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Economic Estimation of Oil Shale Development Methods in Nigeria

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Abstract In Nigeria, oil shale deposits are abundantly located mostly in Benue, Bornu, Adamawa, and Ebonyi States; and there are also potentials for shale gas in the Niger Delta region. The richest deposits, the mid-cretaceous oil shale deposits, which exist in the Lokpanta area of the Abakiliki anticlinorium, a depocentre in the Lower Benue trough, are estimated to contain 5.76 billion tonnes with a recoverable hydrocarbon reserve of about 1.7 billion barrels of oil. Development of this resource has not been undertaken in the past because accessible supplies of conventional hydrocarbons have been available at a lower development cost. However, with depleting supplies of the conventional hydrocarbons, as the nation's future energy needs are enormous, it is important to examine the feasibility of supplementing our conventional hydrocarbons deposits with synthetic fuels derived from oil shale and other convertible fossil fuels. The purpose of this study therefore, is to evaluate the economic viability of embarking on the Abakiliki oil shale mineral ventures. Thus, the various oil shale development methods: Room and Pillar, Chamber and Pillar, Sublevel stoping, and Sublevel stoping with backfilling were considered. Additionally, the estimated annual operational expenses for each method and the estimated capital investment and operating cost for a 50,000 barrel-per-day processing plant were considered. Then, stochastic approach (i.e., Monte Carlo simulation) was used to determine the economic viability of embarking on the Abakiliki shale project. The net present value, discounted payback period and capital ratio were the criteria used to measure the relative advantages of the development methods and operating alternatives. The obtained results indicate that Room and Pillar method provided a better economic alternative for the development of the Abakiliki shale deposit.

Keywords Oil shale, Development methods, Economic viability, Abakiliki deposit, Nigeria

1. Introduction

The advent of oil and gas exploration in Nigeria dates back to 1908, when the Nigerian Bitumen Corporation commenced activities in the Araroni area [1]. These pioneered effort ended abruptly because of the outbreak of the First World War in 1914. However, petroleum exploration activities in Nigeria reopened in 1937 when Shell-BP explored for oil in Owerri, Imo State. This effort expanded to other environs in the Niger Delta; and in 1956, they struck oil at Oloibiri in present day Bayelsa State. Thenceforth, the Niger Delta region became the Nation's bumper scene of intensive exploration and production of conventional oil and gas until the 1980s, when oil shale was discovered in the Benue Trough, Nigeria [2]. Before then, oil shale deposits in the form of wide spread had been reported in many countries like USA, Estonia, China and Brazil [3]. The United States has the largest oil shale resources in the world, with the total of 3340 billion tons; which constitutes 62% of the world's known recoverable oil-shale potential [4]. Also, other countries with substantial oil shale reserves include: Israel, Romania, Egypt, Nigeria, Germany, Jordan, Morocco, Canada, Brazil and many others. In addition, Olawuyi [5] mentioned that studies have suggested that shale deposits are abundantly located in Nigeria, mostly in Benue, Abakaliki, Borno, Adamawa and on other south-eastern and north-eastern parts of Nigeria. Currently, Nigeria and the world face significant challenges to meet future demand for liquid fuels. These challenges are caused by rising demand for oil and other petroleum products. The world demand for petroleum is expected to continue to increase over the next twenty-five years from approximately 80 million barrels to nearly 120 million barrels-per-day by 2025 [6]. Therefore, the question now is, where will the additional supply comes from to cushion the increased demand? So far, the Organization of Petroleum Exporting Countries (OPEC) productive capacity has not increased as fast as production demand [7]. In Nigeria presently, the oil and gas sector is being bombarded with numerous problems which include: the rising demand for oil, gas and other petroleum products, a turn-around decrease in conventional oil and gas reserves, worldwide volatility of oil prices, among others [8]. This situation has exposed the dependency of the Nation in conventional crude oil to recession; as about 75 percent of Nigeria's revenue is from crude oil [9]. Additionally, Nigeria is a prime example of single volatile commodity dependent country. The volatility in conventional crude oil production in Nigeria and the fluctuations in international oil price has once again brought to the front burner anxieties about the future of the conventional oil and gas sector in the Nigerian economy. Therefore, in Nigeria and the world at large, there is a growing need to tap into the alternative source to conventional oil reserves; that is, the need for diversification into the shale oil market. Regrettably, no oil shale development in Nigeria has been undertaken in the past because accessible supplies of oil and gas have been available at a lower development cost. However, with dwindling conventional oil reserves, the need to explore and develop oil shale deposits in Nigeria to increase reserve potentials to meet present and future energy demands becomes an imperative. Therefore, this paper assessed the economic development of the Abakaliki oil shale deposit in Nigeria with respect to its recovery mining methods.

