REAL COST COMPARATIVE ECONOMIC ANALYSIS OF NATURAL GAS-FIRED AND HYDRO-ELECTRIC POWER PLANTS IN NIGERIA

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ABSTRACT

In this study, a comparative economic-analysis of a natural-gas fired and a hydro-electric power-plants in Nigeria was done based on the real electricity cost model. This was done using levelised electricity costs and cost of pollution for each plant. Plant technical and financial parameters for each power-plant were then inputted into Excel models in other to generate net present values for each combination of plant capacity and electricity price. The profitability indices for each plant was also calculated. Plots of net present values were generated for each power-plant at different plant capacities and electricity prices. This was done in other to understand sensitivity of NPV of each plant to plant capacity and electricity price. From these plots, the break even electricity price and plant capacity for power-plant were ascertained. Results obtained reveal that the economics of both gas-fired and hydropower generating plants in Nigeria are highly dependent on electricity price and plant capacity. Precisely, for a CCGT gas-fired power-plant in Nigeria of plant capacities 200,400 and 600 MW, the break even prices are \$186.06, \$120.78, and \$101.19 respectively. And for reservoir type hydropower plant in Nigeria of plant capacities 200,400 and 600 MW, the break even prices are \$249.71, \$124.04 and \$86.50 respectively. In addition, at \$65.28, \$114.25 and \$163.21 per MWh (corresponding to 20, 35 and 50 Naira per kWh respectively) electricity prices, the break even plant capacities for a CCGT gas-fired power-plant in Nigeria are 625, 450, and 245 MW respectively. Also, at the same electricity prices, the break even plant capacities for a reservoir hydropower plant in Nigeria are 800, 450, 320 MW respectively. It was also deduced that natural gas-fired plants are economically-viable at lower plant capacities and electricity prices, while hydropower plants are economically-viable at higher plant capacities and electricity prices.

Keywords: Natural gas, hydropower, power plant, real cost, green energy.

INTRODUCTION

Electricity is most valuable energy source in today's modern world. Some researchers have said that it is electricity produced globally that adds modernity effects to the world as we know it. Since, many gadgets and facilities that people depend on to power the present technological and digital age cannot function without electricity from one source or another. Currently, different electricity-sources include solar, gas plants, hydropower plants, windmills, nuclear power-plants, etc.

However, among these electricity-sources, greener sources are generally preferable than others. This is because these sources are less harmful to the environment and therefore more sustainable. In fact, different countries have set targets to reduce the amount of electricity generated from fossil fuels and other sources like nuclear plants. These countries now favour hydro-electric power because of its numerous benefits like irrigation and bridge construction opportunities. Also, World Bank's current corporate policy stipulates that the bank would no longer sponsor power-plants that are not gas-fired. This scenario presents a kind of dilemma for countries with substantial gas resources and hydro-electric power potentials.

Table 1: Top ten countries by hydro-electric power installed capacity and their generation share in 2010 (IHA, 2012)

Country	Installed capacity (GW)	Country	Hydropower share of total generation (%)
China	210	Norway	99
Brazil	84	Brazil	84
USA	79	Venezuela	74
Canada	74	Canada	59
Russia	50	Sweden	49
India	38	Russia	19
Norway	30	India	18
Japan	28	China	16
France	21	Italy	14
Italy	20	France	8
Rest of World	302	Rest of World	14
World	936	World	16

Table 2: Some existing and proposed hydro-electric power-plants in Nigeria

Power Station	Capacity (MW)	Status
Kainji	760	Operational
Jebba	540	Operational
Shiroro	600	Operational
Zungeru project	700	Proposed
Mambilla project	3,050	Proposed
Gurara II project	360	Proposed
Gurara I project	30	Proposed
Itisi project	40	Proposed
Kashimbilla project	40	Proposed

Nigeria has a gas reserve of over 190 trillion cubic feet, and there exists huge hydropower potentials. Nigeria is blessed with substantial hydropower potentials, including the Mambilla plateau hydropower project with over 2,000 MW capacity. Similarly, the country is blessed with huge gas-reserves, but inadequate power remains a perennial problem in the country. Here, these two sources of electric power will be compared in other to determine the cost effective option.

In spite of these natural resources in Nigeria, the country still faces power outages regularly. In trying to solve the perennial power problem, different sources of electricity has been planned for power generation including hydropower and gas power-plants. Nigeria has recently been developing more of gas plants in recent years despite the huge environmental plus economic benefits of hydropower. It is imperative that these two sources of electricity are compared to ascertain which option gives higher real benefits.

Unit cost of electricity is usually derived from many components, including expenditures on key components, associated power production and delivery costs. These are generally divided into both present and future costs that are normally discounted to arrive at final values. Considering how complex power value chains can be, it can be quite challenging incorporating all cost components. This is usually the case when it comes to futuristic costs as any mistakes might seriously affect project economics. Two main types of strategies frequently adopted in presenting future costs include capital cost estimation and levelised electricity-cost (Breeze, 2010).

The capital cost model only considers the capital costs of the various power generating options. And based on that, a considerable decision can be arrived at using this approach. While levelised cost model entails getting the cumulative cost of combined discounted installation and operating costs divided by the total power produced over the plant's lifetime. This type of costing is frequently favoured by large utility companies, as it gives a better cost estimate provided that all relevant cost components are incorporated. But these two models usually ignore any associated environmental costs that might be cured. Therefore, they still do not give the best estimate of the true cost of electricity.

The real cost does not only consider capital and operating, but also incorporates the any associated cost of pollution, climate change costs and resource depletion. This in turn gives a better idea of the true electricity-costs. This is because apart from the obvious climate change costs, some resources employed are non-reneweable. Hence, depleting the resources today comes with futuristic costs that should be considered. Therefore, basing decisions only on operating plus capital costs might be misleading. Since some power generating options might have low initial capital costs, but high environmental costs (Orcutt, 2018).

