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# Techno-Economic Analysis of Combined Cycle Power Plants for Electricity Generation in Nigeria

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## Abstract
*This paper presents a techno-economic approach to readily assess the profitability or otherwise of combined cycle power plants (CCPPs) for increased electricity production in Nigeria. As a case study for this analysis, a combined cycle gas turbine plant with 650MW installed capacity at Afam VI power station is used to evaluate the installation of a 1000MW and 1500MW CCPP economically. The results and analysis determined a Levelized cost of electricity of N41.57k/KWh and N34.09k/KWh for the 1500MW and 1000MW CCPP, respectively. It signifies an increase of 33.33% and 66.67% in the cost of electricity per kWh between the 1000MW and 1500MW plant capacities respectively, relative to the 650MW CCPP. Therefore, the low LCOE makes it economically viable to install the 1000MW CCPP for electricity production in the country. The paper also proposes upgrading existing gas-fired power plants in the country into combined cycle power plants for improved electricity supply.*

**Keywords:** Combined cycle, Capital cost, Electricity, Levelized cost, Production,

## 1.0 INTRODUCTION

Nigeria's quest to produce a stable electricity supply for her citizens has met many bottlenecks, thereby, her inability to meet the rising demands. It was opined [1] that, energy demand increases rapidly with the growing population and industrialization. The power demand in Nigeria grew at an estimated average annual rate of 15 - 20 % after the oil boom. It was explained [2] that, the Nigerian public electricity generating company -National Electric Power Authority (NEPA), was formed by the government's decree No. 24 of 1972, from the merger of the previous Electricity Corporation of Nigeria (ECN) and Niger Dams Authority (NDA). The decree gave NEPA the mandate to "maintain and coordinate an efficient economic system of electricity supply for all parts of the federation." Later, it was renamed and has existed as the Power Holding Company of Nigeria (PHCN), with 18 business units. The country had a total installed power generating capacity of 4000 MW, derived from hydro and thermal power plants [2]. The NEPA had eight electricity-generating stations throughout the country, as depicted in Table 1.

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***Table 1:*** *Nigeria's electricity generating stations and the installed capacities*

| S/No | Power Station | Installed Capacity (MW) | Year Commissioned |
|---|---|---|---|
| 1. | Ijora Thermal Power Station, Lagos | 60 | 1956 |
| 2. | Kainji Hydropower Station, Niger State | 760 | 1968 |
| 3. | Ogorode Thermal Power Station, Sapele, Delta State | 720 | 1978 |
| 4. | Afam Thermal Power Station, Afam | 776 | 1982 |
| 5. | Jebba Hydropower Station, Jebba | 540 | 1985 |
| 6. | Lagos Thermal Power Station, Egbin | 1320 | 1987 |
| 7. | Shiroro Hydropower Station, Shiroro, Minna, Niger State | 600 | 1990 |
| 8. | Delta V1 Thermal Power Station Ughelli, Delta State | 600 | 1991 |

Source[2]

It was stated [3] that, less than half of Nigeria's population presently has access to grid-connected electricity. They stated that the power supply in Nigeria averaged 3.1 GW in 2015, estimated to be about a third of the country's minimum demand. Nigeria has a per capita power consumption of only 151 kWh per year, being amongst the lower end of the spectrum in Africa. However, the estimated power generation statistics for 2019 showed that Nigeria's power stations generated 33,448,633 MWh of energy. The privatized GenCos generated 19,692,683 MWh, IPP GenCos generated 7,798,253 MWh, while the NIPP GenCos generated 5,957,697MWh. The Egbin power station recorded the highest energy generation with 3,786,313MWh, accounting for 11.32%. Alaoji NIPP recorded the lowest with 209,453MWh, accounting for 0.63% of total energy generated [4]. In 2009, the installed and available electrical capacities in the Nigerian generating stations are shown in Table 2. It showed that despite a total grid capacity of 6037.3MW, only 4732.4MW was available. Thus about 22% of the installed capacity was unavailable. It may be due to operational inadequacies and the inability of units to operate at full capacities of the generating stations and their respective percentage contributions to the total energy products [5].

