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Application of Real Options with Binomial Model in the Valuation of the "Oilnergy-2" Oil Field Investment Project

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Abstract

This study analyzes the application of real options valuation using a binomial model in assessing the offshore oilfield investment project *OILNERGY-2*. The methodology employs the Four-Step Approach developed by Tom Copeland and Vladimir Antikarov to compute the value of embedded options. Traditional capital budgeting techniques, such as Net Present Value (NPV), frequently underestimate project value by neglecting the indirect cash flows arising from managerial flexibility in decision-making. The research identifies two strategic real options within the project: an option to abandon valued at $174,972 and an option to expand valued at $506,432. Utilizing a binomial option pricing model with an annualized volatility of 25%, a risk-free interest rate of 5%, and quarterly time steps, the analysis demonstrates that the incorporation of real options adds value beyond the conventional NPV metric. The aggregated model indicates a total project valuation increase of $174,972 compared to the base-case NPV of $9.5 million. The findings underscore that the real options framework enhances investment decision support by integrating managerial flexibility and uncertainty management. This approach is especially pertinent in oil and gas exploration ventures, which are characterized by high uncertainty and significant *sunk costs* inherent in upstream investments.

Keywords: Real Options; Binomial Model; Oil Field Investment; Capital Budgeting; Managerial Flexibility; Offshore Projects

INTRODUCTION

The global petroleum industry continues to face significant challenges in evaluating the feasibility of investment projects, particularly offshore oil fields, which require substantial capital expenditures and are subject to considerable uncertainty (Jahangiri et al., 2021). Traditional capital budgeting techniques, such as Net Present Value (NPV), often fail to capture the full value of an investment because they do not incorporate *managerial flexibility* and strategic decision-making under uncertainty (Fedorov et al., 2021; Mashhadizadeh et al., 2018; Mun, 2016).

In Indonesia, this issue is particularly acute in the evaluation of oil and gas projects governed by *Production Sharing Contracts* (PSC), which are highly sensitive to variables including reserve estimates, production volumes, and volatile global oil prices. Between 2020 and 2023, oil prices exhibited dramatic fluctuations, dropping below $20 per barrel during the COVID-19 crisis and rising above $80 in 2022–2023, significantly affecting long-term investment planning (International Energy Agency [IEA], 2023).

The urgency to adopt more dynamic valuation methods is reinforced by research highlighting the limitations of Discounted Cash Flow (DCF) models, which often undervalue projects by ignoring options for deferral, expansion, or abandonment (Bollé et al., 2020; Petrou & Gray, 2011; Ransikarbum et al., 2023). Real options analysis has emerged as a robust alternative by providing quantitative tools to assess the value of flexibility in investment decisions.

Recent studies have advanced both theoretical frameworks and practical applications of real options in the energy sector. For instance, Smit & Trigeorgis (2017) introduced real options games to improve strategic decision-making under uncertainty, while Dyer, Espinoza, and Pineda (2022) proposed an integrative approach to flexibility valuation in energy projects. Moreover, Zhao and Lin (2023) demonstrated the efficacy of binomial real options models for evaluating offshore oil field investments amid volatile energy prices.

Although the growing literature recognizes the relevance of real options theory in valuing oil exploration and production projects under uncertainty, much remains to be done in addressing the specific contractual complexities of Indonesia’s PSCs, especially mechanisms such as *cost recovery*, profit-sharing, and regulatory risks. While previous work by Siddiqui and Khan (2020) emphasized the importance of managerial flexibility in managing price volatility, their analyses did not tackle PSC-specific challenges or apply binomial models capable of quantifying strategic options like expansion or abandonment. Similarly, Murtaza et al. (2020) integrated real options with traditional DCF methods but lacked consideration of the Indonesian regulatory framework and did not operationalize real options through a stepwise binomial approach.

This study addresses a critical gap by applying real options analysis—specifically, binomial tree modeling—to offshore oil field investments within the framework of Indonesian PSCs. The novelty lies in valuing two pivotal managerial options: the option to abandon and the option to expand, while incorporating sector-specific features such as cost recovery ceilings and sliding-scale profit sharing.

