4272

INVESTMENT UNDER UNCERTAINTY:

APPLICATION OF BINOMIAL OPTION ANALYSIS

TO DEVELOPMENT OF GEOTHERMAL ENERGY IN INDONESIA

A DISSERTATION SUBMITTED TO THE GRADUATE DIVISION OF THE UNIVERSITY OF HAWAI'I IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN

ECONOMICS

DECEMBER 2002

By
Asclepias Rachmi Soerjono Indriyanto

Dissertation Committee:

Ujjayant Chakravorty, Chairperson
Sumner La Croix
Andrew Mason
Fereidun Fesharaki
Nicholas Ordway

To my parents:

Soerjono Soedibjo – in memoriam

and

Jussilvia M. Roosmailie

ACKNOWLEDGEMENTS

A great many people have knowingly and unknowingly contributed to this accomplishment. Their care, love and patience have given me strength and have helped me overcome many difficulties along the way. Since I might not be able to express my gratitude adequately, I pray to Allah for His blessings over every one of them.

I would like to thank Professor Chakravorty for his advice and willingness to chair the committee, Professor Mason for his thoughtful comments, and Professor Ordway for his ideas and radiant energy that has been contagious. I would especially like to express my appreciation to Professor La Croix for his helpful guidance and constant encouragement, and to Dr. Fesharaki for his tremendous support in many forms that made things possible.

I am indebted to my dear friends Widyanti Soetjipto, Widhyawan Prawiraatmadja, and Wiwik Bunjamin, who are my life support during the hard times away from home. I also thank Gayle Sueda for her generous assistance to ensure a pleasant work environment and to endure the pain in editing the manuscript.

Finally, I would like to express my sincere gratitude to my husband Hartono Indriyanto, our children Dita and Baska, and our extended family, which have been very patient and compassionate during this long journey.

ABSTRACT

Indonesia has identified a large amount of geothermal resource potential throughout the islands. However, geothermal utilization is presently low. One of the main reasons is due to limited government funds to develop the resources. Another contributing factor is the high prices charged by private geothermal electricity producers, which was part of the reason why the government suspended most private geothermal development projects. The common perception blames corruption, collusion and nepotistic behavior of the market participants for this unfortunate situation.

This research shows that even if opportunistic behavior is cast away, the present business arrangement corresponds to an incentive system that brings about high geothermal electricity prices. Applying the Real Option Theory reveals that managerial flexibility in the decision-making process of a geothermal project is valuable, since it allows the use of updated information.

In contrast to the present ex-ante price determination setting, a possible way to incorporate flexibility is to agree on output price after exploration activities are concluded. Under certain conditions, this ex-post price determination setting may produce a wider range of feasible prices that includes those lower than the ex-ante price. As such, incorporating flexibility into the decision process improves project value and may lower its output price.

The research model implicitly assumes the first-best world with respect to the assumptions of symmetric information and a simple self-interest behavior. These two assumptions set the limitation of the model results. In a complex world with incomplete

and asymmetric information as well as opportunistic behavior of the market participants, the ex-post price determination is likely to fail due to reciprocal concerns of the parties. A two-phased negotiation system may attenuate the opportunism concerns, while provides assurance that only viable projects can survive.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Indonesia has identified a large amount of geothermal resource potential throughout the islands. However, geothermal utilization is presently low. One of the main reasons is due to limited government funds to develop the resources. Another contributing factor is the high prices charged by private geothermal electricity producers, which was part of the reason for the establishment of the government policy to suspend most private geothermal development projects. The common perception blames corruption, collusion and nepotistic behavior of the market participants for this unfortunate situation.

This research shows that even if opportunistic behavior is cast away, the present business arrangement corresponds to an incentive system that brings about high geothermal electricity prices. Applying the Real Option Theory reveals that managerial flexibility in the decision-making process of a geothermal project is valuable, since it allows the use of updated information. In contrast to the present ex-ante price determination setting, a possible way to incorporate flexibility is to agree on output price after exploration activities are concluded. Under certain conditions, this setting may produce a wider range of feasible prices that includes those lower than the ex-ante price. As such, incorporating flexibility into the decision process improves project value and may lower its output price.

The research model implicitly assumes the first-best world with respect to the following two assumptions: (i) symmetric information, which means market participants reveal full information when requested, and (ii) minimal opportunistic behavior, which means while maximizing profits; parties are trustworthy and lawful. These two assumptions set the limitation of the model. In a complex world with incomplete and asymmetric information as well as opportunistic behavior, there are implications from incorporating flexibility into the decision process. Although a full study regarding this issue is beyond the scope of this research, an informal discussion in the last chapter addresses some concerns.

This chapter provides a background for the research framework. The first section illustrates the complexities of problems in the electricity sector in Indonesia. The second section specifies the research boundaries. The third section discusses the reasoning of considering uncertainty as an important issue in the research model. The fourth section summarizes the other chapters in this dissertation.

1.1 THE ELECTRICITY SECTOR

Electricity development in Indonesia had remarkable statistics indicated by, among others, a higher than 10% per year average growth in installed generating capacity as well as consumption during the 1980s and early 1990s. However, the electricity sector has been in turmoil following the Asian financial crisis that also hit the country in mid-1997. In only four months the Rupiah, the Indonesian currency, lost 80% of its value. This severe depreciation also posed significant impacts on PLN, the state-owned utility company, which carried heavy US$ debts for infrastructure investments. Moreover, PLN had obligations to pay billions of US$ to independent power producers (IPP) under several existing long-term power purchase agreements (PPAs).

In late 1997, the government was forced to seek a bailout package organized by the International Monetary Fund (IMF). Motoyama and Widagdo (1999) cite a PLN audit report dated 1999, conducted by Arthur Andersen under the instruction of the IMF:

> "The audit report reveals that PLN has to bear a total loss of ... approximately US$29.8 billion, which is about one and a half times the State Budget of Indonesia. Andersen likewise reports that of these incurred losses, US$18 billion is attributable to the abuse of power in the private power purchase agreements ..., US$10.7 billion as losses caused by the increased exchange rate, and US$1.5 billion from the inefficiency of PLN operation."

PLN was on the brink of bankruptcy that it needed to operate under massive government subsidies. It was unable to fulfill its obligation to purchase electricity under its PPAs. Shortly afterwards, this was followed by the suspension of 27 IPP projects with a combined capacity of about 15,000 MW by Presidential Decree No. 37/1997. Although a later revision of the policy reduced the suspension to 16 IPP projects, such disruption has yielded several arbitration and litigation cases (Seymour and Sari, 2002; World Energy Council, 2001; Motoyama and Widagdo, 1999).

The participation of IPPs in the Indonesian electricity sector has been controversial. On the one hand, the World Bank as a major donor in late 1980s suggested that PLN should pursue a strategy of deregulation, decentralization and competition in order to move from bureaucracy to enterprise. Further, they suggested the government, albeit with caution, consider attracting private capital to finance the rapidly increasing demand for electricity as well as to compete with PLN. Competition forces power generators to innovate and operate in the most efficient and economic manner in order to remain in the business and recover their costs, thereby benefiting consumers (Bhattacharya et al., 2001). Hence, private participation was initiated to become one of the drivers for a continuous strong growth of the sector and to provide better service to the customers.

On the other hand, the implementation of this strategy led to several concerns: (i) indication of corruption, since most negotiations took place in unsolicited, non-transparent bidding processes, resulting in higher than estimated costs, high prices, dollar-pegged, and take-or-pay conditions that were commonly considered as in favor of project investors, (ii) large excess generating capacity that showed unwarranted investment, and (iii) involved indirect pressures from donor governments (Seymour and Sari, 2002; Smith, 2002; Institute for Policy Studies and The Transnational Institute, 2001; Howard, 1999).

Among the three concerns, corruption is recognized as one of the biggest problems in Indonesia. There have been a lot of discussions and movements to eradicate corruption.[1] However, its severity remains (Asian Development Bank, 2002; Perlez, 2002).

By now, the Asian crisis has caused multi-dimensional problems in all sectors of the Indonesian economy. The Rupiah stays at around 300% lower value than it was in early 1997. This means that PLN debts to lenders as well as having to fulfill its existing obligations to the IPPs has worsened into three times larger in terms of the local currency. As PLN earns its revenue from electricity consumers, this financial burden eventually falls on the public in the form of significantly higher prices of electricity. In addition, the pattern of an ever-increasing government budget for subsidy allocation is not sustainable.

[1] For example, documents produced by Partnership for Governance Reform in Indonesia (2002), Harahap (1999), and Motoyama and Widagdo (1999) show collaboration among many groups both inside and outside Indonesia, including some international donor agencies, that share similar concerns.

This means there are pressures for gradual elimination of various forms of energy subsidies, which translates into an increasing trend of prices. Combining these factors, it is clear that price adjustments are inevitable. Nevertheless, it has never been an easy task to raise prices when the economy is in distress. The social, political, and security concerns have been complicating the adjustment process.

In summary, most of the public concerns have been focused on the governance issues and opportunism behavior of the market participants. It is also widely recognized that the implementation of the strategies drafted to improve these aspects would take significant time. The ongoing price adjustments are inevitable, but the implementations have been a delicate matter. The whole picture above illustrates the problems and the dynamics of efforts to improve the electricity sector in Indonesia.

1.2 RESEARCH BOUNDARIES

Against this backdrop, the initial interest toward geothermal electricity development was mainly motivated by the following two ironies:

(i) Geothermal resource potential is estimated to be around 20,000 MWe,[2] which is comparable to the current size of PLN generating capacity of combined energy sources. Despite this large estimated potential, there is only 787 MW installed capacity at the moment.

(ii) In contrast to the merit dispatch order, some private geothermal projects with high electricity prices are determined as base load suppliers.

[2] Stands for MegaWatt energy, which reflects equivalent energy to generate electricity of that amount.

The first issue is important with respect to the government policy to diversify the domestic energy utilization. Table 1-1 shows that this policy works for fossil fuels, but has a very small effect on geothermal and none on renewable energy resources (Ariati, 2001). It can be argued that there has been no significant progress towards sustainability in the energy sector, although this may be due to the instability of the currency (Soejachmoen, 2002). Furthermore, combinations of high growth in electricity demand even during the crisis years, decreasing oil production, and tight government budget allocation for imported fuels, calls for more utilization of endogenous energy. A large potential of geothermal energy, which can only be used in the surrounding area, is a good candidate for meeting domestic need.

The second issue is important since as discussed earlier, high prices that are also linked to US dollar had imposed a heavy financial burden to the utility company and led to a halt in geothermal development projects in recent years.

Table 1-1. Share of Energy Utilization (%)

	1970	1998
Oil	88	59
Gas	6	25
Coal	1	19
Geothermal	0	1
Hydro	5	5

Source: Ariati (2001)

The research aims to look at possibilities to improve the utilization of geothermal energy in Indonesia. Nevertheless, considering the peculiarities in the geothermal electricity sector and the larger problems in the Indonesian economy in the background, it was not immediately clear as to how and where to find the possible answers. Are these all about opportunism behavior? Would moral or ethical issues, problems in the legal and judicial system, an unfinished agenda in civil service reform, and inadequate public sector spending describe the driving forces behind the problem? Chances are that all of these factors are intertwined, but also that it would be difficult to distinguish their effects individually. A candidate framework for understanding the complexity and diversity of overall institutional arrangements across the economy would be the Comparative Institutional Analysis approach introduced by Aoki (2001).

On the contrary, this research focuses on the geothermal project itself and less emphasis on the other problems in the electricity sector and the Indonesian economy to avoid the above overwhelming complexities as the starting point. Further, the research concentrates on the significance of natural characteristics of geothermal resources to the project. The benefit of restricting the interest span is to help isolate some inherent issues specific to geothermal electricity projects. On the other hand, a drawback of this approach is that the model does not facilitate a direct examination on strategic behavior of the parties involved in this activity. However, insights on the distinctive nature of geothermal resource developments may compensate this disadvantage and may serve as a base for more complex settings. Based on the research findings, Chapter 6 extends the analysis to address this concern. Another drawback is an unclear picture of the findings impact on the utilization of geothermal energy resources of the country, since the latter also depends on various other factors beyond the project boundary such as investment climate of the economy. Nevertheless, the research findings point toward specific ways that can be used to facilitate the transaction process between the government and potential private developers.

1.3 UNCERTAINTY ISSUE

Investment requires pre-commitment of resources in order to obtain later benefits. As many sources of uncertainty may affect actual benefits to be received, the *initial* decision to devote the resources may or may not be worthwhile. The intricacy of many factors that come into play makes investment decisions under study for a long time.

In a geothermal electricity project, the future benefits would come from sales of converting geothermal energy into electricity, and these future benefits should be large enough to cover the previous expenditures and some profits. The project involves large capital outlays during early years, which are mostly used to obtain more information and knowledge about economic feasibility of the prospect area. Table B-2 in Appendix B illustrate the magnitude of average capital requirement in the existing geothermal projects in Indonesia. Major allocation of capital during this exploratory stage of the project is to drill some wells, which would reveal underground characteristics of the reserve that provide inputs to estimations of reserve size and additional capital requirements. When such search concludes the presence of a feasible reserve, further expenditures are required to prepare for production activities. These costs are mostly for drilling more wells and constructing necessary systems to develop the field as well as power plant facilities. Earnings would start only after exploration and development stages are completed.[3]

A project with the above characteristics is considered risky due to (i) uncertainty in resource existence, quality, and feasibility; (ii) the sizeable capital to be invested early on; and (iii) the lead time of studies and preparation before the project generate earnings. As the resource base is uncertain to begin with, the future earnings of the project are also uncertain. These features show that uncertainty is a major factor in this case.

Furthermore, the institutional economics literature, such as works on transaction costs and incentives treat uncertainty as a precondition for the settings or a prior base of knowledge:

> "But for uncertainty, problems of economic organization are relatively uninteresting. Assume, therefore, that uncertainty is present in non trivial degree..." (Williamson, 1985)

> "The problem of managing information flows was the first research topic for economists, once they mastered behavior under uncertainty ..." (Laffont and Martimort, 2002)

Since uncertainty is a necessary condition, the subject deserves a closer attention. This translates to examining the implications of recognizing the fact that uncertainty is significant in the geothermal electricity case. The issues of opportunism and incentives may enter the discussion, but the main approach for this research is based on uncertainty consideration. Therefore, a growing literature on 'investment under uncertainty' is consulted to find a suitable methodology.

[3] Partial development, such as completing 1 x 55 MW facility of the total 2 x 55 MW planned capacity, is possible.