Figure 1: A natural gas fired power-plant (WKUPR, 2019)

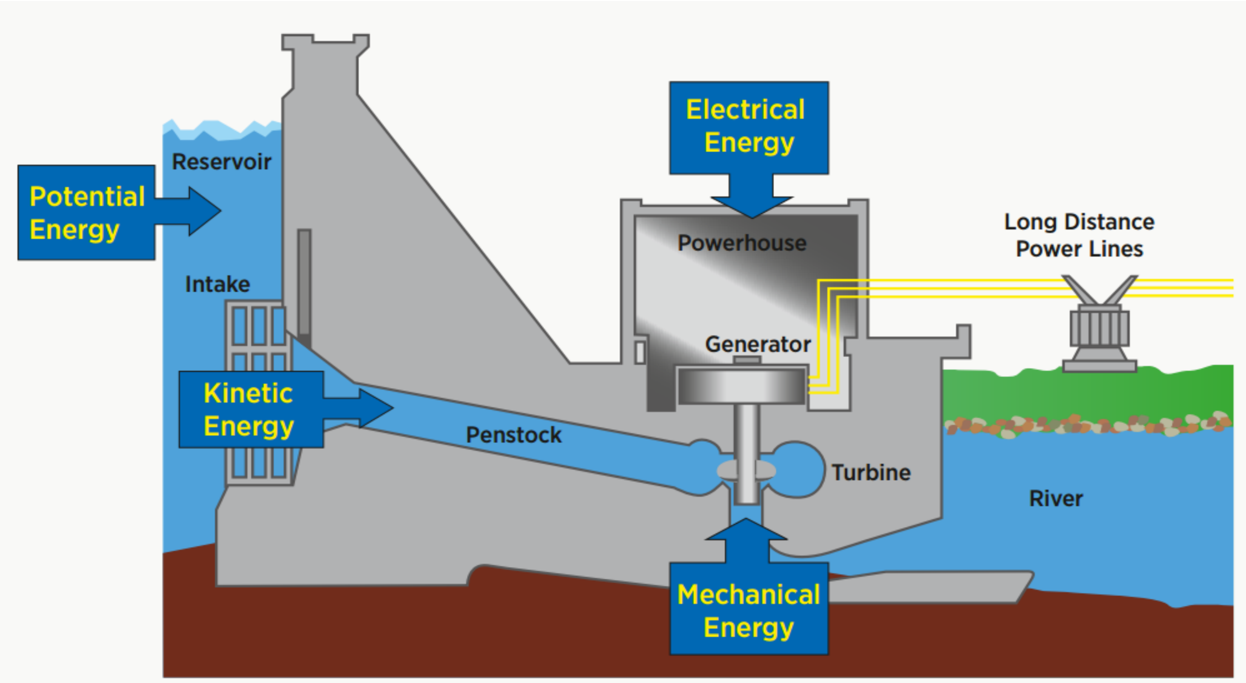

Figure 2: Typical low head hydropower plant with storage (SolaPV, n.d.)

METHODOLOGY

For this study, a comparative economic-analysis of a natural-gas fired and a hydro-electric power-plants in Nigeria was done based on real electricity cost model. It was accomplished using the levelised electricity costs approach of Adamu (2016) and average cost of pollution for each plant. Plant technical and financial parameters for each power-plant (Tables A1-A2) were inputted into Excel models in other to generate NPVs for each combination of plant capacity and electricity price. The profitability indices for each plant were then calculated. Plots of NPVs were generated for each power-plant at different plant capacities and electricity prices. This was done in other to understand the sensitivity of NPV of each plant to plant capacity and electricity price. From these plots, the break even electricity price and plant capacity for power-plant were then ascertained.

For price of electricity, average price in Nigeria was used. According to the Nigeria electricity regulatory commission (NERC), the electricity distribution companies charge electricity bills are based on the category of customer because every electricity customer belongs to a specific tariff class. Five (5) major tariff classes are available, which includes residential, commercial, industrial, special and street lighting. However, according to Abuja Electricity Distribution Company (AEDC), the average price of electricity is N35/kWh, which translates to N35,000/MWh. Converting the electricity price per MWh using the Central Bank of Nigeria's pre-covid naira to US dollar exchange of N306.35 per dollar, the electricity price becomes $114.25/MWh. This represents best estimate of the effective exchange rate that excludes the globally-felt effects of the covid-19 pandemic. This price was used in calculating annual sales revenue for the gas-fired and hydropower plants.

Also, total-cost of pollution attributed to each power-plant was based on reported price of pollution per MWh. The values to be used here were taken from a recent study released by the European Union (EU). According to Mike Orcutt of Massachusetts Institute of Technology (MIT) technology review, the study was commissioned by the E.U. and conducted by Ecofys, a renewable energy consultancy. The study considered the economic costs of climate-change, pollution, and resource depletion as well as the current capital and operating costs of the power-plants (Orcutt, 2018).

Based on the aforementioned study, price of pollution for a natural-gas fired power-plant and a reservoir hydropower plant are about €34/MWh and €2/MWh respectively. Using a Euro US dollar exchange rate of $1.14 for €1, price of pollution in US dollars are $38.76 and $2.28 for gas and hydropower plants respectively. These values were multiplied with the annual power output values in MWh for each plant to calculate total cost of pollution for each plant. However, total costs of pollution were not included in the calculations for annual net tax payable.

RESULTS

Table 3: Variation of electricity price and NPV at different plant capacities for natural gas and hydro-electric power-plants

Power plant	Price (Naira/kWh)	Price ($/MWh)	NPV ($) 200 MW	400 MW	600 MW
Natural gas	20	65.28	-21,717,679,890	-19,967,205,411	-18,216,730,933
	35	114.25	-13,071,832,571	-2,675,510,774	7,720,811,023
	50	163.21	-4,425,985,252	14,616,183,863	33,658,352,978
Hydro-electric	20	65.28	-26,790,030,952	-17,848,048,877	-8,906,066,802
	35	114.25	-19,731,379,184	-3,730,745,340	12,269,888,505
	50	163.21	-12,672,727,415	10,386,558,198	33,445,843,811

Table 4: Summary of profitability indices for natural gas and hydro-electric power-plants.

Profitability index	Natural gas power-plant	Hydro-electric power-plant
Initial capital ($)	480,000,000	1,174,400,000
NPV ($)	-2,675,510,774	-3,730,745,340
IRR (%)	8.21	9.59
Payback period (years)	17.49	13.84