The primary objective is to compare investment valuations derived from the traditional NPV method and the real options approach, emphasizing identification of embedded managerial flexibilities. The research aims to contribute theoretically to capital budgeting literature and offer practical insights for petroleum firms operating in highly uncertain and volatile environments.

The implications are particularly pertinent in the post-pandemic and energy transition context, where oil prices remain unpredictable and regulatory environments continue to evolve. By integrating real options valuation tailored to Indonesia’s oil governance model, the study provides enhanced tools for more accurate and adaptive investment decision-making in the petroleum industry.

METHOD

This study employed a quantitative approach using a case study design applied to the offshore oilfield investment project *OILNERGY-2*. The data included both internal company records and external information from global petroleum industry databases and market reports (IEA, 2023).

The analysis applied a real options valuation framework based on recent advances in binomial modeling techniques for strategic investment appraisal under uncertainty (Zhao & Lin, 2023; Dyer, Espinoza, & Pineda, 2022). The research proceeded through four stages: first, calculating the Net Present Value (NPV) assuming no managerial flexibility; second, developing an event tree reflecting project volatility; third, identifying managerial real options and converting them into a decision tree; and fourth, applying replicating portfolio concepts to evaluate flexible project outcomes (Brandão, Dyer, & Hahn, 2021).

Model parameters included an annual project volatility rate of 25%, a risk-free rate of 5% with continuous compounding, a six-month observation period for the abandonment option, and a ten-year horizon for the expansion option. Exercise prices were set at $8 million for the abandonment option and $1.7 million for the expansion option, aligned with industry development cost forecasts (Fernandes & Cunha, 2021).

The model assumed no dividend payments from the underlying asset, a no-arbitrage market environment, and the construction of replicating portfolios composed of a risky asset and a risk-free bond. The real options valuation was performed using backward induction and validated under the Law of One Price (Smit & Trigeorgis, 2017; Villani & Biancardi, 2022; Watanabe, 2018).

RESULTS AND DISCUSSION

General Description of OILNERGY-2 Field Investment Project

The OILNERGY-2 field is an offshore oil field located in Eastern Indonesia, specifically within the Komachi Block. The field was discovered in 1985 through the drilling of the Tanako-1 well by the contractor UNIFIELD Intl. Ltd. Historically, the block where the OILNERGY-2 field is situated was part of a Joint Operating Body (JOB) contract between Pertamina and UNIFIELD Intl. Ltd., a United States-based company.

Geologically, the field lies in a tectonically complex area on an island in Eastern Indonesia, formed by the collision between the Bonggai Korda microcontinent and the Bonggai Maruta ophiolite belt. Drill Stem Tests (DSTs) conducted during the exploration of the Tanako-1, Tanako-2, Tanako-3, and Tanako-4 wells have confirmed hydrocarbon accumulation at the base of the Komachi Lower Platform limestone formation.

According to engineering analyses, the field is estimated to have an Original Oil in Place (OOIP) of approximately 106.60 million barrels (MMBO). However, due to the complex geological structure, not all of these reserves are considered technically recoverable. Additionally, portions of the reserves are of lower crude quality due to the presence of other compounds. As a result, the company has applied a conservative recovery factor of 10%, leading to an estimate of proven recoverable reserves of about 10.7 million barrels.

Table 1. Petroleum Price per Barrel per Month (in US$)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Agu	Sep	Oct	Nov	Dec
2010	78.33	76.39	81,2	84.29	73.74	75.34	76.32	76,6	75.24	81.89	84.25	89.15
2011	89.17	88.58	102.86	109.53	100.9	96.26	97.3	86.33	85.52	86.32	97.16	98.56
2012	100.27	102.2	106.16	103.32	94.66	82.3	87.9	94.13	94.51	89.49	86.53	87.86
2013	94.76	95.31	92.94	92.02	94.51	95.77	104.67	106.57	106.29	100.54	93.86	97.63
2014	94.62	100.82	100.8	102.07	102.18	105.79	103.59	96.54	93.21	84.4	75.79	59.29
2015	47.22	50.58	47.82	54.45	59.27	59.82	50.9	42.87	45.48	46.22	42.44	37.19
2016	31.68	30.32	37.55	40.75	46.71	48.76	44.65	44.72	45.18	49.78	45.66	51.97
2017	52.5	53.47	49.33	51.06	48.48	45.18	46.63	48.04	49.82	51.58	56.64	57.88
2018	63.7	62.23	62.73	66.25	69.98	67.87	70.98	68.06	70.23	70.75	56.96	49.52
2019	51.38	54.95	58.15	63.86	60.83	54.66	57.35	54.81	56.95	53.96	57.03	59.88
2020	57.52	50.54	29.21	16.55	28.56	38.31	40.71	42.34	39.63	39.4	40.94	47.02