*Table 2: Generating plants - grid stations as at 2009*

| Site | Type | Installed capacity [MW] | Available capacity [MW] | No. of units |
|---|---|---|---|---|
| Afam | Thermal | 776 | 488 | 20 |
| Delta | Thermal | 812 | 540 | 20 |
| Egbin | Thermal | 1320 | 1100 | 6 |
| Ijora* | Thermal | 66.7 | 40 | 3 |
| Sapele | Thermal | 1020 | 972 | 10 |
| Jebba | Hydro | 570 | 450 | 6 |
| Kainji | Hydro | 760 | 560 | 12 |
| Shiroro | Hydro | 600 | 600 | 6 |
| Calabar* | Thermal | 6.6 | 4.4 | 3 |
| Orji River* | Thermal | 60 | Nil | 4 |
| Others | Diesel | 46 | 18 | Nil |
| Total | | 6037.3 | 4732.4 | |

*Non-Operating Assets Source [5]

Recurrent power outages plague the power sector to the extent that some 90% of industrial customers and many residential and other non-residential customers provide their power at a massive cost to themselves and the Nigerian economy. Other multinational companies have resorted to relocating their manufacturing plants to neighbouring African countries where stable electric power is available.

Though Nigeria is blessed with abundant energy resources, it has not fully harnessed its energy potential for electricity generation to meet national demand. Her generation sources are predominantly hydro and gas-fired power plants, but she must seek more modern methods of generating electric power through more efficient, less fuel consumption, and affordable installation cost. The combined cycle power plant presents a viable option. It will result in significant megawatts of electricity production to the national grid within a specified period to meet the demand-supply gap. The global demand for Combined Cycle Power Plants (CCPP) is growing dramatically, with the expectations of geometric growth over the next decades [6]. CCPPs operate by superposing a high-temperature power plant as a topping unit to the steam plant resulting in a higher energy conversion efficiency from fuel to electricity.

The following types of CCPPs exist:

- Gas Turbine – Steam Turbine plant,
- Magneto-hydrodynamic (MHD) – Steam plant,
- Thermionic-Steam plant, and
- Thermoelectric-Steam plant[6].

Combined cycle power plants constitute the general types of power generation bases worldwide that can attain a thermal efficiency of about 60%. They have currently gained high reputation in the electric generation field largely due to higher efficiency and quicker response compared to the other types of power plants [7].They are therefore suitable for base loads and non-peak operations [8]. The CCPP is capable of flexible operations which stabilizes the grid frequency through reduced start-up times [9].The CCPP also considerably reduces emissions and energy consumption. It does not require modification of the existing gas turbine and the construction of the steam power plant will not interfere with the operation of the turbine, thus minimizing plant downtime and productive capacity losses [10].It is noteworthy that combined cycle power plants employing natural gas as fuel provide base and peak loads through gas turbines. They also boast of short facility construction times and the initial investment costs are relatively economical, [11], Bulut & ¨Ozcan, 2021. A CCPP typically consists of a gas turbine plant, a Heat Recovery Steam Generator (HRSG) and a steam turbine plant. The gas turbine plant operating on Brayton cycle and the steam turbine plant operating on Rankine cycle [12].

Nigeria is therefore, poised to increase electricity generation capacity in the short-term by expanding the existing hydropower plants and connecting steam turbines to the thermal plants, to convert the open gas-fired power plants to a combined cycle [13].The country currently operates two CCPPs, namely the Okpai/Kwale CCPP, and the Afam VI CCPP [14]. On the backdrop that the production of sufficient electric power is the key to sustainable national development, this paper focuses on presenting a concise techno-economic analysis of employing the Gas Turbine (GT)

Steam Turbine (ST) type of CCPP to improve Nigeria's electricity generation and heat production. The subsequent information would guide power plant stakeholders and policymakers in Nigeria, to make the right decisions in the choice and establishment of CCPPs.The study considered the existing AFAM VI CCPP as a case study. It is a 3 by 1-combined cycle plant (i.e. 150 MW Gas turbine power and 200 MW Steam turbine power). The thermal and economic models used in the analyses were executed in the Microsoft Excel software.