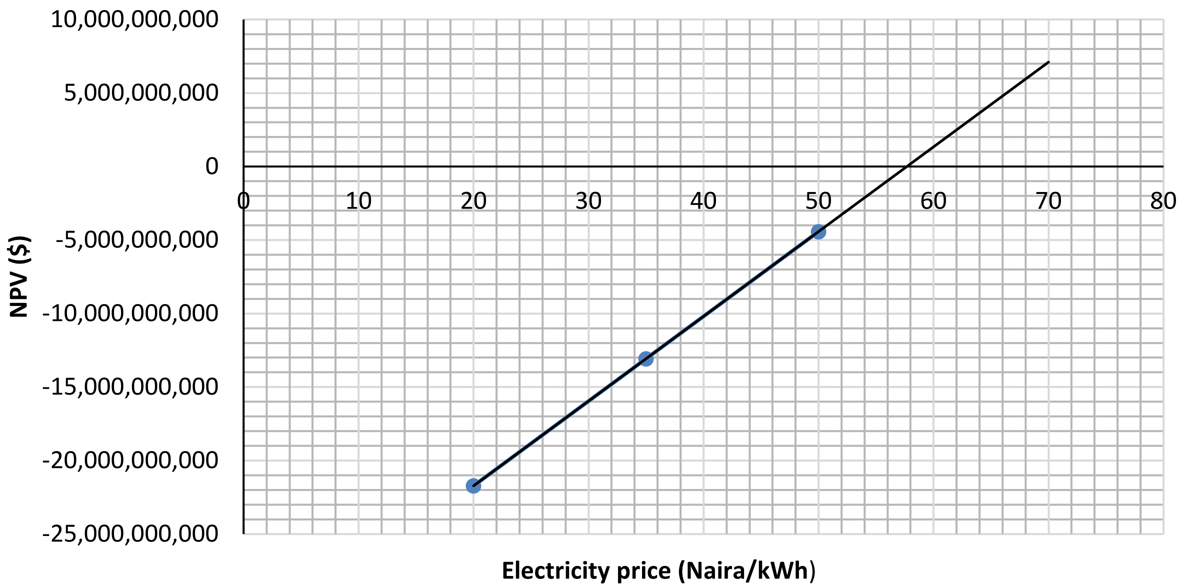

Figure 3: Variation of NPV with electricity price for a 200 MW natural gas power-plant

ISSN 2056-5860

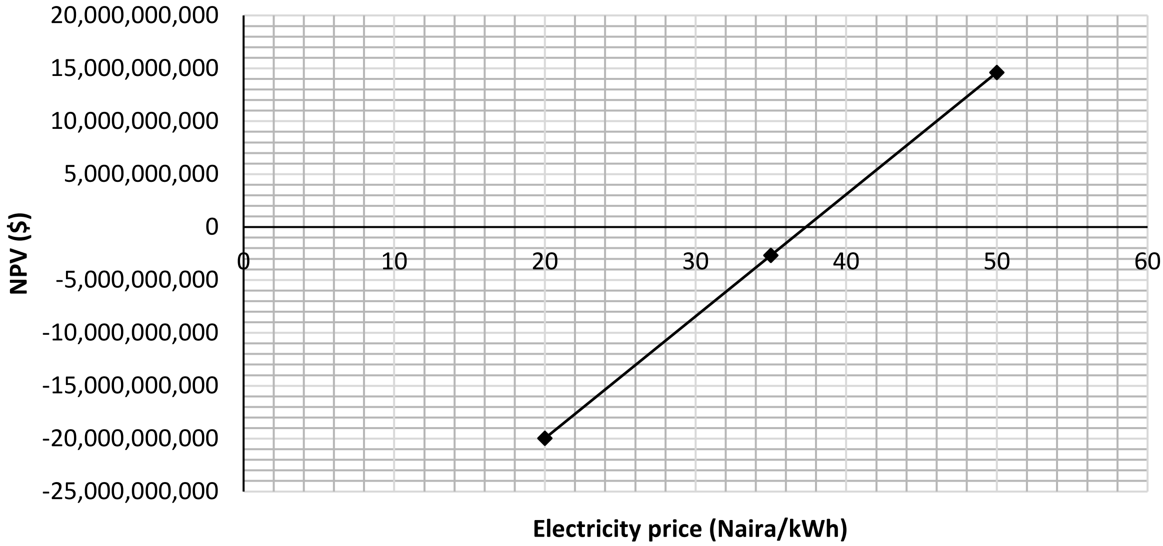

Figure 4: Variation of NPV with electricity price for a 400 MW natural gas power-plant

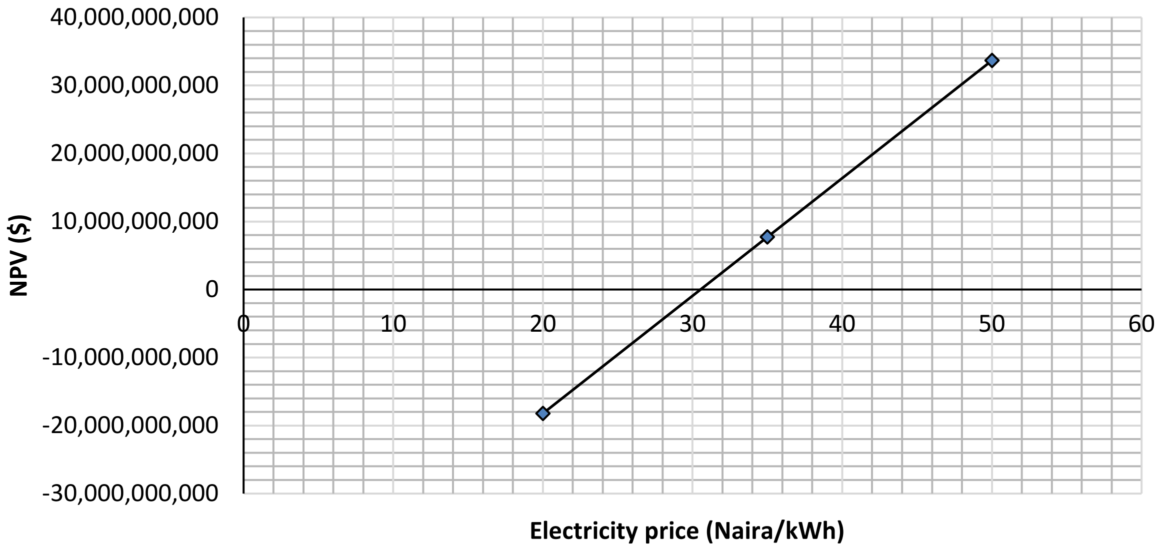

Figure 5: Variation of NPV with electricity price for a 600 MW natural gas power-plant