*) Data up to July 2020 Source: Berry Petroleum Online; www.bry.com.prices.

The development of this 475 square km field requires reclamation of the coral reef located near the Tanako-1 well. This location will be used as a base for drilling and production activities, installation of facilities and supporting facilities, as well as jetty construction, shuttle tanker and storage barge when the oil field has produced at full capacity.

Development Phase and Production Strategy

The development of the OILNERGY-2 field consists of three consecutive phases. Phase I is the Performance Evaluation Period (PEP) which monitors the production performance of two multilateral wells each for 3 months using a minimum leased production facility. The PEP operation will be installed and operated by a third-party company through a rental and service contract for a period of approximately 12 months. The installation and operation will be designed to be able to handle 4000 BOPD (barrel oil per day).

Phase II is the Early Production Scheme (EPS) which will use production equipment for approximately 2 years. EPS will again use production equipment used in the PEP phase for continuous operational activities on the wells that produce during the transition from the PEP phase to the EPS phase. EPS is designed to handle the production of 6 wells with a maximum capacity of 6400 BOPD.

Phase III is the Permanent Production Scheme (PPS) where the decision to build or purchase a permanent production facility will be based on an economic evaluation that will depend on the characteristics of the oil reservoir as determined by the initial production performance (EPS). PPS will begin with the purchase and if necessary modify the EPS facility and then install water injection and additional water facilities.

The company prepares two types of development scenarios based on the technology used. Base Case is a scenario where a company will drill 6 multilateral wells each with 2 branches. Meanwhile, the Expanded Case is a scenario where the company will drill 6 wells plus inject seawater into 4 wells to increase the pressure of oil from the seabed. By adding this treatment, it is hoped that the amount of oil reserves that have been successfully extracted will increase to a maximum of 2% of the Original Oil in Place (OOIP).

Analysis Using Traditional Net Present Value (NPV) Method

In the base case production scenario owned by the "OILNERGY Contractor", the economics of the "OILNERGY-2" Offshore Oil Field Development project are calculated using the assumption of a price of US$18.00/barrel at 29° API oil gravity. The economic calculation includes several main components, namely Production (Million Barrel Oil), Gross Revenue, Profit Oil Split, First Tranche Petroleum (FTP), Cost Recovery, Investment Credit, Contractor Equity to Split, Domestic Market Obligation (DMO), and Net Cash Flow (NCF).

Table 2. OILNERGY-2 Field Economics (Option to Abandon) - in thousands of US$

Year	Production (MBO)	Gross revenue	FTP	Cost Recovery	Breakdown of Contractors' Equity	DMO	Net Cash Flow
1	477	8,585	644	3,385	1,034	0	-6,375
2	1,752	31,536	3,152	14,954	8,880	0	11,552
3	1,752	31,536	3,152	2,103	17,760	0	26,433
4	1,752	31,536	3,152	2,103	17,760	0	26,433
5	1,533	27,594	2,759	1,841	15,540	957	22,353
6	1,314	23,652	2,365	1,578	13,320	711	18,274
7	1,095	19,710	1,971	1,315	11,100	525	14,194
8	876	15,768	1,577	1,052	8,880	0	13,251
9	657	11,826	1,183	789	6,660	0	9,854

Base Case NPV = 9,500,000 US$

Description: BBL = barrel, MM US$ = million US$, MMBO = million barrel of oil

Production shows the gross amount of oil to be produced per year during the project period. For example, in the 1st year, the amount of production was 477 MBO obtained from oil production per day of 1,307 BOPD (barrel per day) multiplied by 365 days. Total Gross Revenue is the multiplication of production and assumed oil prices. In the 1st year, the gross revenue was 8,585 thousand US$ obtained from 477 MBO multiplied by the oil price assumed to be 18 US$/bbl.

