pace for the attainment and sustainability of growth and development of Nigeria economy.
The outcome of the economic evaluation of the selected SC PCC technology assuming 70% equity and 30% debt funding at a company tax rate of 32%, inflation rate of 12% and discount rate of 19.6% (WACC) is as follows;

- The project would cost $1.34 billion (2016 $) over the 5 years construction period and would generate a net present value of $1.13 billion over the thirty years of its economic life.
- The LGC of the electricity from the SC PCC Plant is estimated as 0.045 dollars per kWh at an internal rate of return of 20.8% which means the cost of the electricity supplied to the grid could be up by about 50% and still be within the limit set by Nigeria electricity regulation council (NERC) which is $0.07 per kWh.

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