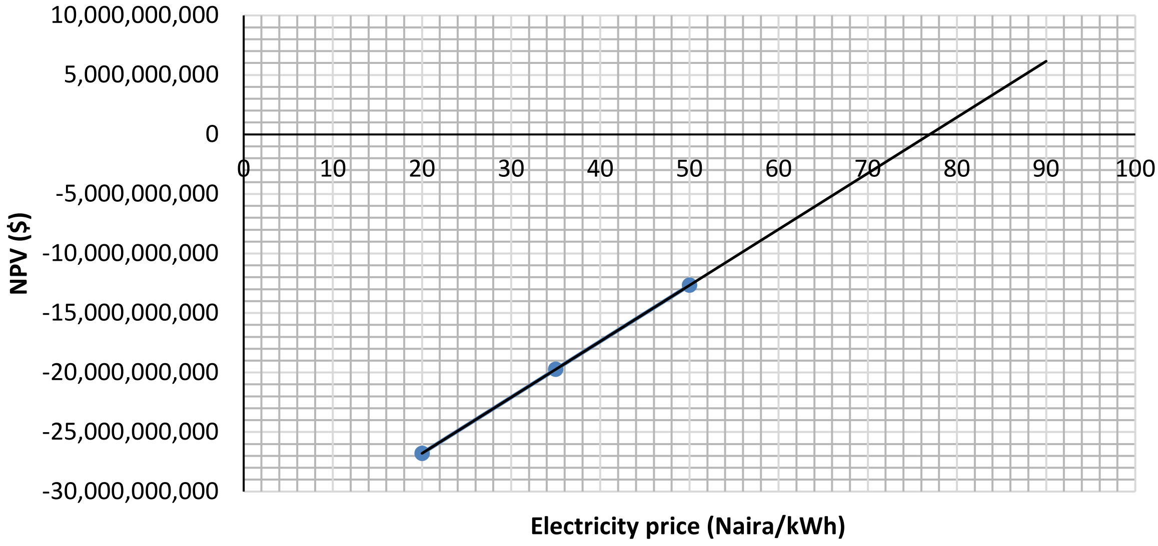

Figure 6: Variation of NPV with electricity price for a 200 MW hydro-electric power-plant

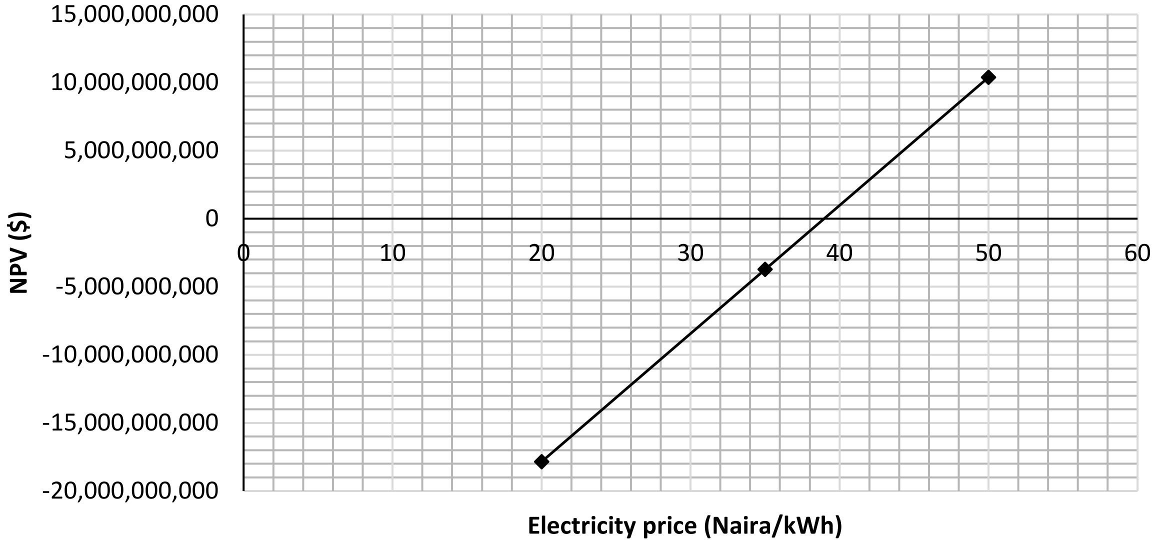

Figure 7: Variation of NPV with electricity price for a 400 MW hydro-electric power-plant

Figure 8: Variation of NPV with electricity price for a 600 MW hydro-electric power-plant

Table 5: Break even prices at different plant capacities for natural gas and hydro-electric power-plants

Power plant	Plant capacity (MW)	Break-even price ($/MWh)	Break-even price (Naira/kWh)
Natural gas	200	186.06	57.0
	400	120.78	37.0
	600	101.19	31.0
Hydro-electric	200	249.71	76.5
	400	124.04	38.0
	600	86.500	26.5

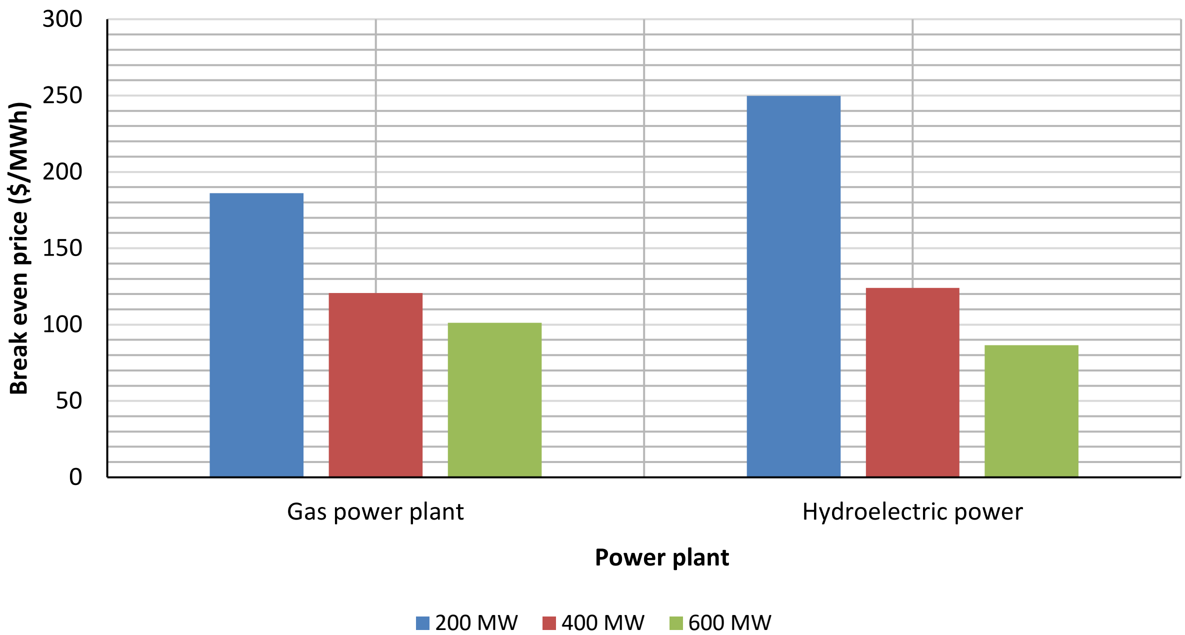

Figure 9: Break even prices at different plant capacities for natural gas and hydro-electric power-plants