1.4 CHAPTERS OUTLINE

The following subsections serve as a brief summary of the rest of the chapters in this dissertation. The first part represents Chapter 2 that discusses the literature on investment and uncertainty. The second part corresponds to Chapter 3 about research contribution. The third part sketches the issues on geothermal development in Indonesia, which details are presented in Chapter 4. The fourth part abridges Chapter 5, highlighting some notes on the application of real option analysis to an investment opportunity in geothermal electricity project. The last part underlines some policy implications discussed in Chapter 6.

1.4.1 Investment Literature and Practices

The rules of optimal investment behavior and major determinants of investment decisions in economic theory are not consistently observed in the actual business practices. The literature on investment under uncertainty is one of the theoretical explanations that attempt to reconcile the gap between investment theory and the observed corporate investment behavior.

The way investments are modeled and assessments are conducted may affect the value attached to the project and its components, as well as the expected future benefits from investment activities. Inappropriately ignoring some of the project features may lead to under-valuation and consequently overlook potentially good investment candidates.

There are two major groups of work in the investment under uncertainty literature, which are (*i*) The Orthodox Theory, and (*ii*) The Options Approach. The first group consists of works based on individual or combinations of the following theories: q-theory of investment, as well as frictions in investment decision such as adjustment cost and irreversibility. The underlying principle of investment decision in these works is the net present value (NPV) rule, which is to select a project with positive NPV and to reject otherwise. The NPV rule has been widely used, although implementations may or may not comply with the underlying assumptions of the theory. Nevertheless, this practice does not allow later decisions to be incorporated into the initial investment valuation.

The second group of approach perceives investment opportunity as an option. Spending initial investment to acquire an investment opportunity does not necessarily require the investor to invest again in the future. Instead, holding investment opportunities allow investors to have a portfolio of future decisions. This translates to flexibility in management decisions, which can be exercised to improve profits or to mitigate losses.

The theory of measuring how much an option is worth originates in the financial options literature. A financial option is a contract that provides the holder a right but not an obligation to buy or sell the underlying financial asset at a predetermined price at a certain future date. Widely known methods to value financial options are (i) those based on the Black-Scholes (1973) formulation, and (ii) based on the Binomial Lattice framework introduced by Cox-Ros-Rubinstein (1979). Both methods are based on the no-arbitrage principle, i.e., they value options by combining two available securities with known payoff to construct a portfolio that reproduces the local behavior of the derivative security (Luenberger, 1998). The basic difference between the Cox et al. method and the Black-Scholes formulation is the assumption of how asset price fluctuates. Black-Scholes assume that the price of the underlying asset fluctuates following an Ito process, which means the approach employs continuous representation of stochastic behavior of the price. Cox et al. assumes binomial distribution with symmetrical up and down steps, which represents fluctuation of the price of the underlying in discrete time.

Table 1-2 lists six variables that determine the value of options. The original Black-Scholes formulation involves only five variables, since it assumes there are no dividends payments during the life of the option. Merton (1973) generalizes the formulation to include dividend payments. These same sets of variables also determine the value of non-financial or real options. The first column of Table 1-2 lists these variables in real option context. In addition, the value of real options may be affected by other variables that characterize the complex setting of the problem.

Table 1-2. Determinants of Option Value

Determinants		The effect of an increase in the value of a determinant	
Real Option	Financial Option	Call	Put
Value of the underlying asset	Stock Price	Increase	Decrease
Exercise price or investment cost	Strike Price	Decrease	Increase
Standard deviation of the value of the underlying asset	Volatility of Stock Price	Increase	Increase
Time to expiration of the option	Time to expiration of the option	Increase	Increase
Risk-free rate of interest	Interest Rate	Increase	Decrease
Dividends payout	Cash Dividends	Decrease	Increase

Source: Copeland and Antikarov (2001), Bodie and Merton (2000)

Although the real option concept is compelling and has been explored in the literature for more than a decade, its implementation is still considered at infancy. The reasons for the slow development are: (i) the complexities surrounding real options, (ii) some significant uncertainties will likely remain at the time of real option decision, and (iii) highly sophisticated mathematical techniques in the literature.

Copeland and Antikarov (2001) proposes an approach that can overcome some parts of the first and third obstacles above, namely identifying the underlying asset, estimating its value, as well as the technique of assessing the real option value. There are two necessary assumptions for this approach. The first assumption is called the Marketed Asset Disclaimer, which uses the present value of the project itself as the underlying risky asset in place of the 'twin security' in the financial option theory. The second assumption asserts that properly anticipated prices fluctuate randomly; therefore, the rate of return on any security would be a random walk. Samuelson (1965) proves the latter assumption, and Copeland et al. (2001) conduct an empirical study to show that, based on Samuelson's proof, it is also true that real equity returns on properly anticipated streams of cash flow fluctuate randomly.

Another work that is used as a reference in this research is Cortazar et al. (2001), which evaluates a natural resource extraction project. The extraction-development-production stages of the project are modeled as sequential compound options. All phases are optimized contingent on price and geological-technical uncertainty. The model collapses price and geological-technical uncertainties into a one-factor model.

1.4.2 Research Contributions

Despite keen interests of various parties to develop geothermal resources in Indonesia, the existing fundamental problems have led to very little or no progress in recent years. Motivated by the present unfortunate condition of geothermal development, this research aims to:

1. Model a geothermal development project using options theory. This approach is expected to enable a wider perspective and better understanding of the present problems in geothermal development in Indonesia.
2. Compare options-based to the standard NPV decision-making.
3. Explore alternative arrangements that are potentially Pareto improving to induce geothermal development.
4. Contribute to the literature on real option and natural resource development in the following ways:
   - The application to geothermal development adds to the body of works in real option analysis on natural resource extraction. In addition, this case combines natural resource extraction with electricity generation activities, which are usually treated as separate subjects.
   - The case highlights the problem of non-traded underlying asset and the way to overcome this barrier to enable the application of real option approach.

1.4.3 Geothermal Developments in Indonesia

Indonesia has identified 244 geothermal prospect areas all over the islands, with estimated potential capacity of around 20,000 MWe. Appendix B shows the locations of these identified geothermal potentials. However, after 20 years of development, there are only 787 MW installed geothermal plant capacity and among them merely 525 MW in operation.

Significant factors causing the slow progress are the existing business arrangements where output price is set before the project starts and the limited initial information about the prospect areas due to restricted government funding. In addition, some geothermal projects operate under Build-Operate-Transfer contract, where private operators are required to transfer plant ownership to the utility company around the midlife of the project operation. This means investors need to recover a portion of their capital outlay in a shorter period of time. These factors combined cause high prices of geothermal electricity supplied by private operators.

A geothermal project is characterized by large capital outlay during the early years, sometimes much higher than that of a similar plant using conventional fuel. However, in a geothermal plant, the energy component costs far less than those of conventional fuels. Therefore, the savings in energy costs should recover the higher capital outlay. Since savings in energy costs are obtained over time, geothermal plants should be designed to have a long enough lifetime to amortize the initial investment (Dickson et al., 1995). In addition, this investment profile suggests that a viable geothermal power requires consistently high revenue, which means steady sales. This condition implies that it effectively competes only with base load power sources (Blair et al., 1982).

The existing geothermal power plants in Indonesia are treated as a 'must-run,' which means they are supplying the base load of the system. This policy is a consequence of contractual obligations that requires the utility company to purchase the power produced by these plants. However, the high prices of some geothermal plants actually position them at a lower order in the merit system of a dispatch. Without the 'must-run' policy and if other base load suppliers can provide the amount at a lower price, the utility company would be better off without supplies from these expensive geothermal plants. A pure merit system of load dispatch would leave these plants out of the system. Hence, geothermal plants are not competitive.

The economic crisis that started in 1997 had strong effects on geothermal development. The government suspended 16 private power generation projects that included seven geothermal projects. These suspensions were followed by legal disputes between several developers on one side and the electric utility company, Pertamina and the government of Indonesia (GOI) on the other side. Despite recent GOI efforts to lift their previous decision, geothermal development progress is still stalled.

In addition, recent changes in several laws and regulations that affect energy sectors aggravate the uncertainties. The previous legal system put geothermal projects in the same position as those of oil and gas, plus some special treatments on taxes. Recent changes separate geothermal from that group, but a new regulatory base has yet to be put in place.

1.4.4 Real Options Analysis for a Geothermal Project

This research considers risks and uncertainties in a geothermal project as the central issue affecting investment decision. The uncertainties over quantity and quality of geothermal reserves contribute to uncertainties of a project's existence and therefore, risking the expected return of the large upfront capital outlay. In addition, the present practice in Indonesia requires the output price for electricity to be produced by the project be determined during a negotiation that takes place before the project starts. This means that a developer needs to propose a price based on very limited information about reserve existence and feasibility, as well as the expenses they would need to disburse.

A smaller than expected reserve translates to smaller power plant capacity and consequently, less electricity revenue. A lower than expected quality may be due to lower enthalpy[4] or higher content of impurities[5] of geothermal fluid in the system, or a less productive well; thus, generally leads to higher costs as more wells or extra equipments and materials are required. Under this condition, a developer would face potential losses if proposing a price based on an estimate of large and good quality reserves but exploration results indicate the opposite.

On the other hand, proposing a price for small and mediocre quality reserves means investors propose a relatively higher price. If the reserve turns out to be great, costs tend to be lower than expected and capacity may be able to be expanded. This would provide room for higher benefits.

Hence, it is logical to consider a worse state of reserve conditions for determining the output price. This means investors would tend to propose more expensive prices than the level dictated by the actual reserve condition. Further, lowering the assumed quality and/or quantity of the reserve would justify increasing the proposed price.

---

[4] The heat (thermal energy) content of geothermal fluids, usually considered as proportional to temperature.
[5] Among others, corrosive substances are the most concerned.

The above line of thinking shows that ex-ante pre-commitment to a certain price adds pressure toward higher price of geothermal power, as well as motivates opportunistic behavior by private developers. This research explores how considering flexibility, as introduced by real options analysis, alter the above picture. Modeling the project as sequential compound options and measuring the value of such options reveal that there is additional value from taking into account the possibility of adjusting investment decisions at future dates. In other words, the prevailing ex-ante price determination system undervalues the project. Furthermore, real options analysis also shows that it is possible to associate a profitable geothermal project with a price that can compete with the average prices of other base-load suppliers.

1.4.5 Policy Implications

The implication of taking flexibility aspect into consideration can be exemplified further by reviewing the implication of a better-than-expected exploration outcome, which is a common feature in the existing geothermal projects in Indonesia. This exercise shows that considering the expansion option presents a wider range of feasible prices for the project.

This is important information to be considered in determining the output price, since it says that it is possible to relate profitable geothermal electricity projects with lower output prices. Since expansion option is known after the exploration works have been concluded, this finding also suggests that it is worth to consider deciding the output price after the exploration stage. A price determination after the exploration phase can be referred to as 'the ex-post structure,' in contrast to the ex-ante system that presently prevails.

Assuming symmetrical information and a simple self-interest seeking behavior[6] by both parties, the ex-post structure offers a set of incentives to develop geothermal resources. From the company's point of view, this structure provides information to consider a lower feasible price than the level dictated by the ex-ante price. These lower and yet feasible prices would improve the chances of the company to compete with the other base load suppliers, and therefore, securing their position in the merit order of load dispatch.

The ex-post structure is also of interest to the utility company, since (i) having geothermal power plants supply power at competitive prices would reduce the financial burden that is presently imposed to the utility due to the 'must-run' policy, and (ii) having geothermal plants in the system means a diversification of supply base that could increase reliability of the system.

From the point of view of the government, the ex-post structure would be able to serve as a self-generating motivation for geothermal development that would hopefully attract more parties to participate. In addition, development of geothermal resources would help ease the pressure on domestic demand for energy.

The above results show that under the assumption of symmetrical information and minimal opportunistic behavior, the ex-post structure is Pareto improving. This improvement would also be socially desirable, especially for many regions where

[6] Information is fully and candidly disclosed upon request, accurate state of the world declaration, and oath- and rule-bound actions (Williamson, 1985).

geothermal potentials have been identified and plans to develop the resources do not materialize due to the existing problems.

However, the two assumptions above imply that the results are applicable in a simple world. When such assumptions are relaxed, then the ex-post arrangement has to deal with consequences of asymmetric information and opportunistic behavior of the parties. Reciprocal concerns of the parties indicate that the ex-post structure is likely to fail.

Williamson (1986) suggested that an adaptive-sequential contract could overcome opportunism behavior of the parties involved in an idiosyncratic investment project. An alternative to incorporate flexibility that also addresses the opportunity concerns is a two-phased price negotiation arrangement, where the first phase sets a boundary of acceptable prices for the project prior to any engagement and the second phase determines a specific output price based on the exploration results.

In this case, the first phase agreement serves as pre-commitment conditions for both parties. It says that only viable projects would survive as candidate suppliers to the base load electricity system, addressing the possible opportunism behavior by the private developer. On the other hand it also says that the price range indicates acceptable charges, therefore it can be seen as a purchase guarantee. Conducting the second phase of negotiation after the completion of exploration activities would provide better knowledge on reserve feasibility, and would facilitate a more realistic project valuation for both parties at the negotiation table. An appropriate agenda for future research is employing a game-theoretic analysis as well as a game-theoretic framework for institutional analysis to identify the safeguard mechanisms against these possibilities.

CHAPTER 2

INVESTMENT OPPORTUNITY

The first part of this chapter summarizes the main thoughts in investment literature, paying special attention to the theory of investment at the corporate level. Recent developments emphasize irreversibility, uncertainty, and timing as important factors affecting investment decisions. A particular interest is given to a growing body of works that view investment as a real option. The discussion covers how well the concept had been accepted as well as impediments in its implementation.

The second section features financial options, which serves as a base to illustrate comparable issues in the real options concept. The main argument is that options offer flexibility that can be valuable, and there are ways to measure their theoretical values. Black-Scholes formulation and Binomial Lattices framework are two major approaches to value financial options. A review on these two approaches highlights the line of thoughts and their distinctive means in representing financial options.

The third part of this chapter takes a closer look at unique characteristics of real options. Despite many similarities between financial options and real options, there are peculiarities in real options that lead to more complex issues concerning the representation of real option situations as well as several aspects about the underlying asset.

The fourth part overviews the applicability of major approaches in representing investment opportunities as real options. Recent works suggest that some form of integration that involves several methods is superior to the use of individual approach in isolation.

The last section summarizes major influences of several existing literatures to this research. These works introduce the real options concept, suggests ways to represent real option situations, illustrate an application of real options concept in natural resource extraction, and provide advancements to overcome difficulties in assessing the worthiness of real options cases. They are selected as references to highlight shared features as well as to point out idiosyncrasies of the case studied in this research.