## 2.0 LITERATURE REVIEW

It was revealed [15] that, the power sector reform activity in 2005 led to the unbundling and renaming of the National Electric Power Authority (NEPA) to the Power Holding Company of Nigeria (PHCN). It resulted in an Act enabling private companies to participate in electricity generation, transmission, and distribution. The PHCN was unbundled into one transmission company (TCN), eleven electricity distribution companies (Discos), and six generating companies (GenCos). The Act also formed the Nigerian Electricity Regulatory Commission (NERC) as an autonomous regulator for the sector. The Federal Government has fully privatised the six GenCos and has sold 60% of its shares in the eleven (11) DisCos to private operators. However, the Transmission Company remains under government ownership [15].

### *2.1 Electricity Generating Plants in Nigeria*

Nigeria's power generation industry is driven by the privatized generation companies (GenCos), Independent Power Producers (IPP), and the generation stations under National Integrated Power Project (NIPP). The current combined installed generating capacity stands at 12,500MW, with about 74% of these generated by the gas-powered plants. The Hydropower station installed capacity is 1,900 MW; however, the available capacity is 1,350 MW [15]. The recent drive of the federal government through its power plan road map led to an upgrade to increase the generating capacity, as indicated in Table 3. The table depicts that Nigeria currently has twenty-three (23) thermal power plants, which are primarily gas-fired, and three hydropower plants in operation, with an additional three planned hydropower plants under construction.

***Table 3:*** *Current and Planned Power Plants in Nigeria and their Locations*

| Power station | Location | Type | Installed capacity (MW) | Year completed |
|---|---|---|---|---|
| AES Barge | Egbin | SCGT | 270 | 2001 |
| Aba | Aba, Abia State | SCGT | 140 | 2012 |
| Afam IV–V | Afam, Rivers State | SCGT | 726 | 1982 |
| Afam VI | Afam, Rivers State | CCGT | 624 | 2009 |
| Alaoji (NIPP) | Abia State | CCGT | 1074 | 2013 |
| Calabar (NIPP) | Cross River State | SCGT | 561 | 2014 |
| Egbema (NIPP) | Imo State | SCGT | 338 | 2013 |
| Egbin | Egbin | Gas-fired steam turbine | 1320 | 1986 |
| Geregu I | Geregu, Kogi State | SCGT | 414 | 2007 |
| Geregu II (NIPP) | Geregu, Kogi State | SCGT | 434 | 2013 |
| Ibom (IPP) | IkotAbasi | SCGT | 190 | 2009 |
| Ihorbor (NIPP) | Benin City | SCGT | 450 | 2013 |
| Okpai | Okpai | CCGT | 480 | 2005 |

| Power station | Location | Type | Installed capacity (MW) | Year completed |
|---|---|---|---|---|
| Olorunsogo I | Olorunsogo | CCGT | 336 | 2007 |
| Olorunsogo II | Olorunsogo | CCGT | 675 | 2012 |
| Omoku I | Omoku | SCGT | 150 | 2005 |
| Omoku II (NIPP) | Omoku | SCGT | 225 | 2013 |
| Omotosho I | Omotosho | SCGT | 336 | 2005 |
| Omotosho II (NIPP) | Omotosho | SCGT | 450 | 2012 |
| Sapele | Sapele | Gas-fired steam turbine | 1020 | 1981 |
| Sapele (NIPP) | Sapele | SCGT | 450 | 2012 |
| Ughelli | Delta State | SCGT | 900 | 1990 |
| Itobe | Kogi State | CFB Technology | 1200 | 2015–2018 |
| Kainji | Niger State | Hydro | 800 | 1968 |
| Jebba | Niger State | Hydro | 540 | 1985 |
| Shiroro | Kaduna State | Hydro | 600 | 1990 |
| Zamfara (Planned) | Zamfara State | Hydro | 100 | 2012 |
| Kano (Planned) | Tiga, Kano State | Hydro | 100 | 2015 |
| Kiri (Planned) | Kiri, Adamawa State | Hydro | 35 | 2016 |
| Mambilla (Planned) | Kakara, Taraba State | Hydro | 3050 | 2018 |

*Source* [16]

*NIPP*- National Integrated Power Project, *SCGT*- Single Combined Gas Turbine, *CCGT*- Combined Cycle Gas Turbine, *CFB* - Circulating Fluidized Bed

### *2.2 Combined Cycle Power Plants (CCPPs)*

It was related [17] that, Combined Cycle Power Plants (CCPPs) constitute the millennium part of fossil fuel power plants, with the gas turbine's centerpiece. A combined-cycle involves a combination of two thermal cycles in one plant to achieve higher efficiencies. The CCPP offers high thermal efficiency, low emissions, low installation cost, flexibility in fuel selection, and low operation and maintenance costs. CCPPs are also suitable for daily cycling operations due to their short start-up times and continuous base load operation. The control of the mass inlet flow using adjustable inlet vanes in the gas turbine leads to part-load efficiencies. The major disadvantage of CCPP is its complexity, and advancements in turbine technologies could take care of this disadvantage [17].