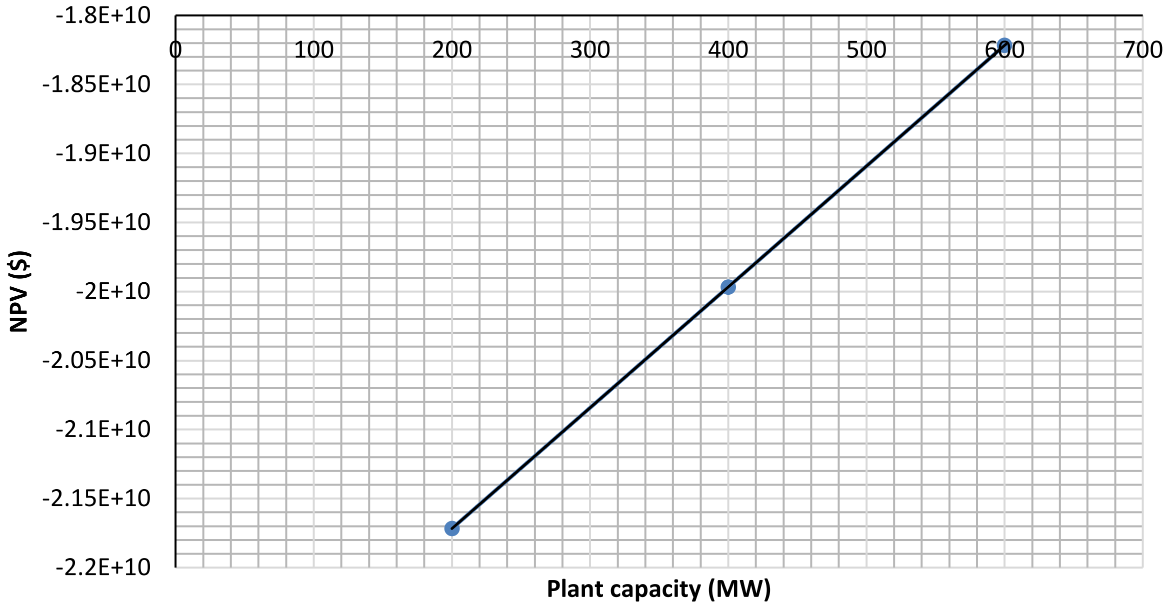

Figure 10: Variation NPV with plant capacities for a natural gas power-plant at $65.28/MWh

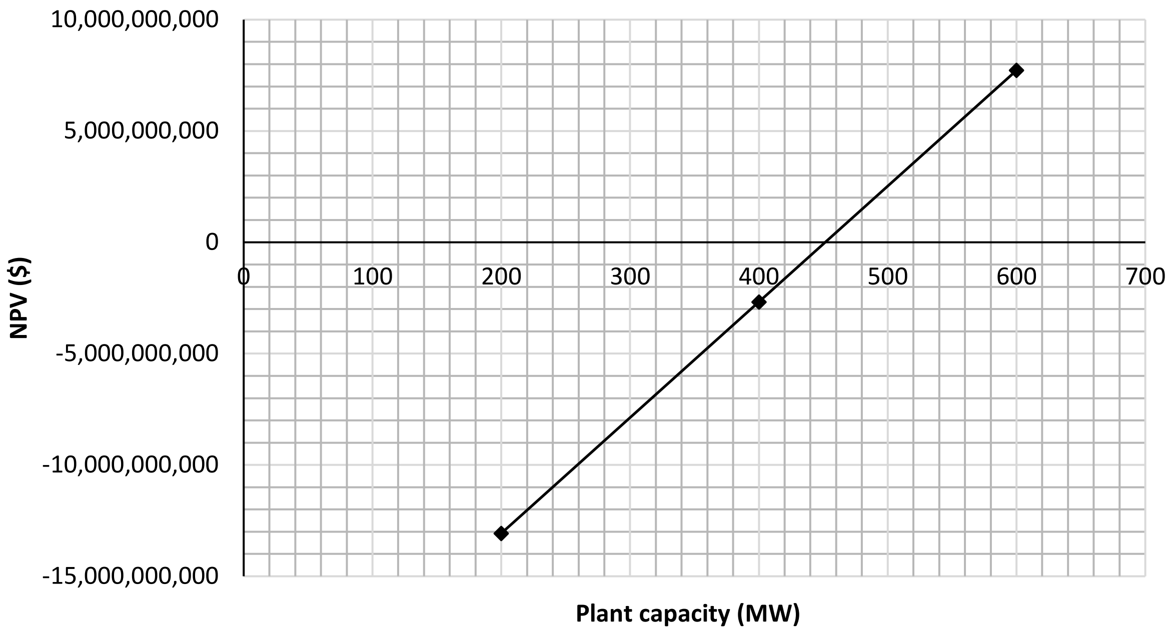

Figure 11: Variation NPV with plant capacities for a natural gas power-plant at $114.25/MWh