1.1. Global Oil Shale Deposits and Development

Oil shale also known as "the Igniting rock" is sedimentary rock that contains solid bituminous materials; called kerogen, that are released as petroleum-like liquids when the rock is heated in the chemical process of pyrolysis. It is one of the world's oldest and largest fossil fuel resources found just as crude oil in many underground deposits worldwide [3]. Over the years, researches have been conducted regarding oil shale reserves and their subsequent development. One of the earliest works on oil shale development was coined from the flammable nature of the richer oil shale and formed the basis for the title of a fascinating book "*The Rock that Burns*" by Savage [10]. The world reserves of oil shale are estimated to be around 660 billion tons of oil equivalents (TOE) content of shale oil and 30% of these are technically extractable [11]. They are therefore superior to the 175 billion TOE of proven reserves of conventional oil. About two-third of the oil shale reserves are in the United States, followed by Russia and Brazil, which together have a share of 20% [12]. In United States, the most important deposits are the Green River oil shale and the Devonian black shale. The Green River oil shale which exists as the largest reserve in the world is the main tertiary age oil shale and is of lacustrine origin. The deposit of Eocene age extends mainly over Piceance Creek basin (Colorado), Uinta basin (Utah), and Green River basin and Washakie basins (Wyoming) [13]. Brazil follows United States, having the world's second largest known oil shale resources, the Irati shale in Sao Mateus do Sul, Parana. The upper Paleozoic Irati Formation is of Permian age and lies in the form of two horizons separated by a thick sediment layer in between [14]. China has an important amount of oil shale potential in Manchuria and particularly near Fushun, a city which is also known as the coal capital of the country [15]. The oil shale of Tertiary age, lacustrine type, and deposited in non-marine regions is mostly associated with coal beds. The oil shale reserves in Fushun region was reported to be around 3.6 billion tons while the total oil shale potential of the country approximates to 4.4 billion tons. The kukersite oil shale deposit in Estonia is of Ordovician age, which was deposited in shallow sea basins. The Estonian oil shale resources are part of the Baltic oil shale basin and are exploited by both surface and underground mining. The deposit is one of the world's highest-grade deposits with more than 40% organic content and 66% conversion ratio into shale oil and gas [16]. The mineable zone is a single calcareous layer 2.5 - 3meters in thickness and is buried at depths of between 7m to 100m [17]. The Estonian oil shale reserves are estimated to be equal to 21 billion tons, which would yield a total of 3.5 billion tons of shale oil [18].

Currently, the shale oil production from oil shale is now about 1 million tons per year, compared to about 4 billion tons of conventional oil [11]. This is an indication that conventional oil sources are over tapped compared to shale oil. Biglarbigi *et al.* [6] presented work that dealt with the economics, barriers and risks of oil shale development in the United States. They stated that oil shale projects, on a commercial scale, could range in size from 10,000 to 100,000 barrels-per-day for a surface retort to as much as 300,000 barrels-per-day for full-scale in-situ projects. Additionally, the capital and operating costs varies depending on the process technology and the quality of the resource. Also, the estimated operating costs fell in the range of $12 to $20 per barrel of shale oil produced, and the capital costs range from $40,000 to $55,000 per stream day barrel of daily capacity. On the other hand, Jaber *et al.* [19] presented an economic analysis of oil shale development in Jordan using various methods of extraction of the shale oil; this include, retorting, in-situ process and surface mining. They establish that above ground retorting method at plant production capacity of 50,000 barrel-per-day of shale oil seem promising for the El Lajjun oil shale deposit in Jordan. Thus, these works provide the basic yardsticks - economic and technology for assessing the feasibility of developing the studied oil shale deposit in Nigeria.

1.2. Oil Shale Deposits in Nigeria

Oluwayi [5] established that Nigeria is not left behind in terms of shale formations. He stated that shale deposits are substantially located in Abakaliki, Benue, Borno, Adamawa, among others. Within the Anambra Basin, the Eze-Aku Shale Formation has been identified as holding considerable shale gas reserves as to warrant active evaluation [20]. Other significant shale oil and gas formations in Nigeria are the Awgu shale formation, the Nkporo/Enugu shale formation and the Afowo shale formation of the Dahomey Basin [21]. The Abakaliki fold belt is found in Ebonyi State, Southeast of Nigeria, as shown in Figure 1. Aghamelu *et al.* [22] wrote extensively on the Abakaliki anticlinorium to state that the first marine transgression of the Benue trough is generally believed to have started with the deposition of the Asu River Group. The Asu River group sediments are predominantly shales, commonly referred to as the 'Abakaliki shale formation' in and around the Abakaliki metropolis (about 452sq.km), and has localized occurrences of sandstone, siltstone and limestone intercalations [23]. Ehinola *et al.* [2] performed an extensive geological mapping and geochemical studies of the oil shale deposit in the Abakaliki fold belt, Southeastern Nigeria as indicated in Figure 2. This was performed to determine its areal extent, reserve estimate, recovery techniques and possible environmental impacts. The areal extent was determined using a grid outlay of 1000m by 1000m to establish area coverage of 72.7sq.km with an exploitable thickness of 34m. The oil shale reserve was estimated to be 5.76 billion tonnes, with a recoverable hydrocarbon reserve estimate of 1.7 billion barrels or 71 trillion gallons of shale oil. Furthermore, they reported that the oil shale deposits in the Abakaliki fold belt of Nigeria may be extracted by surface mining and in-situ method. Additionally, they suggested retorting recovery method for exploitation of local oil shale because of shallow upper soil and relatively cheap cost of establishment.