2.1 INVESTMENT

Investment has been generally defined as current commitment of resources in order to achieve later benefits (Luenberger, 1998). Individuals or groups can attempt to influence their future well-being through direct purchase of intangible or tangible capital assets such as education or a house respectively; or through the purchase of financial assets, which are a form of claims to some pattern of future payments. Firms can invest in the form of certain employee trainings, in 'goodwill' via advertising expenditure, in 'knowledge' via research and development activities, in stocks of finished goods or raw materials or work in process, as well as in fixed capital stock such as plant or machinery, office spaces or vehicles. In the aggregate, investments made by firms are crucial to the short- and long-term economic growth of the country in which the firms operate (Nickell, 1978).

2.1.1 Theory versus Observed Investment Behavior

As one of the oldest subjects in economics, the investment-related literature is vast. Various aspects of the subject are still under intense study, especially the investment behavior of firms. The gap between economic theory and the results of empirical models of corporate investment behavior has been observed for many decades. For example, private investment equations in macroeconomic systems perform poorly in terms of variance explained. At the microeconomic level, the observed determinants of investment are often variables that are theoretically inferior[7] such as hurdle rates or profitability indexes, while important variables in the literature such as the user cost of capital or Tobin's q are often found to be statistically insignificant (Jorgenson, 1963; Sangster, 1993; Chairath et al., 1997; Lensink et al., 2001).

Research to find more convincing theoretical explanations of corporate investment behavior is presently classified into (i) investment under uncertainty, and (ii) investment and capital market imperfection. The first body of work is the underlining theory for this dissertation and hence is discussed in later parts of this chapter. The second group asserts that capital markets are imperfect due to asymmetric information or agency problems. Therefore, in contrast to the view of perfect capital markets, the market alone does not provide a well-defined signal for the value of the investment. This condition implies that internal and external funds are imperfect substitutes. Therefore, financial structure becomes an important determinant of corporate investment, and

[7] They are seemingly arbitrary investment criteria commonly known as 'rules of thumb'. McDonald (2000) examines these ad hoc investment rules and concludes that they can proxy optimal investment behavior. This is apparently because their use in practice might be a result of previous successes of those arbitrary rules to be close to optimal over time.

corporate investment is sensitive to internal funds. Lensink et al. (2001) review theoretical as well as empirical works in both fields to contribute toward reconciliation. However, they conclude that a theoretical synthesis between the two lines of research is rather difficult to make, either due to complications of the resulting models or limitations from assumptions employed.

This dissertation focuses more on investment decisions of firms when the quantity and quality of the natural resource as the main input is not known at the time of project initiation. Moreover, based on such limited information, the firm is required to propose a future output price. Future benefits of this project can vary greatly by the input condition, the proposed output price, as well as the amount of required capital to find the resource and develop the facility. The combinations characterize this activity as a very risky investment that yields a highly uncertain outcome. Thus the research focuses on the impact of these uncertainties to the overall project assessment that underlies the initial investment decision. Therefore, instead of being based on capital market imperfection thoughts, the investment under uncertainty point of view is considered as the more appropriate setting for the research analysis.

Nevertheless, several issues related to the capital market imperfection line of thinking are taken into consideration. The first is difficulties in finding traded assets that have similar risk profile to the project to be valued, which reflects the lack of market information to be used in project assessment. Sections 2.3.2-(d) and 2.4.4 discuss this issue. The second is problems of asymmetric information and opportunism behavior of economic agents, which is addressed in Chapter 6. The third issue is financial structure of the project. The financial model in this research addresses imperfect substitutability of internal and external funding by assigning different returns and allocates their use in specific stages of the project.

2.1.2 Investment Under Uncertainty

There are two major strands of literature for investment under uncertainty, which is commonly grouped as *The Orthodox Theory* and *The Options Approach* (Dixit and Pindyck, 1994; Lensink et al., 2001). Some recent works attempt to consolidate the two views, recognizing that they yield similar results although each provides distinctive insights on the investment behavior of firms.

The works of Orthodox Theory ignore the implications of irreversibility in investment, as well as the possibility to delay investment decision. In the 1960s, a group of works in the literature employed static models that ignored adjustment costs for investment, and primarily dealt with the effect of uncertainty on production and optimal input mix. These models are closely related to Jorgenson's model (1963) that determined the firm's desired cost of capital by equating the marginal product and the user cost of capital. Other similar strands of research follow Tobin's (1969) approach, which compares the capitalized value of the marginal investment to its purchase cost. This ratio is known as *Tobin's q*[8] and the works along this line are often classified as belonging to

[8] Some papers in the literature referred to this ratio simply as *q*. However, Abel (1983) differentiates Tobin's q with the ratio he used in his work that compares marginal adjustment cost with the marginal value of installed capital. Hence, he labeled his ratio as *marginal q* and Tobin's q as *average q*.

the *q-theory* of investment. The common interpretation of the theory is to have a decision to invest based on a criterion of $q \geq 1$. However, empirical works indicate that firms would invest only if $q >> 1$. This suggests that the q-criterion is not able to sufficiently explain the additional requirements that firms impose on investment opportunities. Another group of works in the Orthodox Theory recognized *adjustment cost*[9] in investment decisions, which tries to explain the forces underlying the observable gradual response of investment to shocks that is contrary to the immediate effect predicted by the theory. The adjustment cost is commonly assumed to be convex and to have a value of zero at zero investment. During the 1970s and 1980s, the adjustment cost literature began to merge with the literature on Tobin's q. A later development of the q-theory literature incorporates irreversibility[10] as another type of friction in investment decision (Nickell, 1978; Dixit and Pindyck, 1994; Abel et al., 1994). Despite various ways of addressing determinants and frictions of investment decisions, the underlying principle of these works is the net present value rule (Dixit and Pindyck, 1994).

The Options Approach, the more recent development in the investment under uncertainty literature, views an investment opportunity as an option. Companies engage in capital investments to create and exploit profit opportunities. Spending on R&D is an example: instead of earning cash, spending now creates an opportunity to invest again later (such as construct a new plant and spend marketing expenses) to capitalize the patent and technology, and by doing so, attain a possible profit. However, the present

---

[9] Abel et al. (1994) noted that the seminal work on adjustment cost is by Robert Eisner and Robert H. Strotz, "Determinants of Business Investment," in Commission on Money and Credit, Impacts of Monetary Policy, Prentice Hall, 1963.

[10] Arrow (1968) is known to be the first to discuss the impact of irreversibility in investment.

decision to invest (spend the cost to obtain the opportunity) does not necessarily require the investor to invest again in the future. The decision to invest or not invest at the later time will depend on the situation at that particular future time.

In other words, investment opportunities may be thought of as possible future operations (Luehrman, 1997). Holding investment opportunities allow investors to have some alternatives of future decisions, which means flexibility at the present time. Hence, opportunity means flexibility in managerial decision-making, and such flexibility are valuable whether or not exploited. Companies can take advantage of opportunities to increase profits or to mitigate losses.

The Options Approach emphasizes that *irreversibility*, *uncertainty,* and *timing* are significant factors affecting investment decisions:

(i) Most investment expenditures are at least partly irreversible, since some of the expenditures are not recoverable (sunk cost) should the company decide to disinvest. Dixit and Pindyck (1994) note that irreversibility in investment may be due to one or more of the following reasons: (i) expenditures are firm or industry specific, (ii) buyers of used-machines consider a price that corresponds to the average quality in the market since they cannot evaluate the quality of an item,[11] and (iii) government regulations or institutional arrangements such as capital controls, and high costs of hiring, training and firing employees.

(ii) There is always uncertainty on future rewards from investments, which may come from uncertain future conditions such as the state of demand, prices, costs, or

[11] This is known as 'the lemons problem' (Akerlof, 1970).

regulations. This is so because, as Dow (1985) puts it, "...we can never attain a state of complete knowledge about the past, and even less about the future."

(iii) Time to invest matters as a delay may allow the decision maker to observe future events and acquire information before making crucial investment decision. The opportunity to delay investment may not always exist, but benefits of waiting for more information are often substantial. Since there may be a cost for delay, this cost must be weighed against the benefits of waiting for more information (Copeland and Howe, 2002; Dixit and Pindyck, 1994 and 1995).

The ability to delay irreversible investment expenditure is especially valuable (Dixit and Pindyck, 1994). In contrast to orthodox investment theories that assume a now-or-never investment decision, the options approach recognize that when investment are partly irreversible,[12] then it may be profitable for firms to wait for more information on the future state of the world. On the other hand, it may be optimal to invest when uncertainty is resolved or reduced by investment even when NPV without flexibility (i.e. without taking into account of the presence of options) is negative (Teisberg, 1995).

The above perspective that views investment opportunities as *options* recognizes the importance of *flexibility*, which allow managers to undertake the capital investments only if and when they choose to do so. The new view that considers investment opportunities as options leads to a dramatic departure from the traditional investment theory. The analogy with the theory of options in financial markets enables a much richer dynamic framework than was previously possible (Dixit and Pindyck, 1994).

[12] Abel et al. (1996) develop a model to reinforce the idea that instead of reversible or irreversible, capital investments are in fact have various degrees of reversibility, which means they are partially irreversible.

Abel et al. (1996) made an attempt to bring together the q-theory and option approach, having in mind that the first was originated from macroeconomic literature, while the latter was derived from financial economics, applied economics and international trade. They concluded that these two approaches yielded identical results, but each provided distinct insights into the optimal investment decision. The conceptual and practical contributions of these approaches can be seen in the following ways:

(i) The q-theory produces formulas for the net present value of capital, either total or marginal. These formulas combine the effects of uncertainty and the costliness of reversibility and expandability, which influence the investment decision. As such, they do not provide a means to understand what is the individual contribution of each of these influences. When the general formula is disentangled, the distinct terms have interpretations as the values of options to expand or contract in the future.

(ii) The options approach may help economists better understand firms' investment decisions, as it provides a means to assess different investment alternatives as separate options. As such, the users of standard NPV analysis need to adjust their calculations to take account of these options.

Further progress in the theory of project analysis gives rise to another group in the classification of the investment literature. Brennan and Trigeorgis (2000) classify the Orthodox group of literature as those that use static-mechanistic models, which treat projects as inert machines producing specified streams of cash flows over time whose joint probability distribution is given exogenously. They refer to the second group of literature, the Option Approach, as those that recognize partial controllability of cash flow by internal agent of the firm, which may be able to influence the probability distribution of cash flows generated by the project in the future. Hence, the project cash flow is determined by the inside agent and by nature. In addition to these two groups, some of the most recent works can be grouped into the *Game-Theoretic* project analysis, which see the cash flows from a project as an outcome of a game among the inside agent, outside agent (such as competitors, suppliers), and nature.

In this dissertation, the basic model shown in Chapter 5 assumes the outside agent to be only the government that specifies the form of regulations governing the business. The analysis focuses on the firm's own assessment taking into account the external condition as a given state. Hence according to the classification of Brennan and Trigeorgis, the base model in this research falls inside the boundary of the second group of literature, where agents inside the firm and nature determine the project value. In contrast, a proposed arrangement represented by a model in Chapter 6 adds an external influence in the form of an upper limit of the output price due to the presence of other power producers supplying the market as well as the firm's own assessment to estimate the lower price limit. Although the analysis does not involve the strategies of the other power producers and the government to set the upper price limit, this extension can be seen as indicating a stronger presence of the third parties albeit in a passive mode. Hence, the latter case can also be considered as a shift toward the third group of Brennan and Trigeorgis' classification.

2.1.3 Investment as Option: Implementation

Analogous to *financial option*,[13] opportunities provide rights but not obligations to take some actions in the future. In this respect, investment opportunity can be thought of as an option as well. The type of option where the underlying asset is a real asset, i.e. non-financial asset such as a project or a business unit, is commonly called a *Real Option*. In contrast to financial options that are created by traders on security exchanges, investment opportunities can be thought of as consequences of the circumstances created by real world situations (Kensinger, 1987).

The past twenty years of the literature showcased the adoption of the concept of investment as a real option into various subjects. The valuation of natural resources projects and various corporate strategies were among the earliest subjects, while the most recent areas include, among others, optimal advertising strategy and the timing of contract breaching. Types of real options modeled were, options to defer decision, to abandon project, to switch inputs or outputs or risky assets, to alter operating scale, growth options, and staged investment.

The option pricing techniques are currently the primary approaches to model and value an investment opportunity when future opportunities and prices are uncertain (Lander and Pinches, 1998). This progress is a result of an extraordinary theoretical development in finance, which was also accompanied and supported by an explosive growth of information and computing technology (Luenberger, 1998).

[13] An option in the financial market is a derivative security (a financial instrument whose value depends on the values of other, more basic underlying variables), which gives the holder the right but not the obligation to buy/sell the underlying asset by a certain date for a certain price (Hull, 1997).

Several companies claimed that they have used real options in operations or as bases for management decisions. Table 2-1 lists the companies and their respective projects in which real options had been implemented.

Table 2-1. Real Options Application

Company	When	Use
ICI	1997	New plant construction
Mobil	1996	Development of a natural gas field
Airbus Industrie	1996	Valuing delivery options
Apple	1995-1996	Exit decision for their PC business
Merck	1994	Tap early stage research projects at universities
Tennessee Valley Authority	1994	Power Purchase Options
Enron	1994	New product development, switching options for gas fired turbines
Anadarko Petroleum	1900s	Bidding for oil reserves
Cadence Design Systems	1990s	Options-based methods for valuing licenses
Exxon	1990s	Oil exploration and production
Texaco	1990s	Exploration and production
Hewlett-Packard	1990s	Production and distribution
Pratt & Whitney	1989	Cancelable operating leases

Source: Copeland et al. (2001), Bodie and Merton (2000)

In contrast to the remarkable progress of real option theory in the literature and despite the above real practice examples, the application of real options is still considered at infancy. Although many academics, researchers, as well as practitioners recognize that the new approach allows management flexibility to obtain better project value amidst future uncertainties, as well as offers strong explanatory power to investment behavior of firms, they also assert that the process to reveal this advantage is generally more difficult than that of the commonly used DCF method (Copeland et al., 2001; Amram and Kulatilaka, 1999; Smith and McCardle, 1999; Pinches, 1998; Lander, 1997).

Part of the stumbling blocks may be due to the fact that real options are commonly more complex than financial options, hence more difficult to represent. As a result, real options are generally not considered in the present business practices. Another difficulty is the methods of valuation. Market information are lacking for most real options cases. As such, adopting financial option valuation methods to value real options is appropriate only to real options on assets that are traded in the world commodity markets.

Further discussion on real options valuation is elaborated in Section 2.4. These difficulties are mainly due to lack of market information.