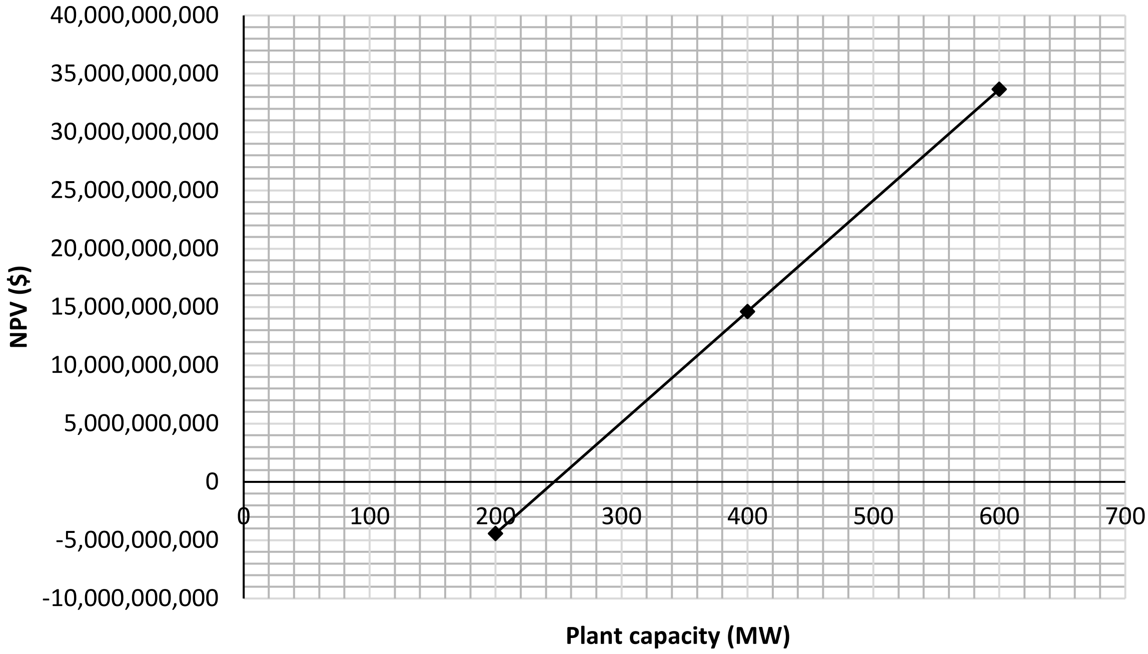

Figure 12: Variation NPV with plant capacities for a natural gas power-plant at $163.21/MWh

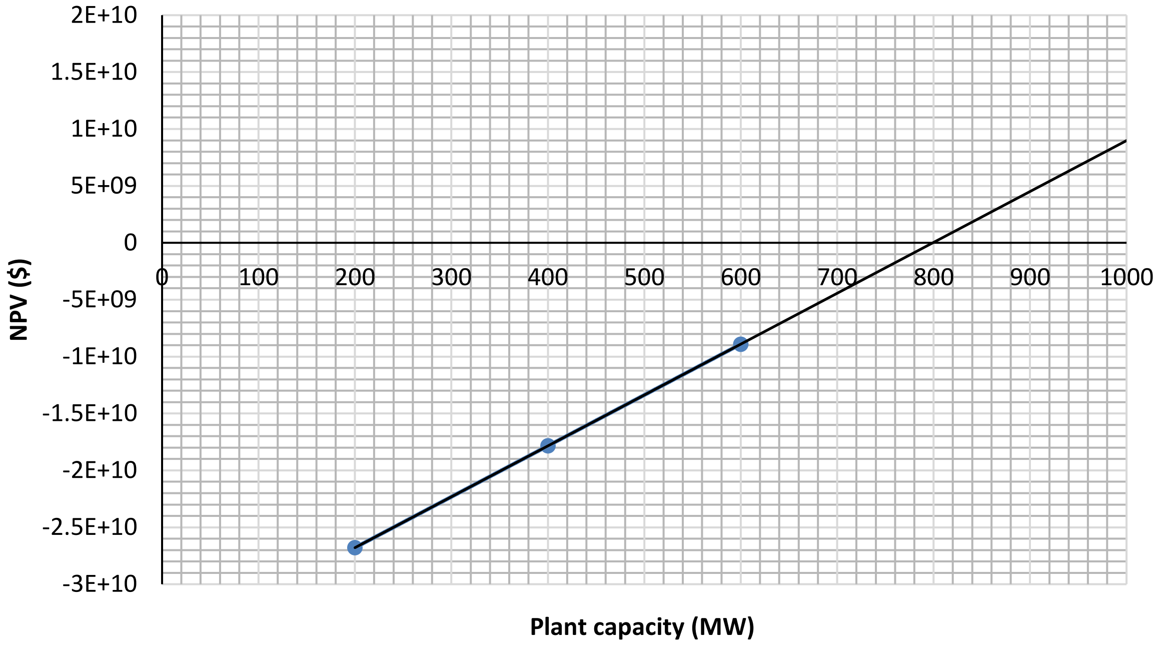

Figure 13: Variation NPV with plant capacities for a hydro-electric power-plant at $65.28/MWh

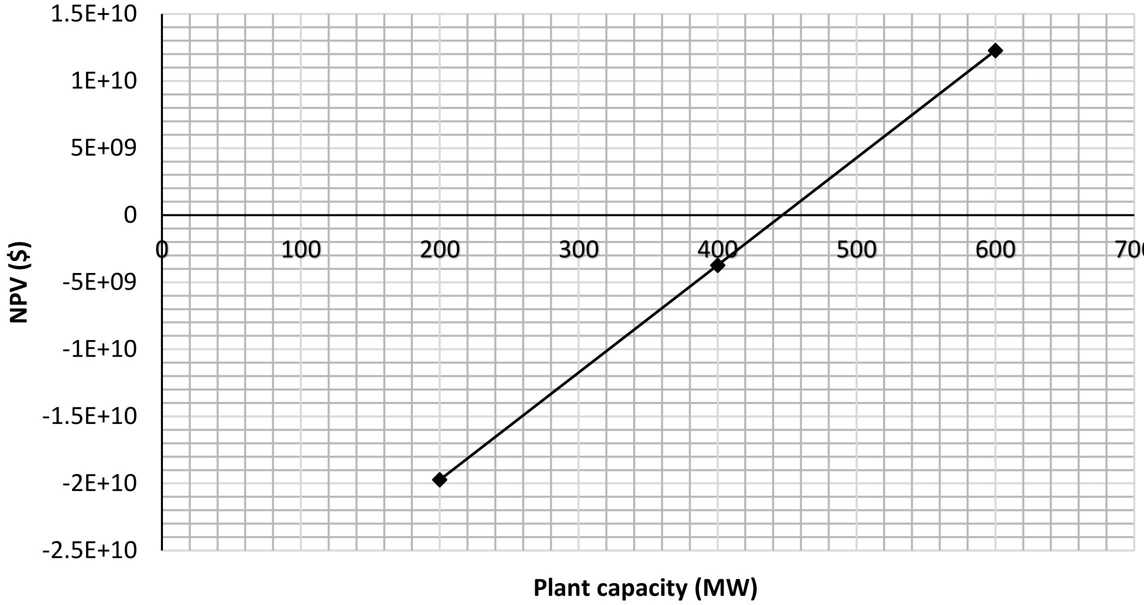

Figure 14: Variation NPV with plant capacities for a hydro-electric power-plant at $114.25/MWh