Typically, when two cycles are combined, the cycle operating at the higher temperature level is the topping cycle which produces waste heat used in a second process that operates at a lower temperature level called the bottoming cycle [18]. It was stated [19] that, CCPPs use a combination of two thermodynamic cycles combined for maximum efficiency, the Brayton combustion turbine topping cycle and the Rankine steam turbine bottoming cycle. The gas turbine cycle (Brayton cycle) operates in a high-temperature and the steam turbine cycle (Rankine cycle) in a low-temperature range by using steam production in a heat recovery steam generator (HRSG).Figure 1 explains the basic principle of operation of a CCPP; where Natural gas or liquid fuel burns in the combustion turbine (1) creating a constant pressure which spins a generator (2) producing electricity; the capture of the exhaust waste heat of the combustion turbine and mass flow in the Heat Recovery Steam Generator (HRSG) unit (3) that creates superheated steam to drive a steam turbine (4) that spins another generator (5) [19].

CCGT power plants exist in many different configurations. However, each gas turbine (GT) has its own associated HRSG, and multiple HRSGs supply steam to one or more steam turbines. The steam turbine matches the number and capacity of supplying GTs/HRSGs [19]. Reviewed [20] is the fact that, the exhaust gas of the gas turbine, which is at a temperature of about 550 to 600ºC, is used as a source to generate steam in a heat recovery steam generator (HRSG). The combined cycle shows higher thermal efficiency of about 55 to 60% compared to the thermal efficiency of about 35 to 40% produced from conventional thermal plants. It was related [21] that, the availability of gas turbine output of 100 – 350MW had made large combined cycle power plants a significant factor in thermal power generation.

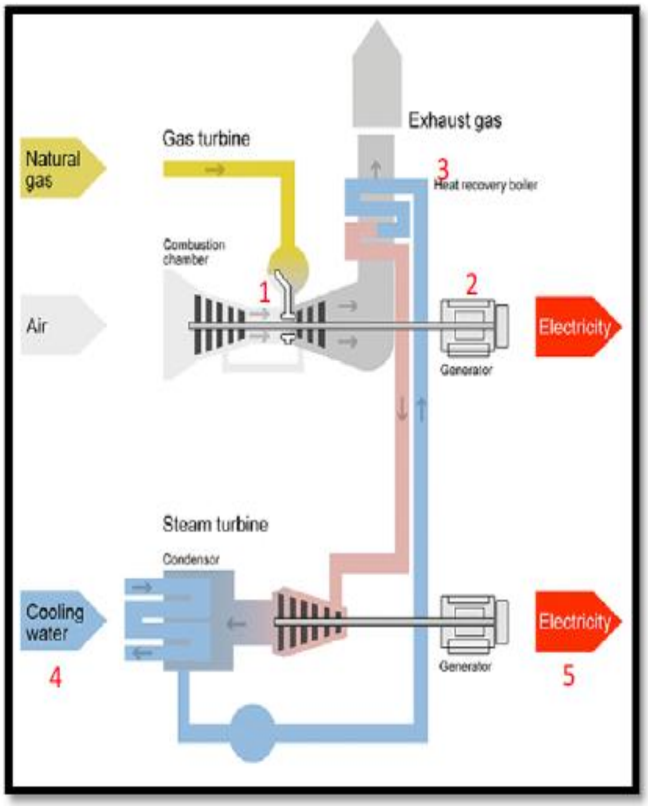


**Figure 1:** The basic principles of operation of a typical CCPP. (Source[19])

The total dependence on imported fuel resulted in Japan being the first large-scale user of combined cycles building several 2000MW stations. Large-scale combined cycle plants with up to 2000MW installations in many countries, including Korea, Malaysia, Hong Kong, Singapore, Argentina, and the USA, with thermal efficiencies above 55% [21]. The power plants in Nigeria employing CCPP technologies are the Alaoji Power station (partially operational), Okpaipower station (operational), and Olorunsogo II power station (partially Operational), with installed capacities of 225MW, 480 MW, and 675 MW, respectively [22].