2.2 FINANCIAL OPTIONS

As financial options theory is where the real options concept originates, this section briefly reviews relevant issues in this field. The purpose is to introduce similar characteristics of both financial and real options, as well as to provide a stage for highlighting the unique features of real options in the later sections of this chapter. The main issues are basic features and the methodologies to assess the theoretical value of financial options.

A financial option is a *financial contract* that provides a right but not an obligation to buy/sell an underlying financial security[14] at a stipulated price. A financial contract is defined as a *derivative security*[15] (or a *contingent claim*) if its value at

[14] Security is an evidence of debt or ownership (Merriam-Webster Inc., 1993, "Merriam-Webster's Collegiate Dictionary"). 'Underlying security,' 'underlying asset,' and 'cash instrument' refer to the same meaning, hence they are used interchangeably.
[15] In addition to option, other derivative securities are futures, forward, and swap contracts.

expiration date is determined exactly by the market price of the underlying cash instrument at time T (Moore, 2001; Neftci, 2000).

Options, as well as other derivatives, are used principally to manage risks. They are instruments to transfer unwanted risks to those more willing and able to bear them. Holding options enable investors to modify their risk exposure to the underlying assets.

The existing traded option contracts include those written for the following five main groups of underlying assets: common stocks, currencies, interest rates,[16] indexes, and commodities. There are also options-embedded securities, which are options written by firms (corporate securities), such as convertible bonds, warrants, stock purchase rights, as well as executive and employee stock options. Moore (2001) explains the difference of these option types and at which exchanges they are traded. In addition, there are also non-standard or exotic options that are tailor-made by investment banks to solve client firms' risk management problem. The latter are usually traded over the counter and not listed on organized exchanges.

2.2.1 Basic Features

There are two types of option, Call Option and Put Option. A call option is the right to buy the underlying asset, while a put option is the right to sell the underlying asset at a predetermined price called the *strike price*.

[16] Neftci (2000) notes that interest rates are not assets, therefore a notional asset needs to be developed. Derivatives on bonds, notes and T-bills can be included in the 'interest rate' category since they are promises by governments to make certain payments on predetermined dates. Hence, the holder of such derivatives takes position on the direction of various interest rates.

The payoff of a call option when exercised is *Max [S-K, 0]*, where *S* represents the asset value and *K* is the strike price or the amount paid to exercise the option. If *S*>*K*, then exercising the option leads the holder of the option to acquire an asset of value *S* by paying only *K*. However if *S*<*K*, then the holder of the option will leave the option alive (does not exercise or 'kill' it before its maturity date) or let it expire and there is no additional cost for this decision.

A call option gives the holder discretion to exercise it (and acquire *S-K*) when the future state is favorable, but imposes no penalty if the holder lets the option expire when the future state is unfavorable. Hence, the payoff of a call option is *non-linear* or *asymmetric* since it is positive for *S*>*K* and zero otherwise. Another way to describe this feature is that options allow the holder to *slice up probability distributions.*[17] A call option represents a claim on only the part of the underlying asset's price distribution above the exercise price, while a put option is a claim on the lower end of the distribution below the exercise price (Moore, 2001; Copeland and Antikarov, 2001).

There are two types of call and put options. *European* options allow exercise only at their maturity dates, while *American* options can be exercised before and on their maturity dates. Hence, the terminology does not correlate to geographical presence of these options.

A *premium* is the amount initially paid to obtain the option. It is a sunk cost and should not influence the decision on whether or not to exercise the option.

2.2.2 Valuations

Options valuations determines what an option *should* be worth; hence, it reveals a theoretical value of options. The valuation models enable forecasting of option values before the options have been marketed (Moore, 2001).

The *value of an option at expiration,* which is also known as the *intrinsic value,* is derived from its basic structure. As illustrated at the previous sub-section, the value of a call option at expiration time T is governed by equation (2-1). The value of a put option at expiration time T is shown as equation (2-2).

$$C_T = Max[S_T - K, 0] \tag{2-1}$$

$$P_T = Max[K - S_T, 0] \tag{2-2}$$

In addition to the value at expiration time, options also have *value at earlier times* because they provide the potential of future exercise (Luenberger, 1998) and this opportunity is valuable whether or not exercised. This value is often referred to as the *time value of options.* Option value is higher at a longer time to expiration.

Luenberger (1998) notes that there are several approaches to calculate the theoretical value of an option, based on different assumptions about: (i) *the market,*

---

[17] As a comparison, holding stocks or bonds or portfolio of the securities expose the holders to the entire probability distribution of their respective future values, which are either making a profit when the price increases or bears a loss when the future price is lower than the purchase price.

(ii) *the dynamics of stock price behavior*, (iii) *individual preferences*, and (iv) *the no-arbitrage*[18] principle. He stated that the latter leads to the most important theories.

There are two major strands of option valuation methods that use no arbitrage principle, (i) those based on the Black-Scholes formulation, and (ii) based on Binomial Lattice framework. Both methods combine two available securities with known payoff to construct a portfolio that reproduces the local behavior of the derivative security (Luenberger, 1998). Fisher Black and Myron Scholes (1973) argued that based on no-arbitrage principle, at each moment two available securities could be combined to construct a portfolio that reproduces the local behavior of the option on one of the securities. This riskless hedged position will cost money to set up, but since it is riskless, the option must be priced relative to the stock so that the hedged investment in the portfolio would get the riskless rate of return (Luenberger, 1998; Haugen, 1997).

The major difference between the two is that the Black-Scholes formulation assumes that the price of the underlying asset fluctuates in a way described by the Ito process. This means that the approach employs continuous form of representation of the stochastic behavior of the underlying asset price and uses Ito calculus to derive the set of *partial differential equations* (PDE) implied by the lack of arbitrage opportunities. The set of PDE is then solved either analytically or numerically. The original work of Black-Scholes applies for a simple structure of option[19] that makes it possible to determine a

[18] Arbitrage is a process to purchase and immediately sell equivalent assets in order to earn a sure profit from a difference in their prices (Bodie and Merton, 2000). Neftci (2000) provides another description of this terminology, which is ".. taking simultaneous positions in different assets so that one guarantees a riskless profit higher than the riskless return given by U.S Treasury Bills."

[19] European option with no dividends.

closed-form solution; hence an analytic solution exists. However, most PDE sets of options valuations need to be solved numerically.

On the other hand, the Binomial Lattice framework represents the stochastic behavior of the underlying asset price in a discrete form. Following the work of Cox et al. (1979), the method combines various proportions of available securities (such as stocks and bonds) to duplicate the next-period outcome of an option. The next-period option value is then discounted back using the risk-free discount rate. This process is repeated at every node of the lattice, starting from the final period and working backward toward the initial time. Neftci (2000) categorizes this procedure as the *method of equivalent martingale measures*, since the arbitrage notion is used to determine a probability measure under which financial assets, once discounted properly, behave as martingales.[20] The probability measure incorporated in this method is a *synthetic probability* that is independent of the actual probability of occurrence of different state of nature.

The Black-Scholes formulation for option valuation has been particularly important in the development of financial asset valuations, as options are important financial instruments. Further, it establishes a foundation to assess non-financial assets and larger areas of interest that can be conceptualized as options. Options theory is also important because it shows that the fundamental principle of investment science can be taken to a new level, which is a level where the dynamic structure is fundamental (Luenberger, 1998).

[20] A stochastic process behaves like a martingale if its trajectories display no discernible trends or periodicities, such that the directions of the future movements are impossible to forecast. The best forecast of unobserved future values is the last observation on that process (Neftci, 2000).

It is worth noting that many new twists in the two strands of approach are developing, as new derivative products are established and offered in the market. The increase in derivative products markets in the past two decades has mainly come from the need to hedge interest-rate and currency risks (Neftci, 2000).

Table 1-2 in the previous chapter shows six variables that determine the value of options and how they influence a call or put option value. The original Black-Scholes formulation assumes no dividends are paid during the life of the option, therefore there are only five variables involved in their valuation formula. The generalization to include dividend payments was introduced by Merton (Bodie and Merton, 2000).

In practice, the determination of fair market values of financial assets works in the following general steps (Neftci, 2000):

1. Obtain a model (approximate) to track the dynamics of the price of the underlying asset.
2. Calculate how the derivative asset price relates to the price of the underlying asset *at expiration* or at other *boundaries.*
3. Obtain risk-adjusted probabilities.
4. Calculate expected payoffs of derivatives *at expiration* using these risk-adjusted probabilities.
5. Discount this expectation using the risk-free return.

The following sub-section discusses the Black-Scholes and Binomial Lattice framework in more formal representations, which is an excerpt of related materials in Luenberger (1998), Glantz (2000), and Neftci (2000). The concepts underlying these frameworks are also utilized in valuing real options, although as described in section 2.3, some adjustments in the procedure and additional features are necessary.

2.2.3 Black-Scholes Formulation

Suppose S is a stock price and its changes can be represented as a Wiener process. Let us consider a stochastic differential equation of the price change over time interval [0,T] with the following special form:

$$\frac{dS}{S} = \mu dt + \sigma dZ \tag{2-3}$$

or,

$$dS = \mu S\, dt + \sigma S\, dZ \tag{2-4}$$

where dZ is a standard Brownian motion (or a Wiener process).

Let $F(S_t, t)$ represents the value of a derivative, where S and t vary over time. At the maturity date, the value of a derivative is $F(S_T, T)$ which depends only on the security price at T and time T. Market participant will not know the functional form of $F(S_t, t)$ at other times than its expiration date. For times before expiration, the function $F(S_t, t)$ needs to be found. For this purpose, we will need to obtain dF through the use of Ito's Lemma, since S is stochastic and therefore F is also stochastic.

$$dF = \left(\frac{\partial F}{\partial t} + \frac{\partial F}{\partial S}\mu S + \frac{1}{2}\frac{\partial^2 F}{\partial S^2}\sigma^2 S^2 \right) dt + \frac{\partial F}{\partial S}\sigma S dZ \tag{2-5}$$

This equation says that the derivative price F fluctuates randomly with the stock price S and the Brownian motion Z. However, due to the presence of dZ, it is very difficult to obtain F from the differential equation (2-5).

To overcome this problem, Black-Scholes presume that there is a risk-free asset (such as a bond) that bears an interest rate r over [0, T]. The value of an option that can be exercised only on a certain future maturity date can be evaluated by creating a perfect hedge that simultaneously being long (short)[21] in the underlying security and holding an opposite short (long) position on a number of options. In order to eliminate arbitrage opportunity, the return on a completely hedged position has to be equal to the risk-free return on the investment.

Let B denote the value of the risk-free asset. B would follow:

$$dB = r\,B\,dt \tag{2-6}$$

Then take a riskless hedge position by forming a portfolio consisting of x_t amount of stock and y_t amount of bond at every time t such that it replicates the behavior of the derivative security. The value of this portfolio is $G(t) = x_t\,S(t) + y_t\,B(t)$. A change in security prices would induce an instantaneous change in the value of this portfolio:[22]

$$dG = x_t\,dS + y_t\,dB \tag{2-7}$$

[21] In the cash market: long position means an ownership of securities; short position means a sale of securities not owned. In the options market: long position means the purchase of an option with no offsetting short position; short position means the sale of an option with no offsetting long position. (Campbell R. Harvey, http://www.duke.edu/~charvey/classes/glossary)

Incorporating (2-4) and (2-6) into (2-7), we have:

$$\begin{aligned} dG &= x_t(\mu S\,dt + \sigma S\,dZ) + y_t\,r\,B\,dt \\ &= (x_t\,\mu S + y_t\,r B)\,dt + x_t\,\sigma S\,dZ \end{aligned} \tag{2-8}$$

For the portfolio change *dG* to behave like the change of derivative *dF*, the coefficients of *dt* and *dZ* in (2-8) should equal to those in (2-5). First, match the dZ coefficient:

$$x_t = \frac{\partial F}{\partial S} \tag{2-9}$$

Then, requiring $G = x_t S + y_t B$ and $G = F$,

$$y_t = \frac{1}{B}\left(F(S,t) - S\frac{\partial F}{\partial S} \right) \tag{2-10}$$

Substituting (2-9) and (2-10) into (2-8), and matching the coefficient of *dt* in (2-5),

$$\frac{\partial F}{\partial S}\mu S + \frac{1}{B}\left(F(S,t) - S\frac{\partial F}{\partial S} \right) rB = \frac{\partial F}{\partial t} + \frac{\partial F}{\partial S}\mu S + \frac{1}{2}\frac{\partial^2 F}{\partial S^2}\sigma^2 S^2 \tag{2-11}$$

---

[22] Luenberger (1998) notes that the equation should include (x_t' S + y_t' B), but it can be shown that this sum is zero.

Or,

$$\frac{\partial F}{\partial t}+\frac{\partial F}{\partial S}rS+\frac{1}{2}\frac{\partial^2 F}{\partial S^2}\sigma^2 S^2 = rF \tag{2-12}$$

Equation (2-12) is *the fundamental PDE of Black–Scholes.* The associated boundary conditions are equation (2-1) for a Call Option, while it is equation (2-2) for a Put Option.

Solving the above PDE with the associated boundary conditions, Black-Scholes obtain an explicit form of function $F(S_t, t)$ for a Call Option:

$$F(S_t, t) = S_t N(d_1) - K e^{-r(T-t)} N(d_2) \tag{2-13}$$

where

$$d_1 = \frac{\ln(\frac{S_t}{K}) + (r+\frac{1}{2}\sigma^2)(T-t)}{\sigma\sqrt{(T-t)}} \tag{2-14}$$

$$d_2 = d_1 - \sigma\sqrt{(T-t)} \tag{2-15}$$

$N(d_i)$, $i = 1,2$ are two integrals of the standard normal density (or cumulative normal probability distribution), which value is the area under the bell shaped curve from $-\infty$ to d_i.

$$N(d_i) = \int_{-\infty}^{d_i} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}x^2} dx \qquad (2\text{-}16)$$

$N(d_1)$ is commonly referred to as the delta, or the partial derivative, of an option. It measures the rate of change of the option's value with respect to the stock price. Delta is the key to setting up a hedge for an option. $SN(d_1)$ reflects the reciprocal value of the riskless hedge when the stock price S adjusts by $N(d_1)$.

$N(d_2)$ is the probability that at maturity the stock price is above the exercise price (i.e. the option is 'in the money'). As such, the second term of equation (2-13) represents the risk-adjusted present value of the exercise price. Hence, equation (2-13) says that the price for the call option equals to the expected stock price $SN(d_1)$ less the risk-adjusted exercise price $Ke^{-r(T-t)}N(d_2)$ (Glantz, 2000).