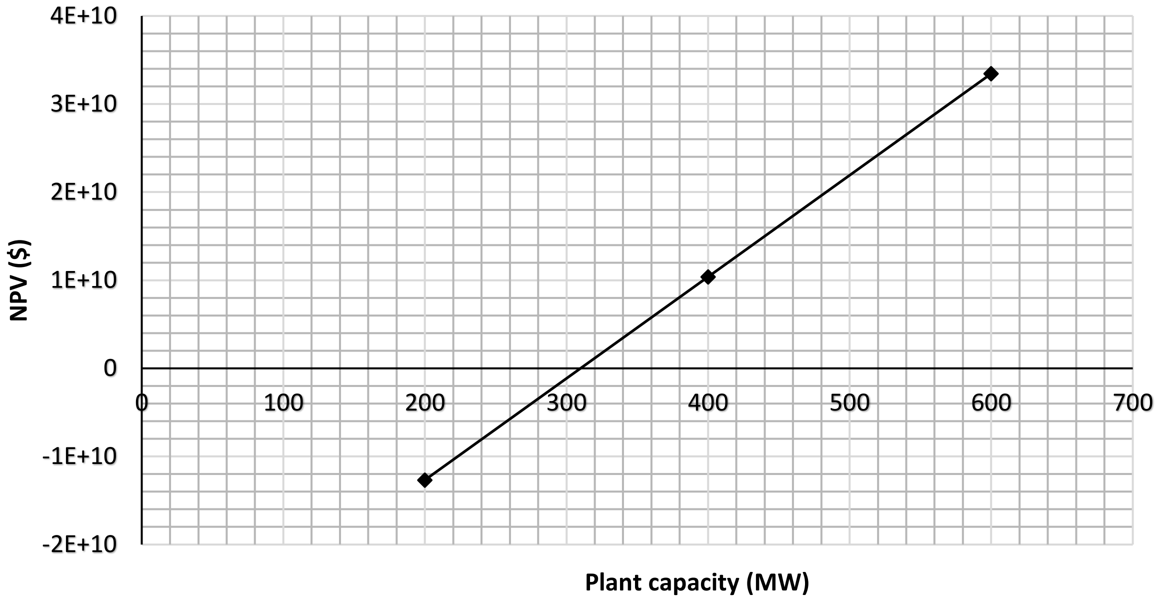

Figure 15: Variation NPV with plant capacities for a hydro-electric power-plant at $163.21/MWh

Table 6: Break even plant capacities at different electricity prices for natural gas and hydro-electric power-plants

Power-plant	Price ($/MWh)	Price (Naira/kWh)	Break even capacity (MW)
Natural gas	65.28	20	625
	114.25	35	450
	163.21	50	245
Hydro-electric	65.28	20	800
	114.25	35	450
	163.21	50	320

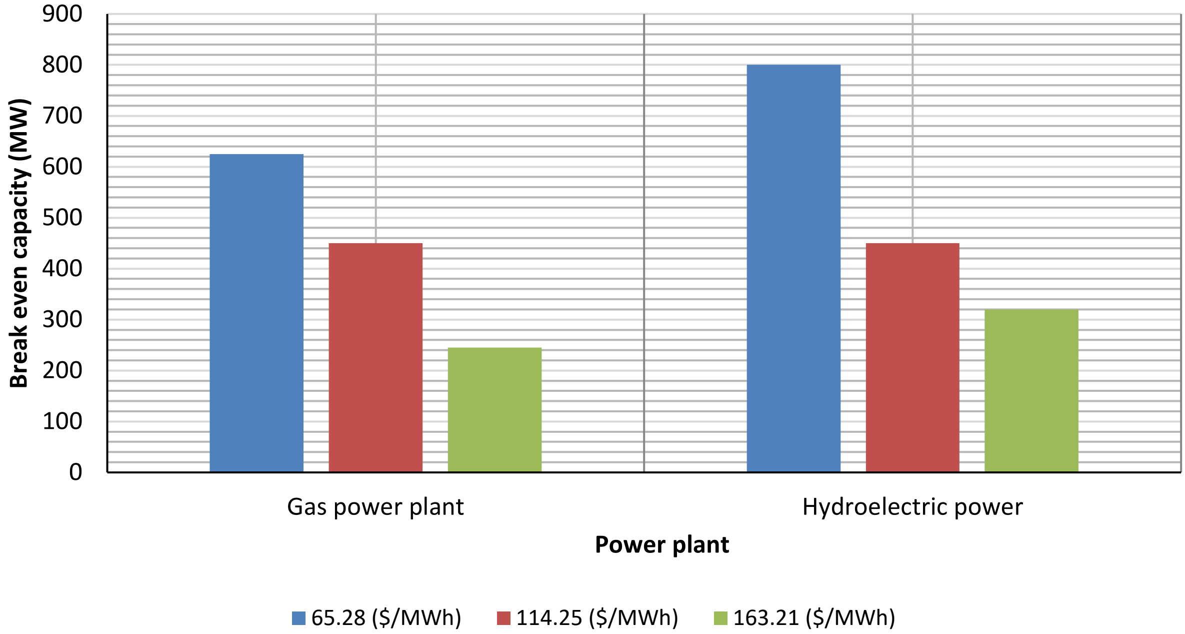

Figure 16: Break even plant capacities for natural gas and hydro-electric power-plants at different electricity prices.

DISCUSSION

Table 3 shows the variation of electricity price and net present values (NPV) at different plant capacities for natural gas and hydro-electric power-plants. From Table 3, it can be deduced that there exists positive correlations between net present value (NPV) and both plant capacity and electricity price. As the price of electricity was increasing, NPVs for both plants were also increasing. Also, as the plant capacity was increasing, the NPV for both plants were also increasing. This is because at higher electricity price and plant capacities, more revenue is generated, thereby increasing the present value of the plant's future cash flows.

Also Table 4 shows a summary of profitability indices for natural gas and hydro-electric power-plants at discount rate and electricity price of 11.38% and 114.25 $/MWh respectively for 400 MW plant capacity. From the table, hydropower plants had higher initial capital cost but lower net present value, internal rate of return, and discounted payback period. Considering investment decision rules, a natural gas plant is better than a hydropower plant in Nigeria considering initial investment cost, since investments with lower initial investment capital are always preferred compared to investments with higher initial capital-costs.

Gas-fired combined cycle plants are modular in nature, that many components brought to site have already been manufactured. This helps make them cheap and easier to build compared to hydropower plants. In contrast, much of a hydropower plant must be constructed at the site, which involves considerable material and labor costs. These costs are part of the reason why hydropower plants are more expensive than gas-fired power-plants.

In addition, in terms of net present value, using strict investment decision rules, at the price of electricity and plant capacity used, none of the plants will be good enough to be invested in, since investments with positive net present values are better than those with negative NPVs. But, if one of them must be selected, a gas-fired power-plant will be selected because it gave a higher (less negative) NPV. This can be explained by the disproportionately larger capital outlays required for building hydropower plants compared to a gas-fired power-plant. This large capital expenditure has immense influence on net present calculations, makes hydropower plants feasible only at higher electricity prices and power-plant capacities, as presented in Table 3. Therefore, from Table 3, it is clear that for a plant capacity of 400 MW, a gas-fired plant would be more feasible in Nigeria than a hydropower plant. But, at a higher plant capacity of 600 MW, hydropower plants are more feasible compared to gas-fired power-plants in Nigeria.