## 3.0 METHODOLOGY

The techno-economic model is presented in this section to assess the economic and technical profitability of a combined cycle power plant for electricity production. The techno-economic analysis of the CCPP used the spreadsheet to consider the cost components of the plant, and the economic appraisal used the net present value approach. The Afam VI power plant constructed in October 2008 is a case study. It is a CCPP with three gas turbine modules generating over 400 MW to the grid via the open cycle phase. A steam turbine module generates 200MW of electricity, attaining a generation capacity of 624 MW through the complete combined-cycle phase [23].

### *3.1 Process Design*

The process design modelled the 650 MW Combined Cycle Power Plant employed in the Afam VI power station. The plant consists of three GT13E2 150 MW gas turbine plant, which is natural gas-fired, and a single ST-1 200 MW steam turbine. Figure 2 shows the model schematic diagram showing the combined cycle power plant process, illustrating the heat recovery steam generators. They consist of an economizer, a boiler, and a super heater.

### *3.2 Equipment sizing*

This section estimates the sizing parameters for each piece of equipment that correlate with cost. The parameters are summarized in the Table 4.

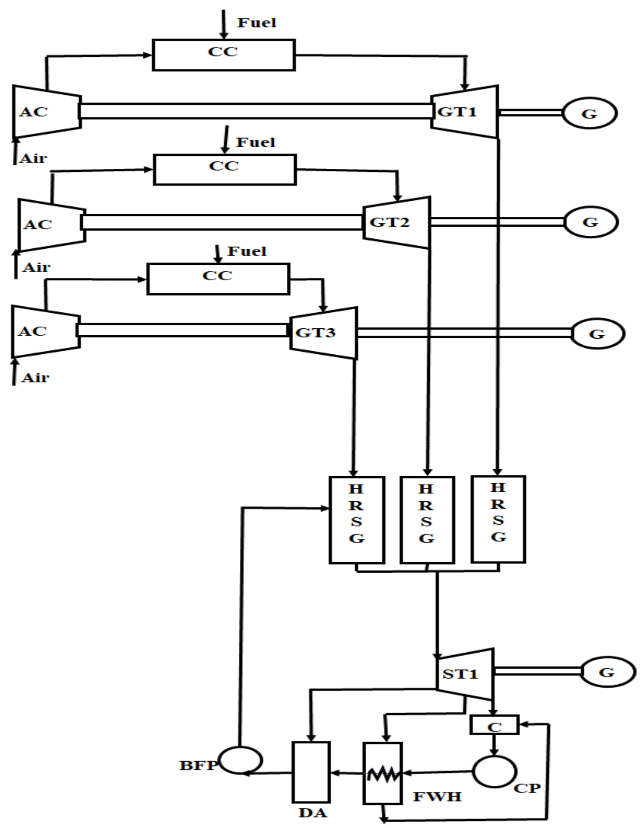


**Figure 2:** Model schematic diagram of the process flow of the CCPP at Afam VI power station

Note: AC- Air Compressor, CC- Combustion Chamber, GT- Gas Turbine, G- Electric generator, HRSG- Heat recovery steam generator, ST- Steam turbine, C- Condenser, CP- Centrifugal pump, FWH- Feed water heater, DA- Deaerator, BFP- Boiler feed pump

***Table 4:** Equipmentsizing showing main components of the plant*

| S | Type | Size(MW) | Number | Unit cost($) | Cost($) |
|---|---|---|---|---|---|
| | | Gas Turbine Module | | | |
| Gas Turbine Engine | GT13E2 | 150 | 3 | 90m | 270m |
| | | Steam Turbine Module | | | |
| Steam Turbine | ST-1 | 200 | 1 | 1m | 1m |

### *3.3 Capital cost*

The capital cost of a combined cycle power plant involves the financing required to design, purchase, build, install, and start up its equipment, auxiliary facilities, and infrastructure. The capital cost could be estimated through three methods: the exponent estimate, the factorial estimate, and the functional unit estimate methods [24]. The exponent estimate (Power Law) method is used to estimate the capital cost in this study. It uses the known cost of existing pieces of equipment and the ratio of the equipment capacities raised to the sixth-tenth exponent. The exponent estimate is given by Equation (1) [24].

$$\text{(Capital cost of New plant)} = \left(\frac{\text{Capacity of new plant}}{\text{Capacity of old plant}}\right)^{n} \times \text{(Capital cost of old plant)} \qquad (1)$$

Where n is the value of the exponent and is between 0.5 and 1.0.