2.2.4 Binomial Lattices Framework

First, let us examine the single period binomial option to present the basic mechanism in this framework as well as the notions of replicating portfolio and risk-neutral probability. The multi-period binomial option is illustrated afterwards.

Let us suppose that the market participant is interested only in three assets shown at Figure 2-1, which are (i) a risk-free asset that gives a risk-free gross return R, (ii) an underlying asset S, which at the end of the period the price would be either uS with probability p or dS with probability $(1-p)$, and (iii) a derivative asset, for example a call option C with strike price K.

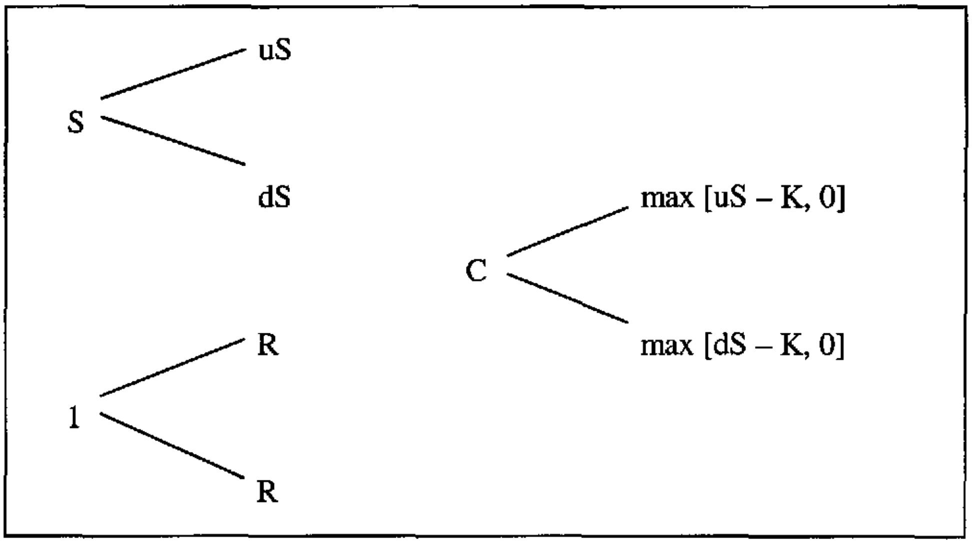


Figure 2-1. Lattices of the three assets

Assume that $u > d > 0$, and that in every period it is possible to borrow or lend at a common risk-free interest rate r. Let $R = 1+r$. To avoid arbitrage opportunities, then the following must hold:

$$u > R > d \tag{2-17}$$

All three lattices move together along the same arcs. For example, if S increases to uS then the other two lattices will assume the upper state of the world, since the value of C is a positive function of S and the risk-free asset is treated as if it were a derivative of the stock with the value at the end of the arc determined to be the same.

When the stock price S is known, then all values are known except the value of the call C. Combination of various proportions of the stock and risk-free lattices can construct the pattern of outcome of the option lattice. Let the value of call option at the end of period be either C_u or C_d,

$$C_u = Max\ [uS - K,\ 0] \tag{2-18}$$

$$C_d = Max\ [dS - K,\ 0] \tag{2-19}$$

Using the risk-free asset and the stock we can construct a replicating portfolio, which is a portfolio that mimics the outcomes at (2-18) and (2-19). Let us purchase x dollars worth of stocks and b dollars worth of bonds. At the end of the period, depending on the state of nature, the portfolio will be worth either $ux + Rb$ or $dx + Rb$. To duplicate (2-18) and (2-19), the following must hold:

$$ux + Rb = C_u \tag{2-20}$$

$$dx + Rb = C_d \tag{2-21}$$

Solving these two equations, we have

$$x = \frac{C_u - C_d}{u - d}$$

Substituting to (2-20) and (2-21),

$$b = \frac{C_u - ux}{R} = \frac{uC_d - dC_u}{R(u - d)}$$

The value of the portfolio is:

$$x+b=\frac{C_u-C_d}{u-d}+\frac{uC_d-dC_u}{R(u-d)}$$

$$=\frac{1}{R}\left(\frac{R-d}{u-d}C_u+\frac{u-R}{u-d}C_d\right)$$

The no-arbitrage principle requires that $x+b$ equals the value of the call option C. Therefore, the value of the call is:

$$C=\frac{1}{R}\left(\frac{R-d}{u-d}C_u+\frac{u-R}{u-d}C_d\right) \tag{2-22}$$

Further, let

$$q=\frac{R-d}{u-d} \tag{2-23}$$

Note that by (2-17) the above relationship gives $0 < q < 1$, which means q can be considered as a probability. Then, equation (2-22) for the value of a call option on a stock governed by binomial lattice can be represented as:

$$C=\frac{1}{R}[qC_u+(1-q)C_d] \tag{2-24}$$

The above form suggests that considering q as probability, the value of a call option is the *expected value of the option discounted at a risk-free rate.* Hence, the probability q is a *risk-neutral probability*, and sometimes also referred to as a *synthetic probability.* Note that q is independent of the probability p (the upward movement in the lattice). In fact, p is never used in the above replicating and matching procedures. Discounting the expected value of the option at the risk-neutral probability q, instead of p, means that it is like using *risk-neutral utility function* (linear utility function) when the actual probability is q. The above procedure of deriving an option value is a special case of *risk-neutral pricing.*

Let us take a two-period binomial lattice to extend the above results, as a simple step to see how they work in multi-period binomial lattice. Figure 2-2 shows the possible values of an option at various states in the lattice.

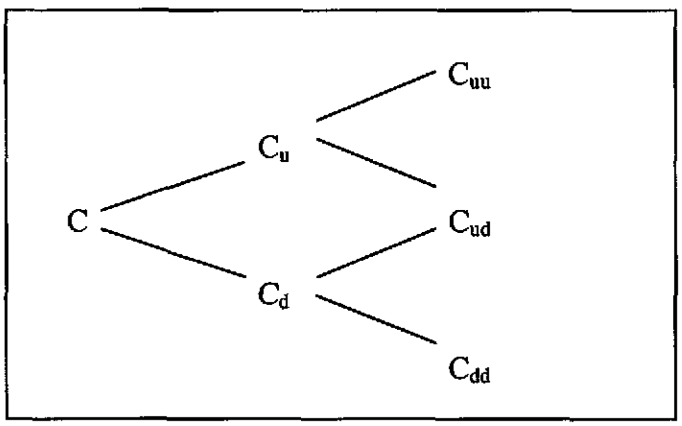


Figure 2-2. Option value in a two-period lattice

The value of the option is known at the final nodes of the lattice:

$$C_{uu} = Max\ [u^2S - K,\ 0] \tag{2-25}$$

$$C_{ud} = Max\ [udS - K,\ 0] \tag{2-26}$$

$$C_{dd} = Max\ [d^2S - K,\ 0] \tag{2-27}$$

Using the previously defined q at (2-23), and assuming that the option is not exercised early, we can use (2-24) to obtain the value of the option at the end of period-1:

$$C_u = \frac{1}{R}\left[qC_{uu} + (1-q)C_{ud}\right] \tag{2-28}$$

$$C_d = \frac{1}{R}\left[qC_{ud} + (1-q)C_{dd}\right] \tag{2-29}$$

Similar risk-neutral discounting procedure can be applied to obtain C, the value of the option at the beginning period:

$$C = \frac{1}{R}\left[qC_u + (1-q)C_d\right] \tag{2-30}$$

These steps show that by working backward starting from the final states of the lattice, the value of the option at the beginning period can be calculated. A similar procedure applies for lattice with more than two time periods.

Note that such calculation is based on the assumption that the option is not exercised early. This means, this valuation is for a European option. An American option has an additional feature, which allows it to be exercised before its maturity. This feature can be taken care of by comparing the option value when it is kept alive and when exercised at every state before maturity. For example, if the option is exercised at the end of period-1, then either one of the following values prevails depending on the state of nature path selection:

$$C_u = max\,[uS - K, 0] \tag{2-31}$$

$$C_d = max\,[dS - K, 0] \tag{2-32}$$

If the nature brings an upstate movement, then the decision whether or not to exercise the option at the end of period-1 shall be done by selecting the greatest value of C_u given by (2-28) or (2-31). That is, if the value at (2-28) > (2-31) then it is better not to exercise the option, which means the option is alive at the next period. On the other hand, if the value at (2-28) < (2-31) then a higher value can be obtained by 'killing' or exercising the option and do not wait until the maturity.

2.3 REAL OPTIONS

The first part of this section presents real options features by contrasting them to those of financial options. The second part illustrates the representations of real option cases in the literature.

2.3.1 Characteristics of Real Options

There are six parameters that affect the value of real options. As shown in Table 1-1 of Chapter 1, each of them has a counterpart in the financial options context with similar effect to the value of the respective options.

Similar to financial options, real options also reflect flexibility. A company that has an investment opportunity is like holding a financial *call* option, i.e. it has the right but not an obligation to buy an asset, which is the entitlement to the stream of profits from the project, at a future time of their choice. Since the investment opportunity does not require the company to invest, holding the opportunity gives the company a flexibility whether or not to make the investment decision. As with the flexibility that is attached to a financial option, this means that the holder of a real option has the ability to respond to information that may be received in the future. Consequently, this means the option allows management to make a later decision based on most recent available information. This is in contrast to investment rules recommended by the traditional capital budgeting to make future decision now based on present information and stick to that rule for the planning horizon.

Flexibility can be used to improve the project cash flow, provided that the management actively assesses the opportunities over time and exercises the options accordingly. Glantz (2000) notes that internal flexibility allows management to modify capital expenditures as external conditions change. He also states that the cash flow improvements can come from external flexibility, i.e. by deciding to pursue an investment opportunity the company could be exposed to yet another investment opportunity and the respective stream of cash flows. Hence, flexibility adds value when exercised appropriately.

However unlike financial options, most real options are not specified in a contract and therefore, must be identified through analysis and judgments. Real options may be naturally present in an investment opportunity, or may be built into it at some additional expenses or consequences (Lander and Pinches, 1998). These costs may be excessive or cause delay that weigh down the benefits of the real options, which means the real options may not be conceivable to the firm. Therefore, one caveat to incorporating real option into the investment analysis is to be sure they exist and are viable for both the investment opportunity and the firm.

Pinches (1998) notes that there are at least three more complexities with real options that are not commonly present with options on financial assets:

(i) There are strategic interdependencies among investment decisions and multiple management decision choices in the same capital project.

(ii) Ownership of real options is generally non-exclusive, where more than one firm may own or can develop the real option. Hence, the value of real option may depend, in part, on the action of other firms.

(iii) The underlying asset is generally non-traded (except for some natural resources), or traded only in imperfect markets.

The presence of multiple sources of uncertainty and a mix of private risk (real options have risks that are not spanned by the set of traded securities) and market-priced risk in an investment project would also be reflected in the complexities of its real option representation (Amram and Kulatilaka, 1999). Moreover, a customized model for each situation is often required to represent the unique circumstances of the project to be reviewed (Bowman and Moskowitz, 2001).

In addition to the complex settings, another difficulty for implementing real options in corporate investment decision is the remaining uncertainty when exercise decision must be made (Coff and Laverty, 2001). The exercise decision of a financial option to purchase is clear: buy if the exercise price is lower than the current market price. In this case, both indicators are observable at the time the decision is to be made and thus a decision maker does not face any uncertainty. However, in real options situation, significant uncertainty may remain at the decision stage because, among others, some uncertainties in the real world may never be resolved completely. For example, the underground reserve size of oil, gas, or geothermal can be estimated by conducting exploratory and development drillings, but the actual size is not known with certainty. As a result, exercising a real option requires very specific managerial decision-making, which can be slow and expensive (Glantz, 2000).

The other factor that hamper practical implementation of the real option concept is the highly sophisticated mathematical techniques used in the previous works, while at the same time these models greatly oversimplify the investment circumstances that are taken as examples. As a result, these models cannot be used as effective tools for the actual management decision consideration. On the other hand, more realistic models tend to be more time-consuming to compute and estimate, as well as more difficult to understand and communicate to people in the decision-making process. Further, the model becomes less intuitive and therefore, prone to undetected errors.

These extreme states indicate that appropriate framing is a very important step in the application of real options. It is necessary to identify the decision and uncertainty that represent the problem, the decision rule governing the process, the relationship to the financial market, as well as the transparency and simplicity of the model (Amram and Kulatilaka, 1999).

In summary, major challenges in the application of real option concept are: (i) modeling project flexibilities that characterize the real problem (Smith and McCardle, 1999), and (ii) the valuation methods, which include the selection of valuation techniques, as well as the appropriate identification and estimation of inputs for the model (Lander, 1997; Teisberg, 1995).

2.3.2 Real Option Representations

Various issues that were addressed in real options literature can be seen in many perspectives. Real world investment circumstances vary greatly and this creates various parameters with varying relative importance. Such nature consequently yields a considerable mixture of real options models.

An alternative to sort out the literature in real options can be based on how they address uncertainty, project structure, alternative decisions, and the identification of underlying asset. This classification is by no means an exhaustive overview of the vast range of topics; rather it is part of an attempt to search for appropriate modeling and valuation methods to be employed in this research.

(a) Modeling Uncertainty

Uncertain benefits could result from uncertain future prices or demands or production profiles. This type of models usually assumes that costs of investment are known, constant or less uncertain than the benefits. This group is commonly modeled like a *call* option, where costs resemble the strike price while uncertain benefits correspond to the stock price. Many applications in energy and mineral investment decisions are of this type. Valuations of oil reserves were studied in the works of Paddock et al. (1988 as well as their previous works) and Pickles and Smith (1993). Valuations of mineral resources projects were done for copper (Brennan & Schwartz, 1985).

Uncertain cost is considered more important than future benefits where projects take time to complete or involve a large amount of capital. Other cases may include variable capital and input prices, especially when they are highly volatile relative to the output price. These projects can be modeled as a *put* option, where the benefit corresponds to the strike price of an option. However, most of the previous works on investment under uncertain costs did not consider investment as an option-like situation. The limited literature that applies OV methodology to address this type of problem includes Pindyck (1993) and Dixit & Pindyck (1994).

A more realistic representation recognizes *multiple sources of uncertainty*, since most real options are affected by many uncertainties at the same time, such as price of output, the quantity to be sold, and uncertain interest rates that affect the present value of the project (Copeland and Antikarov, 2001). This type of option is called a *rainbow option*.

(b) Modeling Project Structure

Compound options are options whose value is contingent on other options. Geske (1977) introduced the solution for this class of problem for the first time. Later works that incorporate compound options in their model include Brennan and Schwarts (1985), Pindyck (1993), Teisberg (1994), Smit (1997), Smith and McCardle (1999), and Cortazar et al. (2001).