But, in terms of internal rate of return (IRR) and discounted payback periods, a hydropower plant performed better than gas-fired power-plant. At a plant capacity and electricity price of 400 MW and $114.25/MWh, a hydropower plant in Nigeria will give a 9.59% return in investment, while a gas-fired power-plant in Nigeria will give a smaller investment returns of 8.21%. While in terms of discounted payback period, it would take a hydropower plant in Nigeria 13.84 years to payback its initial investment capital. But, it will take a gas-fired plant a longer period of 17.49 years to pay back its own initial investment capital. This means that, in spite of a larger initial capital outlay, it makes more economic sense to build a hydropower plant in Nigeria than a natural gas-fired power-plant.

Also, the sensitivity of the NPV of both gas-fired and hydropower power-plants to electricity price was examined. Hence, Figure 3-8 shows the variation of NPV with electricity price for both gas-fired and hydro-electric power-plants at 200, 400 and 600 MW plant capacities. This was done in other to calculate the break-even price of electricity for the power-plants for each plant capacity understudy, with the results given in Table 5.

From Table 5, it is evident that there exists a negative correlation between plant capacity and break-even prices. As the plant capacity was increasing, break-even prices were decreasing. This is because, the bigger a plant's capacity, the higher the revenue it would be able to generate. Thereby, making it possible for the economics of the plant to be able to withstand the financial pressures of low electricity prices. But, at lower plant capacities, sales revenues are however drastically affected and reduced. This puts the plant under excessive financial stress, making it difficult for the investment to break even.

Table 5 shows that at lower plant capacities, break even prices for a gas-fired power-plant is higher than break even prices for a hydropower plant. But, at higher plant capacities, the break even prices for a hydropower plant in Nigeria is lower than break even prices of a gas-fired power-plant. It means that, gas-fired power-plants are more feasible than hydropower plants at lower plant capacities. While hydropower plants are more feasible than gas-fired plants at higher plant capacities. This was depicted using bar charts in Figure 9.

In the same vein, the sensitivity of the net present value (NPV) of both gas-fired and hydropower power-plants to plant capacity was also examined. Hence, Figure 10-15 shows the variation NPV with plant capacities for both natural gas-fired and hydro-electricpower plants at different electricity prices. This was done in other to calculate the break-even plant capacity for both types of power-plants at $ 65.28, $114.25 and $163.21 per MWh electricity prices, with results given in Table 6. From Table 6, it is also clear that there equally exists a negative correlation between electricity price and break-even plant capacity. As electricity price was increasing, break-even plant capacity was decreasing. This means that at lower electricity prices, only power-plants with high installed capacities will be feasible. But, power-plants with smaller installed capacities will be feasible at high electricity prices.

ISSN 2056-5860

It can also be deduced that at lower electricity prices the break even plant capacities for a gas-fired plant are much lower than the break even plant capacities for corresponding hydropower plants. But, at higher electricity prices, the disparity in break-even plant capacities gradually disappear. This helps to confirm that hydropower plants are more feasible at higher plant capacities and electricity prices, while gas-fired plants are more feasible at lower plant capacities and electricity prices. This scenario was depicted using bar charts in Figure 16.

CONCLUSIONS

From the study, the following conclusions can be reached:

(a) Natural gas-fired plants are more viable at comparatively lower plant capacities and higher electricity prices
(b) Hydropower plants are more viable at comparatively higher plant capacities lower electricity prices.
(c) For a particular type of power plant, only power plants of large capacities are economically viable at low electricity prices, while smaller plants are feasible at high electricity prices.
(d) The economics of both gas-fired and hydropower generating plants in Nigeria are highly dependent on electricity price and plant capacity.

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APPENDIX

Table A1: Annual Cash flow of a CCGT Power-plant in Nigeria

Plant variable	Value
Plant capacity (MW)	400
Annual maximum output (MWh)	3,504,000
Capacity factor (%)	80%
Availability factor (%)	95%
Annual output (MWh)	2,663,040
Thermal efficiency (%)	60%
Annual gas feeds (J)	$1.5965074492 \times 10^{16}$
Quantity of feed gas (daily)	42.04 MMcfd
Interest rate	16.90%
Cost of debt	11.83%
Capital cost ($)	480,000,000
Debt ($)	336,000,000
Equity ($)	144,000,000
Cost of equity	18.62%
WACC	11.38%
Price per MWh ($/MWh)	114.25
Annual operating cost ($)	19,200,000
Fuel cost ($)	49,938,147.69
Annual sales revenue ($)	304,248,082.30
Depreciation rate	3.3%
Salvage value ($)	173,597,526.46
Annual depreciation ($)	10,213,415.78
Tax rate	30%
Annual tax saving from depreciation ($)	3,064,024
Annual tax payment ($)	70,532,980.37
Net tax payable ($)	67,468,956.37

Total annual cost ($)	136,607,104.1
Price of pollution ($/MWh)	38.76
Total cost of pollution ($)	103,219,430.4
Real annual cost ($)	239,826,534.5
Real annual cash flow ($)	64,421,547.80
Tax on selling at salvage value ($)	52,079,257.94

Table A2: Annual Cash flow of a Hydro-electric Power-plant in Nigeria

Plant variable	Value
Plant capacity (MW)	400
Annual maximum output (MWh)	3,504,000
Capacity factor (%)	70%
Availability factor (%)	88.64%
Annual output (MWh)	2,174,162
Interest rate	16.90%
Cost of debt	11.83%
Capital cost ($)	1,174,400,000
Debt ($)	822,080,000
Equity ($)	352,320,000
Cost of equity	18.62%
WACC	11.38%
Price per MWh ($/MWh)	114.25
Annual operating cost ($)	5,652,000
Annual sales revenue ($)	248,394,539.6
Depreciation rate	3.3%
Salvage value ($)	422,784,000
Annual depreciation ($)	25,053,866.67
Tax rate	30%
Annual tax saving from depreciation ($)	7,516,160
Annual tax payment ($)	72,822,762
Net tax payable ($)	65,306,601.87
Total annual cost ($)	70,958,602
Price of pollution ($/MWh)	2.28
Total cost of pollution ($)	4,957,089.18
Real annual cost ($)	75,915,691
Real annual cash flow ($)	172,478,848.53
Tax on selling at salvage value ($)	126,835,200