### *3.4 Cash flow analysis*

This section involves a discounted cash flow analysis to compute metrics like net present value (NPV) and internal rate of return (IRR). The net present value concept influences the interest on funds spent in the future, and it represents the sum of money at present, which through compound interest, would, in the future, have a specific value [6]. The present worth value is given by Equation (2).

$$PW = \frac{S}{(1+i)^N} \qquad (2)$$

Where PW is the present worth, S is the annual capital cost, N is the number of payment years and *i* is the interest rate.

Note: the present worth factor = $\frac{1}{(1+i)^N}$

### *3.5 Levelized Annual cost*

Power plants could incur non-uniform costs that vary from year to year. Hence, it is necessary to levelize non-uniform costs. Levelization transforms a series of non-uniform costs into a uniform series; therefore, based on Levelized cost comparisons, economically correct decisions may be made. Each uniform payment is called the Levelized annual cost or the equivalent uniform annual cost. Levelized annual costs are determined using Equation (3) [25].

$$\text{Levelized annual cost} = \frac{\text{Total Present worth of all annual cost}}{\text{Sum of Present worth factor}} \qquad (3)$$

Therefore the levelized cost of electricity (LCOE) used for comparative evaluation is computed using Equation (4) [26].

$$LCOE = \frac{\text{Levelized Annual Cost}}{\text{Annual amount of electricity produced}} \qquad (4)$$

The annual amount of electricity produced is given by Equation (5).

$$\mathrm{kWh_{net}} = \mathrm{kW_{inst}} \times 8760 \times \left(1 - \frac{\mathrm{L_{aux}}}{100}\right) \times \mathrm{n} \qquad (5)$$

Where $kW_{inst}$ is the rated installed generators output; $L_{aux}$ is the power consumed by the auxiliaries; and n is the plant capacity factor[6].

## 4.0 RESULTS AND DISCUSSION

The results obtained from the spreadsheet models are presented in this section. The result of the economic assessment of installing a 650 MW, 1000 MW and 1500 MW combined cycle power plants for electricity production are compared. At the time of this study, the exchange rate was $1 to N415.68k.

### *4.1 Capital cost estimation*

The calculated annual capital cost from the equipment sizing module was used to compute the capital cost for combined cycle power plants of 1000 MW and 1500 MW capacities of electricity referenced to the capacity of the Afam VI CCPP. The capital cost of the 650 MW Afam VI CCPP is valued at N112.7bn ($271m). It is on this basis that the capital cost of the 1500 MW capacity CCPP was computed at N186.1bn ($447.6m), while that of the 1000

MW capacity CCPP is about N145.8bn ($350.9m), as shown in Table 5.

***Table 5:*** *Capital cost estimation of 1500 MW and 1000MW Combined cycle power plants*

| S/NO | PARAMETER | VALUE |
|---|---|---|
| 1. | Capacity of old plant | 650 MW |
| 2. | Capacity of new plant (1) | 1500 MW |
| 3. | Capacity of new plant (2) | 1000MW |
| 4. | Capital cost of old plant | $271000000 |
| 5. | Power law exponent | 0.6 |
| 6. | Capital cost of new plant (1) | $447585524 |
| 7. | Capital cost of new plant (2) | $350930630.70 |

### *4.2* Net present worth value (NPWV)

The capital cost estimates is used to determine the net present worth value (NPWV) of a new CCPP, and it is referenced as the principal amount for payment. The NPWV of the 1000 MW and 1500 MW CCPP are compared to that of the 650 MW Afam VI CCPP. The NPWV of the 1000MW CCPP for a 25 years period is N1.32trillion ($3.19bn), while that of the 1500 MW combined cycle power plant for the same period is N1.7trillion ($4.06bn), compared to the NPWV of N1.02 trillion ($2.46bn) for the 650 MW CCPP as shown in Table 6. This implies an increase in the NPWV for the 1000 MW and 1500 MW CCPP of 30% and 65% respectively.