1.3. Oil Shale Recovery Techniques

It is obvious that oil shale cannot be recovered like the conventional oil. It is rather mined and processed to meet the required specification for further use. The mining methods include Room and Pillar, Chamber and Pillar, Sublevel stoping, and Sublevel stoping with backfilling [24]. Thus, the potential feasible mining techniques for the development of oil shale deposit in Nigeria - the Abakaliki Shale deposit were critically evaluated and selected with reference to certain criteria such as technical feasibility, mining cost, resource recovery, capacity to produce required tonnage, reclamation and environmental impact, to health and safety. The Room and Pillar method involves the mining of part of the ore and leaving certain parts about 30-60ft as pillars for support [25]. The pillar size and shape is dictated by conditions existing, slope size and shape, faults, joints and rock characteristics. The advantage of this mining method comes from its being relatively a flexible system, since it can be modified to suit different conditions and equipment used [26]. The Chamber and Pillar method is a modification of the room and pillar. Here, crosscuts that are driven perpendicular to the entries are enlarged into chambers. The advantage of this method is that, the chambers provide excellent area for underground disposal of spent shale [27]. Additionally, the Sublevel stoping is a high production low-cost method used for mining deposits where ore and country rock are competent [28]. It is essentially a method for steeply dipping ore bodies because it relies on gravity to bring ore down to the loading level with recovery as high as 90% [24]. However, at low dips, below the angle of repose, the method becomes increasingly inefficient. In Sublevel stoping with backfilling unlike Sublevel stoping, here, the slopes are backfilled with spent shale, thus minimizing surface damage and reducing the amount of spent shale disposed at the surface shale [27].

Figure 1: Map of Nigeria showing the States [29]

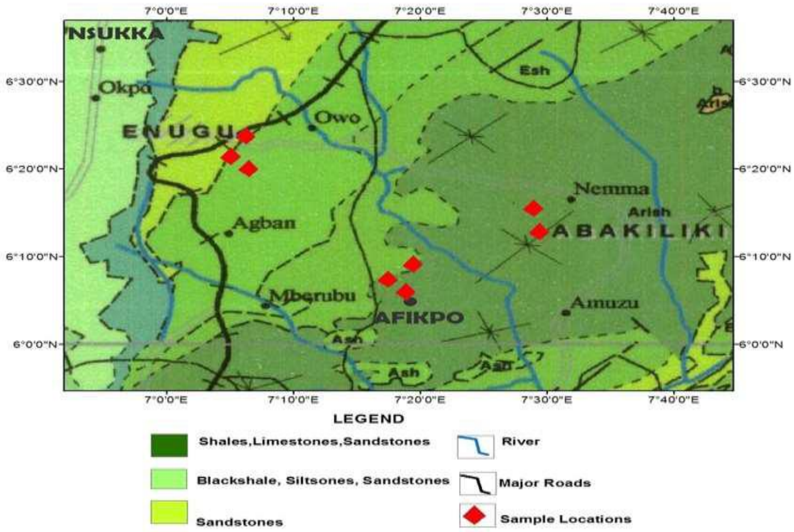

Figure 2: Shale and Tight Sand Deposits in the Southeastern Nigeria [30]

1.4. Oil Shale Processing Techniques

It is well known that oil shale exist in solid form; and it's termed the burning rock, unlike its conventional oil counterpart. Thus, it involves two stages of processing to obtain the oil from the shaly sand. The first stage is pyrolysis**,** which involves the heating of the shaly sand in the atmosphere that does into allow complete oxidation. It is a reaction otherwise called Retorting in oil shale processing. The solid hydrocarbon in the shale decomposes to produce both shale oil and gas; in some cases. The second stage is the upgrading of the obtained shale oil for use. Although, there are other processing methods, pyrolysis retorting; underground or surface, appears to be technically and economically feasible. More importantly, the surface retorting process is considered efficient due to its higher recovery of hydrocarbon than its underground retorting counterpart [24]. In addition, the surface retorting method involves the crushing of the mined shale, heating to a temperature between 850^{0}F - 950^{0}F, after which the waxy solid kerogen is upgraded into liquid and gaseous hydrocarbons.

2. Materials and Methodology

2.1. Data Acquisition

Ehinola *et al.* [2] reported that the total oil shale reserve estimate and recoverable shale oil reserve for Abakaliki shale deposit is as presented in Table 1. These data were used as a benchmark to perform Monte Carlo simulation of the Abakaliki shale oil reserve and recoverable to ascertain the uncertainty in evaluation of the appropriate oil shale development method in Nigeria.