Gross income after deducting recoverable operating expenses is called profit oil. The oil profit is divided between PERTAMINA and the OILNERGY contractor. After tax deductions, the oil profit of the contractor can be referred to as the oil equity of the contractor. For the OILNERGY-2 field project, the amount of FTP allowance is 15% of gross revenue. The FTP for the 1st and 2nd years is 644 thousand US$ and 3152 thousand US$ obtained from gross revenue by multiplying this percentage.

Table 3. OILNERGY-2 Field Economics (Option to Expand) - in thousands of US$

Year	Production (MBO)	Gross revenue	FTP	Cost Recovery	Breakdown of Contractors' Equity	DMO	Net Cash Flow
1	477	8,585	644	3,385	1,034	0	-6,375
2	1,752	31,536	3,152	14,954	8,880	0	11,552
3	1,752	31,536	3,152	2,103	17,760	0	26,433
4	1,752	31,536	3,152	2,103	17,760	0	26,433
5	1,533	27,594	2,759	1,841	15,540	957	22,353
6	1,314	23,652	2,365	1,578	13,320	711	18,274
7	1,095	19,710	1,971	1,315	11,100	525	14,194
8	876	15,768	1,577	1,052	8,880	0	13,251
9	657	11,826	1,183	789	6,660	0	9,854
10	438	7,884	788	526	4,440	0	6,570

NPV Expanded Case = US$ 8,700,000

Cost recovery is a company's operating costs that can be obtained after the company starts production. Cost recovery in the 1st and 2nd years amounted to 3,385 thousand US$ and 14,954 thousand US$. This value is obtained by a calculation that requires judgment in connection with the provisions of cost carried forward and cost reimbursed carried forward if the revenue is less than the amount of cost incurred.

The size of PERTAMINA's share is 32.5% and the size of the OILNERGY contractor's share is 67.5%. In the 1st year, the contractor's oil equity was 1,034 thousand US$ obtained by multiplying the contractor's share by 62.5% by the contractor's equity to split (profit oil) which amounted to 1,655 thousand US$. The contractor's NCF is the Total Revenue minus the Total Cost. NCF in the 1st year amounted to -6,375 thousand US$ obtained from Total Revenue which amounted to 8,187 thousand US$ minus Total Cost which amounted to 14,542 thousand US$.

Through the economic calculations above, it is known that the net present value (NPV) of the project is 9,500,000 US$ for the base case and 8,700,000 US$ for the expanded case. A positive NPV value indicates that the project is financially viable based on traditional valuation methods. However, traditional NPV analysis does not take into account management's flexibility in making future decisions based on new information obtained during the project's operational lifetime.

Implementation of the Real Options Method

The application of Real Options uses the Binomial Model Solution Method developed by Tom Copeland and Vladimir Antikarov through the Four Step Approach. This method was chosen because it can combine the source of uncertainty into one source of uncertainty and is able to direct the calculation to be algebraic so that it tends to be easy to understand by management.

The OILNERGY-2 field investment project has two main options that can be taken by management. The first is the Option to Abandon, which is the option to abandon a viable project if new information from the Early Production Scheme proves conclusively that the reserves do not show the reserves and production rates as large as expected and the difference is significant. If this option is taken, all the costs that have been invested cannot be recovered (sunk cost), but the estimated selling price of this offshore investment field is estimated at 8,000,000 US$ at any time.

The second is the Option to Expand, which is the option to expand/expand the project if new information can prove conclusively that the proven reserves that can be developed are greater than originally estimated. The OILNERGY contractor plans to implement this option on a fairly conservative scale by increasing the term from 9 years to 10 years and installing water injection. Through this effort, the amount of oil reserves produced is estimated to increase ± 10% of the base case, from 10.38 million barrels to 11.34 million barrels. To increase the scale of the investment project, an additional cost of US$ 1,700,000 is required consisting of capital costs and operational costs.