Staged or phased investments are *sequential compound options*, where the exercise of an option would yield other options. An exploration and development project is an example of compound options, since spending exploration cost (exercise the exploration option) to undertake the exploration activities would lead to another opportunity to develop the resource if exploration results are successful, or to stop otherwise (i.e., it yields a development option).

Another type of compound options is *simultaneous compound options*, where the underlying option and the option on it are simultaneously available. For example, consider a call option that is written on the equity of the firm as the underlying risky security, where the equity is subordinate to debt. In this case the other option is the equity that is an American call on the value of the firm. They are simultaneous compound options since both the equity and the call option on the equity are alive at the same time.

(c) Modeling flexibility

A right to delay the start of a project is a *deferral option.* Previous works that modeled deferral options were McDonald and Siegel (1986) and Pindyck (1991). A *growth option* or *strategic option* provides future investment opportunity from undertaking a project (i.e pay the exercise price). Almost any future investment opportunity that (i) can be deferred or modified, or (ii) create new investment opportunities could be viewed as a growth option (Lander, 1997). Both deferral and growth options are American call options.

An *abandonment option* gives investors the right to discharge (sell or permanently close down) a risky asset at a fixed price. Previous works in this area were Kensinger (1980) and Myers and Majd (1990). A *contract* or *scale back* option allows the company to sell a fraction of it for a fixed price. The abandonment as well as contract/scale back options are American put options.

Switching options provide the right to switch between two modes of operation at a fixed cost, such as activate peak load generating equipment when electricity demand or price go up and switch it off when they come down. Switching options are a portfolio of American call and put options.

Real world application suggests that multiple real options and their interactions in an investment project are not uncommon. Trigeorgis (1993) argued that although the value of real options may not be additive, the combined flexibility may be as economically significant as the value of the project's expected cash flows.

(d) Underlying Asset

As the value of real option is tied to the value of an underlying asset, it is sensitive to the way the behavior of the underlying variable(s) is modeled (Lander, 1997). Since options originated in the financial markets, the earliest applications to non-financial assets were naturally pertinent to traded commodities. Traded commodities with active markets can carry the role as the underlying asset, which is the source of information that is observable by any would-be investors. As such, the value of the underlying asset would be readily identifiable. A classic example is investment associated with oil, gas, gold, copper, palm-oil, rubber and other commodities that are traded worldwide (Brennan & Schwartz, 1985; Paddock et al., 1988; Bailey, 1991).

Further extension of the option valuation application is to the case where the asset is not actively traded in the market or does not have a market at the time the valuation is exercised, such as R&D projects. The lack of direct market information is substituted by finding a reasonable connection to other existing markets. An example is the case of a biogenetic engineering firm searching for a bacterial mutation useful for commercial operation (Willner, 1995). Another example (O'Reilly, 1995) values the right to pump underground water. Since there is no market price for groundwater, he ties the valuation problem to the utilization of groundwater and results to crop productivity. This in turn allows him to use information from the price of the crop yield, in this case the market prices of cotton, wheat, and alfa-alfa. Nevertheless, the literature does not have many examples to determine similar ways of overcoming the lack of a market for the underlying asset.

However, recent works by Copeland and Antikarov (2001) and Hubalek et al. (2001) criticize the common approach in previous works that use surrogate assets as the underlying assets. They claimed that these practices arbitrarily assume that the volatility of the underlying project without flexibility is the same as the volatility of the world commodity, while in general this is inappropriate. For example, the volatility of the value of a gold mine is not the same as the volatility of the price of gold since there are different forces that drive their respective volatilities. In practice it is nearly impossible to find a priced security whose cash payouts are perfectly correlated with those of the project in every state of nature over the life of the project. As a result, it is impossible to acquire a market-priced underlying risky asset.

Instead of searching in financial markets, Copeland and Antikarov (2001) introduced an approach that uses the present value of the project itself, without flexibility, as the underlying risky asset (the twin security). They argue that the closest relationship of a real investment project would be the project itself after the investment is completed. Hence, the underlying asset would be the completed project, and its value is the respective projected cash flow. While the concept of using the discounted value of cash flow forecasts to represent the market value of an asset has been widely accepted in business practices, its use as the underlying asset of an option valuation for the relevant project is a new proposition. Some empirical evidences supporting this concept are found in Kaplan and Ruback (1995) and McKinsey & Company, Inc. (2000). Section 2.4.4 describes more about this approach.

2.4 INVESTMENT VALUATIONS

The literature contains at least three groups of techniques to value investment decisions: (i) Capital Budgeting, (ii) Option-Based Approaches, and (iii) Graphical Representation Model. Proponents of each technique argue that when used correctly these techniques result in correct valuation of the project or strategic decision under consideration. Most claim that the method selected in the respective research is superior to the rest, while some show that the method is equivalent to another under certain conditions. Table 2-2 summarizes the underlying assumptions, strengths, and weaknesses of these groups of models.

Frameworks to model and value *investment opportunities that have real options* are a subset of the above works. Lander (1997) reviews various frameworks that could support the modeling and valuation of real options and suggests that the following models can be used for the purpose:

- *Option-Based models* that use either the binomial or continuous-time option pricing techniques.
- *Decision Tree models*, which are graphical modeling tools that have been used to 'enhance' the traditional DCF analysis.

- *Influence Diagrams*, which are another form of graphical modeling tools. They have not been widely used, but Lander (1997) argues that this is in fact an appropriate framework for modeling and valuing investment with real options. Further, she suggests that this framework may be an effective tool to bring options valuation into the applied arena due to the following features: (i) it represents decision problems in a more descriptive, intuitive, and compact manner than previous frameworks, (ii) it is mathematically equivalent to decision tree models, and (iii) under certain conditions, influence diagram models and option-based models give the same valuations and optimal strategies.

Nevertheless, assumptions and approximation are different across techniques and across practitioners (Tiesberg, 1995). Lander (1997) states that each decision-making framework requires some inputs that are difficult to estimate, therefore there is no one right or best framework to always use.

The rest of this sub-section discusses major features of the above-mentioned frameworks. Further elaboration of the strengths and weaknesses of these models is presented in Appendix A. The evaluation aims at identifying an appropriate model to represent the case of interest, while it is also important that the approach be clear. The latter is especially important to communicate the research findings to those who are unfamiliar with the real options perspective, especially practitioners involved in the development of natural resources.

Table 2-2. Methods to Value and Model An Investment Opportunity

	Traditional Capital Budgeting	**Option-Based Approaches**	**Graphical Models**
Family of Models	• Traditional DCF • DCF with sensitivity, scenario, simulation	• Continuous-Time • Finite-Difference • Binomial • Lattice (Trinomial & others)	• Decision Tree • Influence Diagram
Major Assumptions	• Investment is irreversible, or a now-or-never opportunity • Discount rate is known, constant, and a function of only project risk	• Complete market • No arbitrage opportunity	• Uncertainty can be modeled by a set of probabilities
Strengths	• Relatively straight forward procedure	• Model risk directly • Can account for and value flexibility in project management • Use risk-neutral probabilities and risk-free rate, hence avoids the issues of risk preferences and risky discount rates	• Graphical modeling tool that can provide a compact, expressive and flexible representation of the problem • Software to assist in the computation are publicly available
Weaknesses	• Relevant only in relatively certain environment • Cannot incorporate the 'strategic' value of an investment opportunity	• Assumptions are often violated in real world • Difficult to determine and model the state variable • Severely limited if there are more than one or two fundamental sources of uncertainty • Involve sophisticated mathematical formulation that is not intuitive for most people	• Difficult to determine the discount rate for the tree • Size or complexity of the tree • Estimation of probabilities of the future cash flow

Source: Lander (1997)

2.4.1 Capital Budgeting

The *traditional* Capital Budgeting framework does not facilitate the real options way of thinking; it is presented first to set the stage for the current methods. In contrast, the *dynamic* capital budgeting framework is capable of handling real options.

The conventional (static) capital budgeting uses discounted cash flow (DCF) method, which involves calculating the net present value (NPV) of expected cash flows that are discounted to take account for the time value and potential risks. A risk-adjusted discount rate is required to determine the project's net present value. The existence of similar projects can be useful in providing estimated future cash flows and other project performance parameters; otherwise subjective estimates are necessary.

The static DCF assumes a predetermined decision path and a single (expected) scenario of future cash flow, which implicitly says that the expected cash flow are given and it is acceptable proxies for the cash flow distribution. The underlying assumptions are that investment is static, and it is either irreversible or a now-or-never proposition. As described earlier, these assumptions ignore strategic importance of future uncertainty and flexibility to respond to different situations. In this respect, the static DCF is not capable of properly assessing the option-like characteristic of certain investment opportunities.

Another weakness is on the assumptions that discount rate is known, constant, and only a function of project risk. It can be argued that the risk of projects may vary throughout a project's life, which may come from different components of the cash flow (e.g. costs may have different risks than revenues), different states of the world, or different stages of a project's life. In other words, there is no one correct discount rate that can be appropriately applied for the entire project. On the other hand, determining a set of risk-adjusted discount rates in the presence of complex statistical structure of the cash flows is very difficult.

In practice, some attempts to subdue these weaknesses involve the use of 'what if' or sensitivity analysis, scenario analysis and simulation. However, sensitivity analysis only evaluates one variable at a time and does not look at combinations of errors occurring at one time in a set of variables (Lander, 1997). Typically, only few scenarios are involved in an analysis (e.g. high-medium-low), and the selection of such scenario is often arbitrary. A simulation may consider all possible combinations of the variables, but the cost (e.g. analyst's time, computer resources) to perform this evaluation may be high.

Other dynamic versions of DCF method involve the use of a decision tree or a dynamic program to identify important future uncertainties and the possible future contingent decisions. This approach can be considered a mixture between this group and the other group of models in Table 2-2; therefore, the evaluation of both groups of models is relevant.

The difficulty in applying a dynamic DCF method, namely to define a set of appropriate risk-adjusted discount rates, has caused practitioners to compromise and determine one particular rate as the risk-adjusted discount rate arbitrarily. However, some problems in public private partnership like the geothermal project studied herein, as illustrated in Chapter 4, are caused by the arbitrary rate.

2.4.2. Options-Based Models

As mentioned earlier, real options are commonly more complex than financial options. The prominent Black-Scholes formula is not suitable for real options valuation, since the following assumptions are likely to be violated in the application to other than simple European options: (i) the underlying asset is a stock, (ii) the stock does not pay dividends, (iii) the derivative asset is a European style call option, (iv) the risk-free rate is constant, and (v) there are no indivisibilities or transaction costs such as commissions and bid-ask spreads (Neftci, 2000; Copeland and Antikarov, 2001).

More complex options would mean that the analytical solution for the PDE sets is likely to be unavailable for most of the cases. Hence, obtaining the option valuation and investment rule would need to employ numerical procedure. Table 2-3 of Appendix A summarizes various approaches that are used to model and value real option circumstances.

The continuous-time model is considered the most confining for practical application, due to assumptions underlining the parameters and the sophistication requirement for mathematical formulation of the model. It uses Ito's calculus formulation to represent the option features, which involved complex mathematical relationship such that it is appropriate for cases where there is only one source of uncertainty. In addition, since analytical solutions often do not exist, then numerical approximation is needed. In the latter case, essentially the framework shifts to the numerical solution technique.

Table 2-3. Option-Based Models

	Characteristics	Remarks
Continuous-Time	• Assume the value of underlying asset follows a lognormal distribution, or returns are normally distributed • Changes in the value of the underlying asset are modeled as a Geometric Brownian Motion (GBM) • Assume Risk-free rate is constant and known • Straightforward investment opportunities use the Black-Scholes pricing formula or its modifications. Complex cases* commonly assumes underlying asset follows GBM, then derive and solve an appropriate PDE • Analytic solution often do not exist	• Most appropriate for cases with one fundamental source of uncertainty • Models are not intuitive, the least well understood by practitioners, maybe difficult to implement • Requires sophisticated mathematical knowledge to develop and to solve • Straightforward practical application are few
Finite-Difference	• A type of numerical approximation of option value • Convert the appropriate PDE into a set of discrete-time difference equations, then solve using the 'rollback' iterative process	• Requires sophisticated mathematical knowledge to develop and to solve • Can be difficult to implement • Straightforward practical application are few
Binomial	• Assume the underlying asset follows a multiplicative binomial distribution • Assume the parameters (up and down movements, as well as the volatility of the underlying asset) are constant and known • Use risk-neutral rate and pseudo probabilities for valuation • It is a tree technique, and the solution process is a recursive 'folding back' of the tree	• Most appropriate for cases with one fundamental source of uncertainty • The tree may become large and cumbersome • More intuitive than continuous-time • Require less mathematical background and skill to develop and use
Lattice	• A type of numerical solution technique • It represents the discrete-time approximation of a continuous-time stochastic process of GBM as well as other types of processes • It is a tree technique, and the solution process is a recursive 'folding back' of the tree or lattice • When some transition probabilities become negative or are functions of the expected rate of return of the underlying asset, another model of market prices or an equilibrium asset pricing may be required	• Most appropriate for cases with one or two fundamental source of uncertainty • The tree may become large and cumbersome • More intuitive; flexible to handle multiple options, complex option payoffs, and downstream decision • More acceptable to practical implementation • Not sure whether this is a better approximation than simply increasing the number of steps in binomial model

*Cases with many but finite number of periods, multiple uncertainties, state/time dependent input parameters, multiple options, compound options
Source: Lander (1997)

The finite-difference model is a general method for numerically approximating the value of an option. It requires the development of appropriate discrete-time difference equations and boundary conditions. Highly sophisticated mathematical skill is still needed to formulate and solve the difference equation set. Practical application is limited since it can be difficult to implement and is considered as not intuitive.

The general binomial model has similar difficulties to that of the continuous-time model, namely that it is appropriate for the case with only one fundamental source of uncertainty. A specific problem of this tree technique is that the size of the tree can grow excessively large when the time period increases. The presence of the following problems may significantly contribute to the growth of the tree: (i) the tree does not recombine, (ii) the number of steps is increased to compensate for only having two outcomes per node, and (iii) if the decisions are also explicitly modeled in the tree. As a numerical approximation, the valuation result of a binomial model is consistent[23] with the Black-Scholes values only 'in the limit'. In addition, although this model is more intuitive than the continuous time and require less mathematical background, Lander and Pinches (1998) report that corporate managers do not intuitively comprehend the risk-neutral valuation and the use of risk-neutral probabilities.