Table 1: Presents Reserve Estimates of Abakaliki Shale Deposit

Estimated Oil Shale Reserve	$5.76 \times \mathbf{10^9}$ tonnes
Estimated Recoverable Shale Oil Reserve	1.70×10^9 barrels

Source: Ehinola *et al. [2]*

Five thousand (5000) triangular distributed random numbers were generated using Minitab 17.1.0. These distributed random numbers/randomly distributed numbers were used to compute the possible shale oil recovery less than and greater than the estimated average shale oil recoverable (OS_{avg}) stated in Table 1, using the expanded equations 1 and 2, respectively.

$$OS_{\min} = OS_{avg} - \left[OS_{avg} \times RAND(\ ) \right] \quad (1)$$

$$OS_{\max} = OS_{avg} + \left[OS_{avg} \times RAND(\ ) \right] \quad (2)$$

Thence, the obtained ten thousand possible recoverable reserves of the Abakaliki Shale deposit were used to produce a probability distribution curve (Figure 3) to establish possible, probable and proved recoveries, that is, P10, P50, and P90 respectively. In most Petroleum literatures, P66 - P100 gives the least uncertainty of Hydrocarbon recovery, therefore, this yardstick was used to select the shale oil recovery for the analysis in the study.

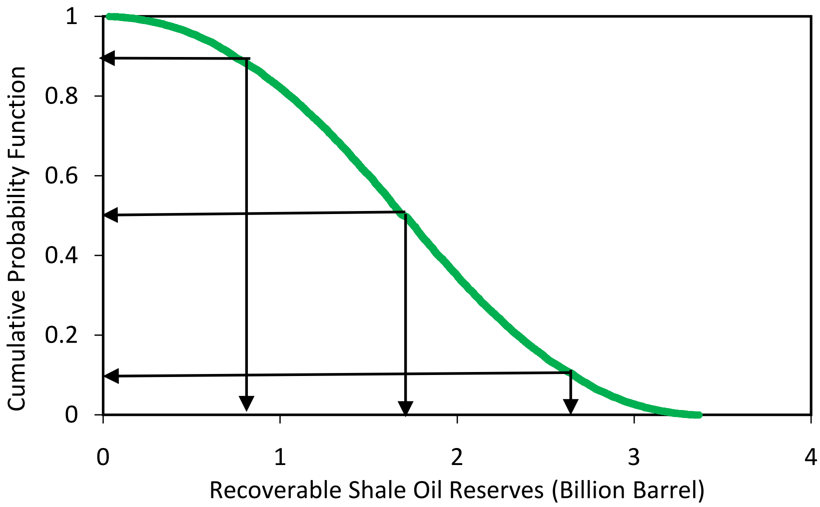

Figure 3: CPF- Shale Oil Reserves Stochastic Curve

2.2. Economic Analysis

In this study, the surface retorting processing approach was used to assess the various mining techniques: Room and Pillar, Chamber and Pillar, Sublevel Stoping and Sublevel Stoping with backfilling in developing the Abakaliki oil shale deposit. The stochastically established recoverable shale oil reserve for P-66, 67, 68, 69, 70 and 74 obtained from Figure 3 were used for the economic analysis. Also, the operating expenses associated with the various mining techniques and its processing cost of production per barrel of shale oil was within $12 to $15. This cost was estimated by Udoh [24] and have been escalated by 100 per cent by the authors to capture inflation and depreciating time value of money. Further assumptions made include: economic rate of return from 5%-25%; the production processing capacity of 150,000bbl/day and selling price of $45; with reference to oil price as at March 2016. Additionally, the summary of the various mining techniques input parameter as provided by Udoh [24] are presented in Tables A.1 through A.6 in the Appendix A. Thence, the net present value, Capital ratio and discounted payback period were used as the economic yardstick to evaluate the feasibility of the various mining methods to develop Abakaliki oil shale reserves.

3. Results and Discussion

As earlier alluded, the recoverable oil shale estimated within the stated range of certainty (i.e., P-66 to P-74) were used to estimate the total revenue, average annual revenue and active years of production as shown in Table 2**.** This estimation resulted in possible total revenue within $54.2 - $62.2 billion with average annual revenue of about $2.5 billion for 24 years of active production.

Table 2: Preliminary Cash Inflow Estimate

Percentile (%)	Oil Shale Recoverable Billion (bbl)	Revenue - Billions($)	Years	Average Annual Revenue - Billions ($)
66	1.382	62.184	25.24	2.464
67	1.361	61.245	24.86	2.464
68	1.340	60.308	24.48	2.464
69	1.317	59.284	24.06	2.464
70	1.297	58.353	23.69	2.464
74	1.205	54.238	22.01	2.464

3.1. Economic Analysis for Room and Pillar

Table 3: Summary of Economic Analysis for Room and Pillar Mining Technique

ROR (%)	Net Present Value Billions($)	Discounted Payback Period (Years)	Capital Ratio
5.0	12.171	0.85	8.51
7.5	10.661	0.87	7.45
10.0	9.393	0.89	6.56
12.5	8.322	0.91	5.81
15.0	7.410	0.93	5.18
18.0	6.486	0.96	4.53
22.0	5.480	0.99	3.83
25.0	4.859	1.02	3.39