***Table 6:*** *Net present worth value for a 25 year period*

| Number of years (N) | Present Worth Factor | Present Annual Worth ($) (650 MW) | Present Annual Worth ($) (1000MW) | Present Annual Worth ($) (1500MW) |
|---|---|---|---|---|
| 1 | 0.9091 | 246363636.36 | 319027846.07 | 406895931.26 |
| 2 | 0.8264 | 223966942.15 | 290025314.61 | 369905392.05 |
| 3 | 0.7513 | 203606311.04 | 263659376.92 | 336277629.14 |
| 4 | 0.6830 | 185096646.40 | 239690342.65 | 305706935.58 |
| 5 | 0.6209 | 168269678.55 | 217900311.50 | 277915395.98 |
| 6 | 0.5645 | 152972435.04 | 198091192.27 | 252650359.99 |
| 7 | 0.5132 | 139065850.04 | 180082902.07 | 229682145.44 |
| 8 | 0.4665 | 126423500.04 | 163711729.15 | 208801950.40 |
| 9 | 0.4241 | 114930454.58 | 148828844.68 | 189819954.91 |
| 10 | 0.3855 | 104482231.44 | 135298949.71 | 172563595.37 |
| 11 | 0.3505 | 94983846.76 | 122999045.19 | 156875995.79 |
| 12 | 0.3186 | 86348951.60 | 111817313.81 | 142614541.63 |
| 13 | 0.2897 | 78499046.91 | 101652103.47 | 129649583.30 |
| 14 | 0.2633 | 71362769.92 | 92411003.15 | 117863257.55 |
| 15 | 0.2394 | 64875245.38 | 84010002.86 | 107148415.95 |
| 16 | 0.2176 | 58977495.80 | 76372729.88 | 97407650.86 |
| 17 | 0.1978 | 53615905.27 | 69429754.43 | 88552409.88 |
| 18 | 0.1799 | 48741732.07 | 63117958.58 | 80502190.80 |
| 19 | 0.1635 | 44310665.51 | 57379962.34 | 73183809.82 |
| 20 | 0.1486 | 40282423.19 | 52163602.13 | 66530736.20 |
| 21 | 0.1351 | 36620384.72 | 47421456.48 | 60482487.45 |
| 22 | 0.1228 | 33291258.84 | 43110414.98 | 54984079.50 |
| 23 | 0.1117 | 30264780.76 | 39191286.35 | 49985526.82 |
| 24 | 0.1015 | 27513437.06 | 35628442.13 | 45441388.02 |
| 25 | 0.0923 | 25012215.51 | 32389492.85 | 41310352.74 |
| TOTAL | 9.0770 | 2,459,877,845 | 3,185,411,378.28 | 4,062,751,716.43 |

***Table 7:*** *Annual Electricity Production Parameters*

| Parameter | Symbol | Value | Unit |
|---|---|---|---|
| Current Installed Output | $KW_{inst}$ | 6.50 x $10^5$ | KW |
| New Installed Output (1) | $kW_{inst}$ | 1.50 x $10^6$ | KW |
| New Installed Output (2) | $KW_{inst}$ | 1.00 x $10^6$ | KW |
| Auxiliary power consumed | $L_{aux}$ | 25 | % |
| Existing Plant capacity factor | N | 1 | |
| Plant capacity factor (1) | n | 0.43 | |
| Plant capacity factor (2) | n | 0.65 | |

### *4.3 Levelized Annual cost*

The Levelized annual Cost (LAC) is the economic assessment of the cost of electrical energy from a power plant produced annually over a specified period obtained from the net present worth value. The LAC for the 650 MW CCPP was computed to be N112.65bn ($271m). Therefore, the LAC for a 1500 MW combined cycle power plant amounts to N186.1bn ($447.6m) implying a 65% increase, while the LAC obtained for the 1000MW CCPP is N145.8bn ($350.9m) implying an increase of 29.5%. It is essential to determine the Levelized cost of electricity (LCOE) to compare the different plants under evaluation. LCOE is the ratio of levelized annual cost to the annual electricity produced. The parameters used for the computation of the annual electricity production are in Table 7.