The lattice model assumes the underlying asset is governed by continuous-time stochastic process, and the model represents the discrete-time approximation of such process. With respect to this notion, since a binomial model approximates a standard GBM, then it is also a lattice model. However, process representations in lattice models

[23] When the mean and the variance of the discrete-time approximation process is the same as for the underlying continuous-time stochastic process (Lander and Pinches, 1998)

are less restrictive that they allow wider possibilities of portraying a real world problem. It can handle multiple options, complex option payoffs, and downstream decisions. Compared to continuous-time models, lattice models represent investment opportunity more intuitively. The weaknesses of lattice models are due to consequences of the assumptions of option-based models, the technical difficulties pertinent to the tree technique, and also the limitation of the numerical approximation technique employed in the model.

2.4.3 Graphical Models

The graphical models represent the underlying structure of a problem and depicting the decision-maker's current knowledge about the situation. Lander and Pinches (1998) also describe this family of models as 'Uncertain Reasoning Models' or 'Directed Acyclic Graphs'. This approach for modeling and valuing real-option problem is considered the most appropriate when no market information on the underlying asset is available.

Decision Trees (DT) is one model in this family. DT can present the hierarchical nature and sequential attributes of the options problem. Capital investment is valued by calculating the expected utility of the project or decision based on the information about the project that is available to the decision-maker at the time of the analysis. In practice the problem becomes, how the decision-maker values the project. The expected utility of the decision-maker does not necessarily reflect how she or he believes the market value of the firm may be affected by those uncertainties. When the decision-maker values risks differently than does the market, or when not all of the relevant market information is taken into account, then the expected utility differs from the market values.

A Decision Analysis Model is a special case of decision tree models. It does not use discount rate to capture risk preferences or risk and time preference, but uses a utility function instead. This approach can accommodate the perspective of any decision-maker that is not necessarily in conformity to that of the market, or of corporate management that is not necessarily similar to the shareholders. This is useful, for example, to represent project-specific risks that are perceived as undiversifiable.

Influence Diagram (ID) is another member of the family. It is a very general modeling technique, which is appropriate when uncertainty can be modeled by a set of conditional probability distribution. An ID is a compact representation of a Bayesian decision problem. It consists of (i) the graphical part (the pictures), and (ii) the numerical part (the tables). Lander and Pinches (1998) state that ID shares the same strengths as decision trees. In addition, it has additional features such as more compact representation of the problem and more manageable size and complexity of the model.

However like DT, ID has the problem of determining what discount rate is appropriate in the presence of an option. With respect to this issue Lander (1997) argues that:

- Discount rate used may not be as critical a factor in valuation as the cash flow estimates;
- A NPV profile will show the range of discount rates when NPV is positive;

- The discount rate issue is relevant only if the optimal strategy changes within a reasonable range of discount rates.

2.4.4 Finding Solutions

Each of the above approaches to model and value a real option has both strengths and weaknesses. This implies that none of them is superior in all circumstances. The unique characteristics of a particular real investment problem may lead one approach to be more appropriate than the other.

In contrast to older views that tend to suggest various approaches for valuing risky project as competing methods, recent research propose some form of integration to take advantage of their individual strengths. Different methods are then applied to different parts of the problem, or serve a specific task in the modeling and valuation procedure.

An example is the work of Smith and Nau (1995) that combines an option-based valuation with decision analysis. They show that when applied correctly, option pricing and decision analysis gives consistent results. Further, these two approaches can be profitably integrated in the following way: (i) option pricing techniques can be used to simplify decision analysis when some risks can be hedged by trading, (ii) decision analysis techniques can be used to extend option pricing techniques to problems with incomplete security markets. Smith and McCardle (1998 and 1999) use an integrated approach to value oil and gas properties.

Lander (1997) provides a guideline, shown in Table 2-4 to select which decision-making framework is appropriate to model and value investment opportunities having real options. She also suggests that combining option-based valuation with influence diagrams can provide several advantages, which includes a compact representation of the problem and make possible the use of non-standard binomial process (non-constant parameters throughout the tree) that allows for local volatility.

Table 2-4. Which Approach is Appropriate?

Project Characteristics	DCF	DT	OPT	ID
1. Little or no managerial flexibility	++	0	-	0
2. Flexibility is valuable and the optimal strategy is not sensitive to the discount rate	-	+	0	+
3. Flexibility is valuable, the optimal strategy is sensitive to the discount rate, and there are 'no modeling problems'	-	-	++	+
4. Flexibility is valuable, the optimal strategy is sensitive to the discount rate, and there are 'modeling problems'	-	0	0	+

Notes: DCF = discounted cash flow; DT = decision tree; OPT = option-based; ID = influence diagram
++ = highly appropriate; + = appropriate; 0 = possible but not the best; - = not appropriate.
No modeling problems means:

- There are only one or two uncertainties
- Market values for the underlying asset(s) are available
- The underlying asset(s) reasonably follows an assumed distribution
- Payout ratios and convenience yields can be determined from market values and can be modeled as dividend-like payments
- The mathematics required are not computationally burdensome
- If the model is a discrete-time model, the tree or lattice does not explode

In Lander's guideline, geothermal electricity project studied in this research would fit into cases 'with modeling problems' since it is difficult to find a twin security to be used as the underlying asset for the option valuation.

One alternative to overcome this intricacy is to adopt the following two assumptions proposed by Copeland et al. (2001) and McKinsey & Company, Inc. (2000), which provide a means to simplify the process of applying the real option methodology in real-world settings:

(i) *Marketed Asset Disclaimer*, which is to use *the present value of the project itself*, without flexibility, as the underlying risky asset in place of 'twin security' in the financial option theory. As discussed previously in sub-section 2.3.2-(d), they argued that it is nearly impossible to find market-priced underlying risky asset for most real options case. Instead, it is sensible to assume that the present value of the cash flow of projects without flexibility (i.e. the traditional NPV) is the best-unbiased estimate of the market value of the project were it a traded asset.

(ii) *Properly anticipated prices fluctuate randomly.* Samuelson (1965) proves that the rate of return on any security would be a random walk regardless of the pattern of cash flows it is expected to generate in the future, as long as investors have complete information about those cash flows. Copeland et al conduct an empirical study to show that, based on Samuelson's proof, it is also true that real equity returns, or the rate of return on properly anticipated streams of cash flow, fluctuate randomly in a world with positive discount rates, regardless of the pattern that the cash flows follow through time. This assumption implies that multiple, correlated sources of uncertainty can be combined into a single multiplicative binomial process.

Similar to an NPV analysis, real option analysis is also based on the *Separation Principle*, i.e: (i) managers of firm should maximize shareholder's wealth by taking investments that earn at least the market-determined opportunity cost of capital, and *(ii)* the wealth-maximizing rule for investment is separate from any information about shareholder's individual rates of time preference or utility function.

Table 2-5 outlines a procedure to value real options as proposed by Copeland and Antikarov (2001). Step 1 is to calculate the base-case project value without flexibility using a standard net present value analysis. The Entity Free Cash Flow is discounted at weighted average cost of capital, representing the gain in shareholder's wealth or the value of the underlying.

Entity FCF, also known as FCF from Operations, is the cash produced by a business without taking into account the way the business is financed. In other words, it is the after-tax cash flows the company (i.e. the entity) would have if it had no debt (Copeland et al., 2001). The figure can be derived in many ways, one of which is as follows (Benninga, 2001):

Entity FCF = Profit after taxes + Depreciation + After tax interest payments

- Increase in current assets + Increase in current liabilities

- Increase in fixed assets at cost (2-33)

The FCF does not take into account debt shares; however, the contribution of debt in the project is represented in the cost of capital. Therefore, the discount rate to be used for calculating the project value is the Weighted Average Cost of Capital (WACC):

$$WACC = \left(k_b (1-T) * \frac{B}{B+S} \right) + \left(k_s * \frac{S}{B+S} \right) \tag{2-34}$$

Where B = bond (debt) and S = share (equity)

k_b and k_s are marginal cost of debt and equity respectively

T = tax

Step 2 is to model the uncertainty that drives the value of the underlying asset over time. Using the value of an asset without flexibility, which is the project present value by the DCF model, and the volatility estimate, an event tree can be generated. In most cases the volatility estimate can be derived by using Monte Carlo analysis to combine multiple uncertainties that drive the value of the project into a single uncertainty, which is the distribution of returns on the project. It is important to recognize in this step that the uncertainty of a project within a company is not the same as the uncertainty of the variable(s) that drive the uncertainty.

Step 3 identifies the types of managerial flexibility that are available and builds them into the nodes of the tree, which turns the event tree into a decision tree. A decision tree shows the payoffs from optimal decisions conditional on the state of nature.

Step 4 is to recognize that the exercise of flexibility alters the risk characteristics of the project. Therefore, the risk-adjusted discount rate is no longer the weighted average cost of capital as was used in Step 1. Rather, the valuation of the payoff uses either the replicating portfolio method or risk-neutral probabilities.

Table 2-5. General Approach to Apply Real Option to the Real World Problem

	Step 1 Compute base case present value without flexibility using DCF valuation model	Step 2 Model the uncertainty using event trees	Step 3 Identify and incorporate managerial flexibilities creating a decision tree	Step 4 Conduct Real Options Analysis (ROA)
Objectives	Compute base case present value without flexibility at t=0.	Understand how the present value develops over time.	Analyze the event three to identify and incorporate managerial flexibility to respond to new information.	Value the overall project using a simple algebraic methodology and an Excel spreadsheet.
Comments	Traditional present value without flexibility.	Still no flexibility; this value should equal the value from Step 1. Estimate uncertainty using either historical data or management estimates.	Flexibility is incorporated into event trees, which transforms them into decision trees. The flexibility has altered the risk characteristics of the project, therefore, the cost of capital has changed.	ROA will include the base case present value without flexibility plus the option (flexibility) value. Under high uncertainty and managerial flexibility, option value will be substantial.

Source: Copeland et al. (2001)

This combined option valuation methodology is a variation of standard discounted cash flow models, which adjusts for management's ability to modify decisions as more information becomes available. The steps show that this procedure incorporate all approaches listed in Table 2-4 except influence diagram.

2.5 RESEARCH METHODOLOGY

Figure 2-3 summarizes various components of the literature that are incorporated in this research. There are four sources in the literature that provide major influence to shape the research framework.

The Literature		This Research
Dixit & Pindyck (1994) • Real option concept • Investment as real option	✓ ✓	The book motivates the idea to adopt real options framework
Lander (1997): • Influence diagram is appropriate for real options 'with modeling problem' (refer to sub-section 3.4.4)	✓	Influence diagram is used to generate the initial model structure and the alternative setting for policy exercise
Cortazar et al. (2001): • Compound options at natural resource project • Continuous time model • *Solving by implicit finite-difference numerical method*	✓ ✗ ✗	Compound options at natural resource project Lattice approach Solving by spreadsheet and influence diagram
Copeland and Antikarov (2001) • Assumptions to simplify modeling investment problem • Procedure to value real options	✓ ✓	Adopt the assumptions Adopt the procedure

Note: ✓ reflects conformity, ✗ reflects different approach

Figure 2-3. Relations of Research Model and The Literature

The book of Dixit & Pindyck (1994) introduces the concept of real options. It motivates the idea to consider an opportunity to engage in a geothermal electricity project as real options.

Lander's (1997) idea to combine influence diagram and option-based models to obtain a compact model representation is adopted to represent the structures of the models and support the analysis stage. Although spreadsheet software has the ability to perform tedious numerical procedure, it requires extensive programming effort to include uncertainty analysis such as Monte Carlo simulation. This research uses an influence diagram framework that provides more flexible settings to balance this difficulty. Another important role of influence diagram in this research is to automatically implement Bayes' Theorem to calculate joint probabilities from conditional probability information in the model.

Cortazar et al. (2001) represent a real option application to model investment in natural resource extraction as a compound options. In this research, sequential investment stages in a geothermal electricity project are modeled as compound options as well. *Committing to exploration expenditures would yield development option,* and exercising the development option by developing the field and constructing the power plants (paying development costs) would lead to the operation stage where the project benefit is generated.

Similar to the above model, the project is facing geological-technical as well as market uncertainties. The model also simplifies the effect of price and geological-technological risk by collapsing both of them into one factor. However, in this research the project starts with an estimate in price and reserve characteristics. The price uncertainty is resolved at the same time as the geological-technical uncertainties. After the exploration stage is completed, both uncertainties resolute. Another source of uncertainty is the level of demand, which depends on the final price level.

The valuation of the project proceeds backward in the following stages: (i) valuing the completed project provided that the exploration is successful, then (ii) valuing the development investment decision, then (iii) valuing the exploration phase. The procedure is a consequence of modeling the project as embedded options, since the value of the first option (exploration option) is contingent on the value of the second option (development stage), and the value of the second option is contingent on the value of the completed project. The value of a completed project is reflected by the projected cash flows during the operation or extraction stage.

In contrast to Cortazar et al. (2001) that use implicit finite difference method to solve the problem, this research uses lattice approach to facilitate numerical solution procedure. This approach requires moderate mathematics and gives rise to a simple and efficient numerical procedure for valuing options for which premature exercise may be optimal.

Copeland et al. (2001) provides theoretical foundations and a practical approach to undertake the real options analysis. Their two assumptions avoid the difficult task of finding an underlying risky asset that has similar risks as the project at any time. In particular, this new insight makes ROA applicable to projects that previously fit in a case 'with modeling problem' (following Lander, refer to the notes below Table 2-4). In addition, their four-step procedure provides a guideline on how to proceed toward finding the numerical solution of real options. This procedure is especially important to construct the structure of the basic model in this research.

CHAPTER 3

RESEARCH OBJECTIVES

This research selects the development of a geothermal electricity project in Indonesia as its case. The initial interest in this subject emerged in 1995-96 when the author was a team member that assisted the Government of Indonesia (GOI) in preparing guidelines and necessary software to accommodate private participation in electricity generation projects, in particular geothermal and combined cycle.[24] It was apparent that GOI is very keen to develop this indigenous natural resource, while there were significant interests of private investors to participate in the undertakings. However, high output price and other circumstances discussed in Chapter 4 made developments slow. Only a few years later the economic crisis escalated the problems, causing all private electricity generation projects to be suspended including seven geothermal projects. Although recently GOI has initiated actions to revive these projects, the results are not encouraging. This condition motivates further interest to look into the problem.

The objectives of this research are as follows:

1. Model geothermal development project using options theory.
2. Compare options-based to the standard NPV decision-making.
3. Explore alternative arrangements that are potentially Pareto improving to induce geothermal development.
4. Contribute to the literature on real option and natural resource development.

[24] Combined cycle power generations use both gas and steam turbine cycles in a single plant.