Table 3 presents the economic evaluation for Room and Pillar mining method at various rate of return. From the Table, the discounted payback period was within or about a year, not minding the rate of return. This imply that the return of investment (cash inflow) is more than the cash outflow in the first hypothetical year to settle the capital expense (CAPEX). Also, the net present value (NPV) of the investment for the period of ten (10) years with this mining approach resulted in between $4.9 - $12.8 billion; an indication that this mining approach is viable and profitable for the development of Abakaliki oil shale reserve. This assertion is further shown by the minimum capital ratio of 3.39 and maximum capital ratio of 8.51. Meaning, the investment will yield more than three times the invested capital at rate of return of 25% and about eight times or more at rate of return of 5%.

3.2. Economic Analysis for Chamber and Pillar

Table 4 shows the result for Chamber and Pillar mining method. The obtained results depict discounted payback of about 1.0 to 1.30 year. This means, the invested capital will be recouped within the first year and few months of the investment. Also, the result further shows net present value (NPV) range of $4.4 - $11.5 billion. Additionally, the maximum and minimum capital ratio of 2.61 and 6.81 were obtained for this mining approach with the rate of return of 25% and 5%, respectively. From the capital ratio result, it indicates that the investment will yield more than twice and about seven times yield of the invested capital at the stated rates of return (i.e., 25% and 5%).

Table 4: Summary of Economic Analysis for Chamber and Pillar Mining Technique

ROR (%)	Value Net Present Billions($)	Discounted Payback Period (Years)	Capital Ratio
5.0	11.527	1.04	6.81
7.5	10.059	1.07	5.95
10.0	8.827	1.09	5.22
12.5	7.786	1.12	4.60
15.6	6.707	1.16	3.96
18.0	6.002	1.20	3.55

22.0	5.025	1.25	2.97
25.0	4.421	1.29	2.61

3.3. Economic Analysis for Sublevel Stoping

Table 5: Summary of Economic Analysis for Sublevel Stoping Mining Technique

ROR (%)	Net Present ValueBillions($)	Discounted Payback Period (Years)	Capital Ratio
5.0	11.857	0.89	8.05
7.5	10.377	0.92	7.04
10.0	9.135	0.94	6.20
12.5	8.085	0.96	5.49
15.0	7.191	0.98	4.88
18.0	6.286	1.01	4.27
22.0	5.300	1.05	3.60
25.0	4.691	1.08	3.18

Table 5 presents the economic evaluation for Sublevel stoping mining method at various rates of return. From the Table, the discounted payback period for the considered rates of return was within or about a year. This indicate that the return of investment (cash inflow) is more than the cash outflow in the first hypothetical year to settle the capital expense (CAPEX). In addition, the net present value (NPV) of the investment for the period of ten (10) years with Sublevel stoping mining approach resulted between $4.7 - $11.9 billion; an indication that this mining method is feasible and profitable for the development of Abakaliki oil shale reserve. This assertion is further supported by the minimum capital ratio of 3.18 and maximum capital ratio of 8.05. Therefore, the investment will yield more than three times the invested capital in worst case scenario; at 25% rate of return, and about eight times at 5% rate of return.

3.4. Economic Analysis for Sublevel Stoping with backfilling

Table 6 shows the result for Sublevel stoping with backfilling mining method. The obtained results depict discounted payback of about 0.99 to 1.23 years. This means, the invested capital would be recouped within the first year and few months of the investment. Additionally, the result shows net present value (NPV) range of $4.3 - $11.2 billion. Also, the obtained maximum and minimum capital ratio were 2.76 and 7.14 at rate of return of 25% and 5%, respectively for this mining approach. From the capital ratio result, it indicates that the investment using Sublevel stoping with backfilling method would yield more than twice or about seven times of the invested capital at the considered return rate limits - 25% and 5%.

Table 6: Summary of Economic Analysis for Sublevel Stoping with Backfilling Technique

ROR (%)	Net Present ValueBillions($)	Discounted Payback Period (Years)	Capital Ratio
5.0	11.193	0.99	7.14
7.5	9.775	1.02	6.23
10.0	8.586	1.05	5.47
12.5	7.275	1.08	4.64
15.0	6.726	1.10	4.29
18.0	5.859	1.14	3.73
22.0	4.916	1.19	3.13
25.0	4.334	1.23	2.76