Volatility and Event Tree Calculations

In determining the event tree, the volatility of this investment project (underlying asset) must be obtained first. Tom Copeland asserts that the volatility of a project is not the same as the volatility of input variables or elements of uncertainty, such as selling price or production quantity. The right basis for forming an event tree is the volatility of the rate of return. Each uncertainty parameter is directed to form an estimated present value, the result of which is then converted into the rate of return using the formula:

$PV_t = PV_0.e^{\wedge rt}$

$\ln PV_t = r_t$ Equations (4.1)

Due to the limitations of the Monte Carlo simulation program facilities, the authors use management estimates as the basis for determining project volatility. It is believed that the volatility of this field is 0.25/year. Based on the volatility value of 0.25/year, the value of the upward movement ("u") can be calculated with the formula:

$u = e^{\wedge(\sigma\sqrt{T/n})}$ or $d = 1/u$

where σ is volatility, e is an exponential function of magnitude 2.7183, T is the project lifespan, and n is the number of periods over the life of the project.

The lifespan of this project is 9 years with the number of periods throughout the life of the project is 36 periods (in a year there are four periods). Thus the values of "u" and "d" are:

$u = e^{\wedge(0.25.\sqrt{9/36})} = e^{\wedge 0.125} = 1.133148$ $d = 1/1.133148 = 0.8822497$

The risk free rate (r_f) is 5% per year and is continuously compounded. The cost of capital set by the corporation is 15% annually. Objective probabilities can be calculated by utilizing the triangularity that occurs between three parameters, namely between objective probabilities, cost of capital, and expected payoff at the end of each period based on volatility.
$1 = p.u.e^{\wedge -kt} + (1-p).d.e^{\wedge -kt}$
By calculation: p = 0.621245 ; 1 - p = 0.378755

Analysis Options to Leave

The option to abandon has a maturity date of 6 months with a quarterly observation period so that there are two observation periods in total. The calculation starts from the decision tree endpoints at the endpoints that have optimal payoffs and then the work is carried out backwards. The payoff at each endpoint is obtained using the following criteria:
payout = MAX [Vt, X]

This criterion indicates that the payoff will not be smaller than the predetermined exercise price, which is 8,000,000 US$ at any time.

Table 4. Optimal Payoff on End Points - in thousands of US$

Point	Value of Underlying Assets	Training Pricing	Optimal Payouts	Decision
D	12,198	8,000	12,198	Go
E	9,500	8,000	9,500	Go
F	7,399	8,000	8,000	Abandon

Replicating portfolios is used based on calculations that have been obtained from the previous steps. The portfolio used to replicate payouts consists of a number of units of twin security or underlying risky assets and a number of B units of risk-free bonds.

Table 5. Recapitulation of Option to Abandon Calculation Results

Titik	m	B	Value of Put Option	Decision
D	N/A	N/A	12,198	Go
E	N/A	N/A	9,500	Go
F	N/A	N/A	8,000	Abandon
B	0.9985	19,281	10,768.134	Go
C	0.7128	2,695.391	8,671.506	Go
A	0.88	1,287.972	9,647.972	Go

The backward calculation starts at point C which is determined by two points, namely point E and point F. Using the replicating portfolio equation:

$$m = (Pdu - Cdd) / [dV_0(u - d)] \quad B = [uCdd - dCdu] / [(1 + r_f)(u-d)]$$

For point C: m = 0.7128 and B = 2,695,391 US$. The replicating value of the portfolio is equal to the put option value at point C of US$8,671,506. Furthermore, the backward work shifts to point B which is related to endpoint D and endpoint E. With the same calculation, m = 0.9985 and B = 19,281 US$ are obtained. The put option value at point B is 10,768,134 US$.

The backward work then switches to point A with the optimal payoff value of the A point compiler, which is 10,768,134 US$ in the "up" (Cu) condition and 8,671,506 US$ in the "down" condition (Cd). The calculation yields m = 0.88 and B = 1,287,972 US$, so the put option value at point A is 9,647,972 US$.

This value is the total value of the investment field project where Total Value = NPV + the value of the option to abandon. Thus, the additional value obtained by including the option to abandon is 9,647,972 US$ - 9,500,000 US$ = 147,972 US$.