Comparative analysis showed that the net annual electricity produced in KWhby the 1500 MW plant (with capacity factor of 0.43), the 1000 MW plant (with capacity factor of 0.65) and the 650 MW plant (with capacity factor of 1.00) are relatively the same at 4,270,500,000 kWhnet. Therefore, the LCOE for the 1500MW CCPP amounts to N41.57k/kWh (10 cents/kWh), the LCOE for the 1000MW CCPP amounts to N34.09k/kWh (8 cents/KWh), and the LCOE for the 650MW CCPP amounts to N24.94k/KWh (6 cents/KWh). It signifies an increase of 33.33% and 66.67% in the cost of electricity per kWh between the 1000MW and 1500MW plant capacities respectively, relative to the 650MW CCPP. The annual amount of electricity produced by the 650MW and 1000MW within 25 years showed no variance and are relatively the same, as shown in Figure 3.

However, a slight variance of 0.77% was observed between the 1500MW and the 650MW CCPP. Thus, installing the 1000MW CCPP for electricity production would be economically viable. However, the marginal difference of 0.77% in the LCOE for the 1500MW makes it a cost effective solution for increased electricity generation.

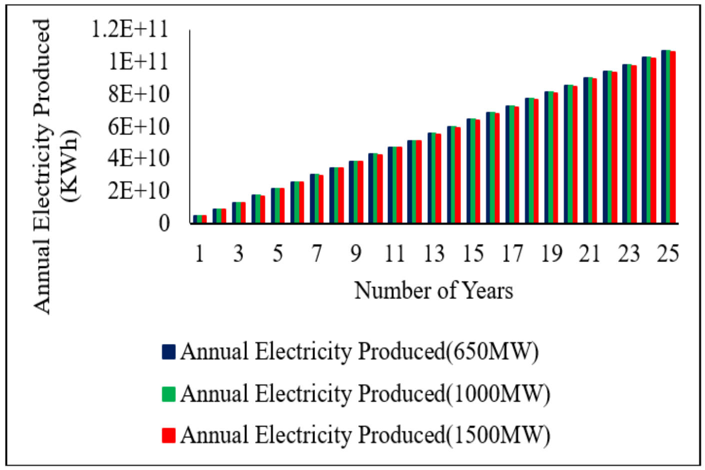


**Figure 3:** Annual electricity production for 650MW, 1000MW and 1500MW CCPP for 25 years period.

## 5.0 CONCLUSION

A techno-economic assessment of employing the combined cycle power plants (CCPPs) for increased electricity production is presented in this paper. The spreadsheet method was used to quickly evaluate the economic implications of setting up two CCPPs of 1500MW and 1000MW capacities relative to the existing 650MWfor electricity production. The results would guide selecting a CCPP that gives the minimum investment cost. The net present worth of the 1000MW CCPP for 25 years is N1.32trillion ($3.19bn), and that of a 1500 MW CCPP for the same period is N1.7trillion ($4.06bn). It yielded the levelized annual cost for the 1500 MW combined cycle power plant of N186.1bn ($447.6m) and the levelized annual cost for the 1000MW CCPP of N145.8bn ($350.9m). It translated to a levelized cost of N41.57k/KWh (10 cents/KWh) and N34.09k/KWh (8 cents/KWh) for the 1500MW and 1000MW CCPP, respectively. It signifies an increase of 33.33% and 66.67% in the cost of electricity per kWh between the 1000MW and 1500MW plant capacities respectively, relative to the 650MW CCPP. Therefore, the low LCOE makes it economically viable to install the

1000MW CCPP for electricity production in the country. However, the marginal difference in the LCOE for the 1500MW makes it a cost effective solution for increased electricity generation.

## 6.0 RECOMMENDATIONS

For a sustainable economy by the year 2050, the paper makes the following recommendations:

1. The Federal government should begin constructing modern combined cycle power plants with large generating capacities as base load plants and encourage private partners to invest in this technology area to increase our electricity generation.
2. Existing gas power plants which constitute the mainstream of our thermal power plants, should be upgraded, where possible, into Combined Cycle Power plants (CCPPs) to increase the current electricity production output.
3. Where feasible, the government should also encourage the development of Integrated Gasified Combined Cycle (IGCC) power plants from coal to maximize the full potential of her coal deposit in electricity generation.
4. There should be complete monitoring of projects in the power sector to improve and strengthen the governance structure to enhance accountability and minimize corruption.

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