3.5. Economic Comparison of the Oil Shale Development Methods

The economic analysis of each mining method as presented in Tables 3 through 6 determine the economic viability of embarking on the Abakaliki oil shale deposit development. Each mining approach - Room & Pillar, Chamber & Pillar, Sublevel stoping and Sublevel stoping with backfilling, resulted in feasible mining venture of the oil shale deposit. However, some of the mining approaches have an edge over the other, as depicted in Figures 4 through 6. Therefore, Figure 4 presents the analysis of the various mining techniques at different rate of return (ROR). Although the obtained net present values (NPVs) for the different rate of return and mining techniques were relatively close, the obtained NPVs for Room & Pillar method were higher than its other counterparts. Additionally, very close NPVs were obtained for Chamber & Pillar and Sublevel stoping with backfilling techniques from return rate of 12.5% through 25%. This implies, the two mining methods would yield the same NPVs for the Abakaliki oil shale venture from ROR of 12.5%. On the other hand, Figure 5 presents the Discounted Payback Period (DPBP) against Rate of Return (ROR) for the various mining techniques of the oil shale venture. The Figure indicates that the invested capital could be recouped within the first and half years of investment, irrespective of the mining techniques used. Additionally, the Room & Pillar mining method presented the least DPBP at the various ROR. A comparison of the various mining methods' DPBP indicates that Chamber & Pillar resulted in the highest DPBP at the various ROR of the oil shale venture. Also, Figure 6 shows the comparison of the Capital Ratio against Rate of Return (ROR) of the various mining techniques for the Abakaliki oil shale venture. The result indicates that Room & Pillar has the highest (favourably) Capital Ratio for the various ROR for the oil shale deposit development. This mean, Room & Pillar technique present more promising mining method for the Abakaliki oil shale deposit venture than its other counterparts; as it would requires less initial capital (CAPEX) than the other techniques to explore the oil shale deposit. Thus, in all the economic analyses of the various mining methods presented, Room & Pillar has the most economic potential that is viable for the investor to venture into the Abakaliki oil shale deposit development.

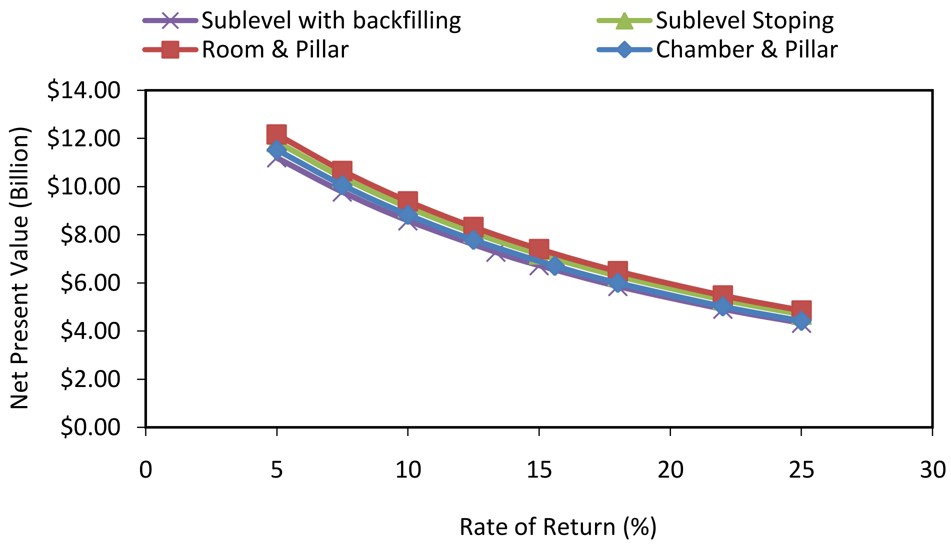

Figure 4: Net Present Value (NPV) vs. Rate of Return (ROR)

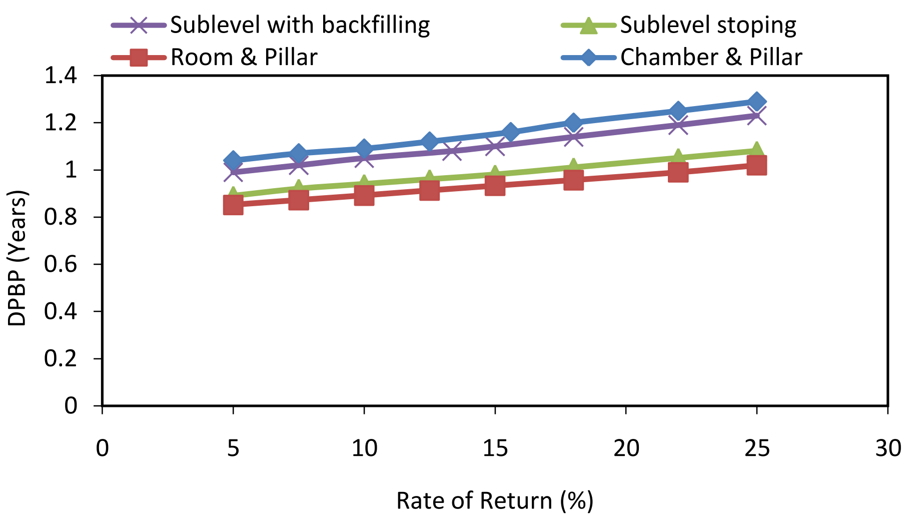

Figure 5: Discounted Payback Period (DPBP) vs. Rate of Return (ROR)