Analysis of Options to Expand

For the option to expand, the assumptions used are the same as those applicable to the option to abandon, namely project volatility of 0.25/year, the number of periods of 40 periods (4 x 10 years), up movement (u) = 1.133148, down movement (d) = 0.882497, risk free rate (rf) = 5%/year, cost of capital = 15%, and probabilities (p) = 0.621245.
The optimal payoff criteria at the endpoints are determined by the following criteria:
Payout = MAX [Vt, X]
where X is the value of the project after deducting the expansion cost of US$1,700,000.

Table 6. Payoff at Endpoints for Option to Expand (End Nodes) - in thousands of US$

Titik	Value of Underlying Assets	Value of Practice	Optimal Payouts	Decision
D	11,171,012	10,558,113	11,171,012	Go
A	8,700,000	7,000,000	8,700,000	Go
F	6,775,568	5,075,568	6,775,568	Go

Table 7. Option to Expand Calculation Results Recapitulation

Titik	m	B	Call Option Value	Decision
D	N/A	N/A	11,171,012	Go
E	N/A	N/A	8,700	Go
F	N/A	N/A	6,775,568	Go
B	0,9986	-16,391	9,827,795	Go
C	0,9986	-13,059	8,700,879	Go
A	0,527	-4,682,432	9,206,432	Go

For example, at point D, E, and F, if you leave the "kept alive" option and the company maintains the base case, the value of the project at point D is $11,171,012. Meanwhile, the value if the company chooses to exercise the option, the value obtained is only US$ 10,558,113. This happens because of the consequence of an additional investment cost of US$ 1,700,000 in exercising the option to expand.

The backward work begins at point B with the calculation of replicating the portfolio which results in m = 0.9986 and B = -16.791. The payoff value of the option at point B is 9,827,795 US$. Furthermore, the work shifted to point C with the result m = 0.9986 and B = -13.0595. The value at point C is 8,700,879 US$. At point A, with a value at point B of 9,827,794.8 for the ascending condition (Cu) and 8,000,879.5 for the descending condition (Cd), the calculation yields m = 0.527 and B = 4,682,432. The current value at Point A is 9,206,432 US$.

Based on these results, the Total Value of investment projects increased by US$ 9,206,432 - US$ 8,700,000 = US$ 506,432.

Mutually *Exclusive Alternatives*

In considering which option to choose for this project, it is necessary to conduct a simultaneous assessment (combination review) so that it can be known what decision will be taken at each decision point.

Table 8. Payoff at Endpoints for Combination of Options - in thousands of US$

Titik	Go (Not Exercising)	Abandon	Expand	Optimal Payouts	Decision
D	12,198	8,000	10,558	12,198	Go
E	9,500	8,000	7,000	9,500	Go
F	7,399	8,000	5,699	8,000	Abandon

The payoff of each mutually exclusive decision is assessed from the end point. The decision with the highest payoff is the one that is chosen as the optimal decision. At point D, the comparison between the three options yields: MAX [12,198; 8,000; 10,558.11] = 12,198 (Go). At point E: MAX [9,500; 8,000; 7,000] = 9,500 (Go). At the point F: MAX [7,399; 8,000; 5,699] = 8,000 (Abandon).

The work is backward to Point C and Point B. At Point B, the calculation results in a payoff option value of 10,768,134 US$.

CONCLUSION

This study demonstrated that the real options approach using a binomial model offers a more comprehensive evaluation of offshore oilfield investments than the traditional NPV method. The option to abandon added $174,972 in value, and the option to expand added $506,432, although only the abandonment option was optimally exercised under adverse conditions. This increased the total project value to $9,674,972 from the conventional NPV of $9,500,000, supporting investment in a previously marginal project. Real options effectively capture the indirect cash flows associated with managerial flexibility amid high uncertainty typical of the petroleum industry. The study recommends integrating real options with traditional capital budgeting, supported by robust governance frameworks and the development of internal expertise and computational tools to accurately estimate inputs and ensure successful implementation. Future research could explore real options valuation under dynamic regulatory conditions and market shifts specific to emerging oil markets to improve decision-making adaptability.

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