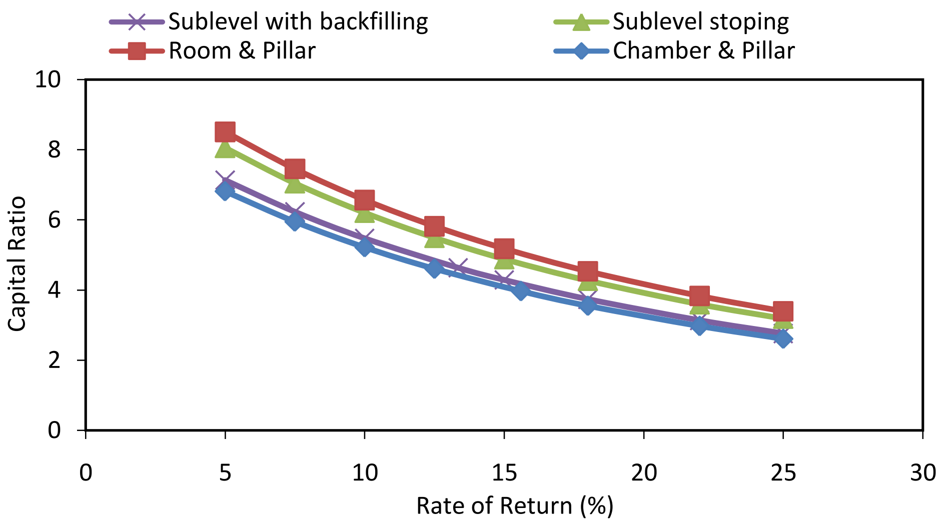

Figure 6: Capital Ratio vs. Rate of Return (ROR)

4. Conclusion

Nigeria is naturally endowed with both conventional and nonconventional hydrocarbons. Her conventional hydrocarbon - crude oil is well tapped over the years to a stage to depletion, regrettably, the nonconventional - oil shale remains unexploited. Therefore, as energy demand is on the increase, in this country and even at the world at large, the need to explore this unconventional hydrocarbon deposit becomes pertinent. In the course of this, the economic viability of the various oil shale development methods: Room & Pillar, Chamber & Pillar, Sublevel stoping and Sublevel stoping with backfilling were evaluated to assess their feasibility on developing Abakaliki oil shale deposit in Nigeria. Thus, the following conclusions were drawn:

- the Room and Pillar technique has a net worth range between $4.9 - $12.8 billion, a Capital ratio range of 3.39 - 8.51 and a maximum discounted payback period of one year;
- the Chamber and Pillar technique has a net worth range between $4.4 - $11.5 billion, a Capital ratio range of 2.61 - 6.81 and a maximum discounted payback period of one year and four months;
- the Sublevel stoping technique hasa net worth range between $4.7 - $11.9 billion, a Capital ratio range of 3.18 – 8.05 and a maximum discounted payback period of one year and one month; and
- the Sublevel stoping with backfilling technique having net worth ranging between $4.3 - $11.2 billion, a Capital ratio range of 2.76 - 7.14 and a maximum discounted payback period of one year and three months.

Thus, the economic viability of the various development methods of the Abakaliki shale deposit indicates that Room & Pillar method seems promising. Since, Investment decisions are made based on several important factors, one of which is profitability. It is recommended that the Room & Pillar technique should be the most considered method in the exploitation and recovery of the Abakaliki Oil Shale Reserve.

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APPENDIX A

Table A.1: Cost Summary for Sublevel Stoping

Capital Costs	Price
Surface Mining Support Facilities	$52,827,500.00
Surface Fuel/Service Station	$1,395,000.00
Surface utilities	$110,442,500.00
Surface Sitework	$20,877,500.00
Surface Water facility	$25,152,500.00
Preliminary Site Development	$71,625,000.00
Service Shaft & Facilities	$65,342,500.00
Contingency (9%)	$43,347,500.00
Equipment Cost	$175,605,000.00
Indirect Cost (6%)	$38,067,500.00
Total	**$604,682,500.00**
Annual Operation Cost	
Supervisory labour	$44,560,000.00
Underground labour	$199,500,000.00
Surface labour	$16,800,000.00
Utilities	$65,330,000.00
Operating Supplies	
Fuel and Lubrication	$39,930,000.00
Explosives	$40,000,000.00
Material	$33,180,000.00
Contingency (9%)	$10,180,000.00
Insurance	$22,000,000.00
Indirect Cost	$4,490,000.00
Total	**$475,970,000.00**
Grand Total	**$1,080,652,500.00**

Table A.2: Cost Summary for Sublevel Stoping with backfilling

Capital Costs	Price
Surface Mining Support Facilities	$52,452,500.00
Surface Fuel/Service Station	$1,395,000.00
Surface utilities	$110,067,500.00
Surface Sitework	$20,877,500.00
Surface Water facility	$25,152,500.00
Preliminary Site Development	$71,250,000.00
Shafts Sinking (4)	$43,282,500.00
Contingency (9%)	$30,677,500.00
Equipment Cost	$100,757,500.00
Indirect Cost (6%)	$28,355,000.00
Total	**$484,267,500.00**
Annual Operation Cost	
Supervisory labour	$36,280,000.00
Underground labour	$151,200,000.00
Surface labour	$13,650,000.00
Utilities	$64,110,000.00
Operating Supplies	
Fuel and Lubrication	$30,660,000.00
Explosives	$40,000,000.00
Material	$37,580,000.00
Contingency (9%)	$9,740,000.00
Insurance	$15,220,000.00
Indirect Cost	$3,830,000.00
Total	**$402,270,000.00**
Grand Total	**$886,537,500.00**

Table A.3: Cost Summary for Chamber & Pillar

Capital Costs	Price ($)
Surface Mining Support Facilities	$52,452,500.00
Surface Fuel/Service Station	$1,395,000.00
Surface utilities	$110,067,500.00
Surface Sitework	$20,877,500.00
Surface Water facility	$25,152,500.00
Preliminary Site Development	$71,250,000.00
Outside Ore Pass	$2,500,000.00
Contingency (9%)	$25,532,500.00
Equipment Cost	$108,015,000.00

Table A.4: Cost Summary for Room & Pillar

Capital Costs	Price ($)
Surface Mining Support Facilities	$52,452,500.00
Surface Fuel/Service Station	$1,395,000.00
Surface utilities	$110,067,500.00
Surface Sitework	$20,877,500.00
Surface Water facility	$25,152,500.00
Preliminary Site Development	$71,250,000.00
Service Shaft and facilities	$64,967,500.00
Production Headframe (2)	$62,505,000.00
Shafts (5)	$68,797,500.00

Indirect Cost (6%)	$25,035,000.00
Total	**$442,277,500.00**
Annual Operation Cost	
Supervisory labour	$34,800,000.00
Underground labour	$137,290,000.00
Surface labour	$12,600,000.00
Utilities	$41,250,000.00
Operating Supplies	
Fuel and Lubrication	$37,440,000.00
Explosives	$40,000,000.00
Material	$35,000,000.00
Contingency (9%)	$10,120,000.00
Insurance	$3,490,000.00
Indirect Cost	$15,010,000.00
Total	**$367,000,000.00**
Grand Total	**$809,277,500.00**

Contingency (9%)	$42,972,500.00
Equipment Cost	$144,350,000.00
Indirect Cost (6%)	$38,067,500.00
Total	**$702,855,000.00**
Annual Operation Cost	
Supervisory labour	$37,770,000.00
Underground labour	$152,510,000.00
Surface labour	$16,800,000.00
Utilities	$60,220,000.00
Operating Supplies	
Fuel and Lubrication	$41,560,000.00
Explosives	$40,000,000.00
Material	$37,160,000.00
Contingency (9%)	$10,680,000.00
Insurance	$16,050,000.00
Indirect Cost	$3,470,000.00
Total	**$416,220,000.00**
Grand Total	**$1,119,075,000.00**

Table A.5: Annual Operating Cost for 50, 000bbl/d Plant

	Retorting	**H_2S/Solid Waste Removal**	**Refining**	**Total**
Natural Gas	0	0	$5,229,894.45	$5,229,894.45
Water Use Charge	$7,126,229.06	$6,457,302.74	$4,767,886.38	$18,351,418.18
Annual Catalyst & Chemicals	$0.00	$9,293,022.14	$7,039,753.53	$16,332,775.67
Direct Labour	$10,797,717.66	$10,761,789.70	$9,080,426.12	$30,639,933.48
Supervision	$7,435,176.01	$7,364,571.66	$5,472,226.68	$20,271,974.34
Maintenance Labour Supervision	$7,412,625.04	$6,743,596.49	$4,921,396.44	$19,077,617.97
Maintenance Labour	$11,733,039.65	$9,104,511.82	$8,375,452.13	$29,213,003.61
Maintenance Materials	$11,733,039.65	$9,104,511.82	$8,375,452.13	$29,213,003.61
Operating Supplies	$8,098,289.63	$7,029,890.24	$5,696,075.72	$20,824,255.59
Payroll Overhead	$9,391,299.02	$8,679,103.51	$7,342,388.01	$25,412,790.53
Admin & General Overhead	$7,356,018.58	$6,510,730.80	$4,912,841.70	$18,779,591.08
Land	$7,356,018.58	$9,136,770.27	$14,533,188.85	$31,025,977.70
Improvement	$12,657,904.17	$9,136,770.27	$14,533,188.85	$36,327,863.30
Insurance	$11,994,411.00	$9,480,524.38	$13,149,697.21	$34,624,632.58
Total	**$113,091,768.05**	**$108,803,095.84**	**$113,429,868.21**	**$335,324,732.10**