3.1 Modeling

The first challenge in modeling an Indonesian geothermal project is the complex and interrelated issues described in Chapter 1. The second layer of challenge is discussed in Chapter 2, which points out that different ways of viewing an investment opportunity may leave out important features of project characteristics. This in turn may lead to under or over valuation, and also inappropriate decisions. The search for a compelling and practically attainable theoretical base turns out to be long and intricate.

The real options theory provides a novel look that highlights the problem of forcing pre-commitment too early with this type of investment. However, the application of the theory is a green field. The complex settings of real options and the requirement for market-based information are among the limiting factors for the application. Fortunately, recent developments in the literature offer a breakthrough that allows sensible use of the theory. This approach enables a wider perspective and better understanding of the present problems in geothermal developments in Indonesia.

3.2 Impact of Flexibility in Project Assessment

This research examines the impact of taking into account flexibility in the assessment of a geothermal project. As shown in Chapter 5, viewing this particular investment opportunity as a sequential compound options provides additional value to the project and suggests that some changes in the present arrangement may be able to provide a set of incentives to develop geothermal electricity projects as well as to create social benefits.

3.3 Alternative Business Arrangement

A proposed method to take advantage of a more flexible arrangement is a two-phased negotiation for determining the output price. The first phase would set a range of acceptable prices that justifies the presence of geothermal electricity as a base load generation. This negotiation is positioned before the project starts, to ensure that only viable projects go forward. The second phase would consider the results of the exploration stage to determine the output price.

Assuming symmetric information and a simple self-interest behavior, this arrangement is expected to be Pareto improving, thereby generating incentives for geothermal development. However, taking opportunism possibilities into account, Pareto-improving condition may not be guaranteed. Although this arrangement may reduce the opportunistic behavior of the private developer, it is open for such behavior on the part of the government. A future research agenda may use a game-theoretic analysis to examine the institutional arrangement and to identify necessary safeguards for this transaction.

3.4 Literature Contribution

The case selection contributes to the literature in the following ways:

a) The application to geothermal development adds to the body of work in real option analysis on natural resource extraction. Although geothermal extraction has some similar features to other natural resource extraction activities such as oil or extractive minerals like gold and copper, it also has unique characteristics that distinguish it from others. In addition, this case combines natural resource extraction with electricity generation activities, which are usually addressed by separate models.

b) This case highlights the problems of applying real option approach where market information to value the underlying asset is not available. Much of real option research on electricity takes advantage of a restructured market with selections of electricity derivatives that can be used as underlying risky assets (Deng et al., 2001; and Frayer et al., 2001). This is not a feasible approach; as such a market does not exist in Indonesia. This research applies a methodology proposed by Copeland et al. (2001) that enables the application of real options analysis in the absence of a tradable underlying asset.

CHAPTER 4

GEOTHERMAL DEVELOPMENT IN INDONESIA

Indonesia has identified 244 geothermal prospect areas all over the islands, with estimated potential capacity of around 20,000 MWe. However, after 20 years of development, there are only 787 MW installed geothermal plant capacity and among them merely 525 MW in operation.

As illustrated at Chapter 1, the economic crisis started in 1997 caused government decision to suspend 16 power generation projects including 7 geothermal projects. The resulting legal disputes between the electric utility company and the private developers have halted geothermal development progress. Significant factors that intertwine in this problem are the existing business arrangements, limited initial information about the prospect areas, and restricted government funding, which lead to high prices of geothermal electricity. The recent changes in several laws and regulations that affect the energy sectors further aggravate the uncertainties.

The following sections describe circumstances in geothermal development, which provides a foundation for the application of the real option analysis to this particular case. The first section illustrates general characteristics of geothermal energy and its utilization worldwide. The second section features geothermal potential, utilization and the business environment in Indonesia.

4.1 GEOTHERMAL RESOURCES

Geothermal is the natural heat of the earth that comes from deep within. The crust of the earth, which consists of six major and a few smaller discrete plates, are always in a state of relative motion. Where they spread apart, molten rock beneath the crust flows upward; where they move together, one plate goes up and the other goes under and melts into the interior. The heat from the interior of the earth emerges to the surface at these junctions of the plates (Goodman & Love, 1980).

Geothermal energy is defined generally as the thermal energy stored at accessible depths in the earth's crust (Mock, Tester & Wright, 1997). Geothermal resource is identified with the useful accessible geothermal resource base, where it is concentrated into restricted volumes comparable to the concentration of hydrocarbon or ore deposits, and it is close enough to the surface (Jessop, 1990). This means that although many countries have geothermal resource potential, not all of them are feasible to be harnessed.

Compared to other energy alternatives, geothermal energy is known to have benign environmental consequences. Some of the features, as discussed by Mock et al. (1997), are the following:

a) CO_2, SO_x, NO_x and particulates emissions are negligible.[25] Many geothermal systems approach emissions- and waste-free operation, which minimize point-source pollution.

b) Major elements of a geothermal system are located underground and the entire fuel cycle is located at a single site, resulting in modest use of land and water.

[25] The subscript x indicates various structures involving different compositions of the oxygen atom.

c) Although natural water recharge rates for hydrothermal systems may be extremely slow unless artificially supplemented, geothermal energy is renewable in the sense that a complete recovery of original temperatures will occur within a period of time less than 10 times of the production period.

4.1.1 Geothermal Extraction

Geothermal resources must be actively sought using available geological and geophysical tools. Traditionally, only places associated with tectonic plate boundaries and areas of recent geological volcanic events are the ones identified with geothermal resources. However, recent progress in technology provides future possibilities at places of less obvious physical indication.

The term *heat mining* is often used to describe the efforts to harness the earth's thermal energy. The extraction of the natural heat of the earth depends on a material carrier. At present, the most common types of geothermal resources exploited worldwide are *hydrothermal* resources, where water acts as the heat transfer medium present naturally in the system. A hydrothermal system contains steam or liquid water of temperature up to 350^{o} C.

In addition to hydrothermal, other types of geothermal resource are, (i) *hot dry rock*, where fluids are not produced spontaneously, (ii) *magma*, which consists of partially or completely molten rock in regions of recent volcanic activity, and (iii) *geopressured*, which consist of hot high-pressure brines containing dissolved natural gas (methane) (Mock, Tester & Wright, 1997).

The above classification is one of several ways of distinguishing geothermal resource types. Table 4-1 shows another example of classifying geothermal resources, with a slightly different grouping but with additional details.

Table 4-1. Classification of Geothermal Resources

No.	Main Category	Sub Classification
1	Hydrothermal Convection System	1.1. Vapor-dominated systems 1.2. High-temperature liquid-dominated systems (> 150° C) 1.3. Moderate-temperature liquid-dominated systems (90° C - 150° C)
2	Hot Igneous Systems	2.1. Molten Part 2.2. Crystallized part (hot dry rock)
3	Regional Conductive Environments	3.1. Geopressured part 3.2. Normal pressured part

Source: Goodman et al., 1980.

Many features of geothermal project activities are comparable to that of oil or other mining activities, such as:

(i) The earliest resources to be exploited were found in areas where surface indicators were obvious, while the hidden reservoirs were incomparably larger than those with surface manifestations (Jessop, 1990), and

(ii) Tapping new sources requires a sequential process consisting of prospecting, exploration, development, and production (Petrick, 1986).

Table B-1 in Appendix B illustrates various activities that are commonly accounted for in the sequences in a geothermal project. The prospecting stage is also known as 'reconnaissance' survey, where the objective is to identify the possible existence of geothermal resources and the possible use by examining surface manifestations and undertaking limited field surveys. The activities determine the boundaries of the prospect area and estimate its potential size.

The exploration stage involves activities to obtain information on the characteristics of the resource, which include drilling some exploratory wells of 1,000-3,000 meter depths. This stage would determine the existence, size, quality and productivity of geothermal resource in the tract. This will allow the investor to infer the cost requirement for taking the resource out from the ground. Favorable results of an exploration stage may lead to a development stage.

During the development stage, more wells (called production wells) need to be drilled. Further activities include establishing necessary facilities to extract the geothermal energy as well as to prepare for its subsequent designated use such as constructing the power plant to convert the thermal energy into electricity.

In geothermal electricity projects, both field and power plant developments shall be completed at the same time. Since field development may take longer time than power plant construction, the latter action may start after some development progress is underway. A completed development stage provides the required facilities to produce electricity from geothermal energy.

4.1.2 Geothermal Utilization

At year 2000, almost 100,000 GWh geothermal energy were in use worldwide. The statistics shows that a little bit more than half of its utilization worldwide is in the form of heat. In contrast, the figures for developing countries indicate that more usage is in the form of electricity (Michaelowa, 2001).

Geothermal resource that is used for electricity generation typically has water temperature of above 150° C. However, it is also possible to produce electricity from geothermal waters of 100° C such as at the Wendell-Amedee in California (Wright, 1998).

A geothermal electricity system is simple, safe and adaptable with modular (1-50 MWe) plants. The modular characteristics of geothermal plants can support the reliability of an electricity grid system, as well as electrify remote areas where the grid is not yet established (Mock et al., 1977).

Lower-temperature geothermal resources are used for direct heat applications. Commercial uses of this type include drying, ore-leaching operations, greenhouses, and district heating system. In addition, other forms of utilization such as domestic heating, bathing and cooking were known long before the commercial uses mentioned above.

4.2 GEOTHERMAL IN INDONESIA

4.2.1 Resource Potential

Geothermal energy is one of the indigenous energy alternatives of Indonesia. The country is located at the junction of three major plates of the earth's crust, namely the Pacific, India-Australian, and Eurasian Plates. This condition results in a significant amount of geothermal manifestations such as volcanoes and hot springs all over the country. The chain of volcanoes along Sumatera, Java and other large islands (except

Kalimantan) is known as part of the so-called 'Pacific Ring of Fire'.[26]

Figure 4-1 shows the locations of geothermal prospects and existing commercial fields throughout Indonesia, while Figure B-1 in the Appendix details their names and respective locations.

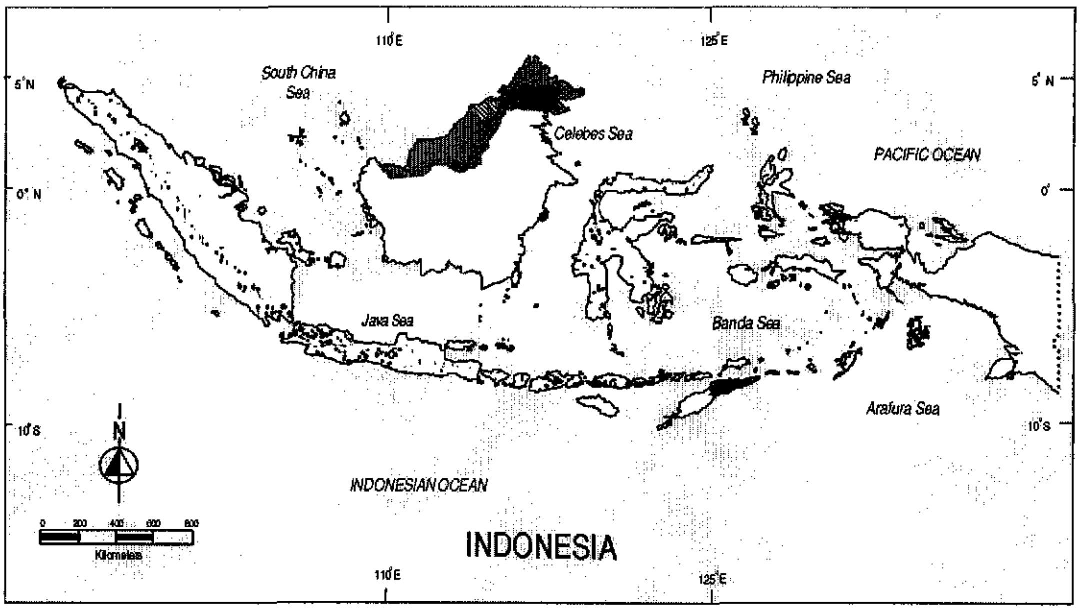


Figure 4-1. Geothermal Locations in Indonesia

Table 4-2 indicates the classifications and estimated size of identified geothermal prospects in the islands of Indonesia. The proven, probable and possible potentials are estimated to be around 20,000 MWe. Almost half of the potential is located in Sumatera and nearly 30% is in Java. This means around 80% of the resource potential is located in

[26] The terminology refers to the chain of volcanoes that was created by the upward intrusion of magma (molten rock) at the edge of the Pacific Plate. The 'ring' extends along the west part of the America continent, the Aleutian Islands, Japan, the Philippines, Indonesia, the South Pacific and New Zealand (Wright, 1998).

the islands that are home for 80% of the country's 206 million population,[27] which means that geothermal resources are located near the demand centers.

Table 4-2. Geothermal Resource Potential in Indonesia

Classification*	# of Prospect	Locations	Size (MWe)
Proven	7	Java (4), Sumatera (2), Sulawesi (1)	1,192
Probable	14	Java (9), Sumatera (3), Sulawesi (1), Nusa Tenggara (1)	2,250
Possible	55	Java (26), Sumatera (21), Sulawesi (3), Bali (1), Nusa Tenggara (2), Maluku (2)	14,089
Hypothetical	55		6,132
Speculative	162		36,500

Note: * From top to bottom, the list indicates a decreasing degree of certainty that reflects the quality and quantity of available information on geothermal system at the prospects. Refer to Table B-1 in the Appendix for additional explanation.
Source: Directorate General of Oil and Gas, 1996

Compared to 20,761 MW capacity of the existing power plant under the management of PT. PLN (the National Electric Company),[28] geothermal resource potential is obviously an important alternative energy source to support the system. Large resource potential and favorable locations are important advantages of geothermal energy in Indonesia.

4.2.2 Resource Utilization

The Government of Indonesia (GOI) encourages geothermal development as part of the energy diversification policy, which among others is intended to ease the pressure of domestic demand for oil. The national energy policy as well as the existing regulation

[27] BPS Statistics Indonesia for year 2000. (http://www.bps.go.id/sector/population/table1.shtml)
[28] As of year 2000, the total installed generating capacity in Indonesia was 37,591 MW and PLN owns 69% of them. (Statistik Ketenagalistrikan, http://www.djlpe.go.id/informasi/frame_informasi_listrik_2.htm)

categorize geothermal as renewable energy. For small power producers, the energy diversification policy leads to a favorable regulation that dictates a higher priority for power supplies that uses renewable energy including geothermal plants. In large power supplies division, geothermal plants have been regarded as 'must run' suppliers to the system that indicates the highest priority in the dispatch order.

Despite those favorable conditions, however, progress of geothermal utilization has been very slow. After more than a decade of development, direct application is limited to traditional use and few experimental projects. The commercial geothermal utilization is only for electricity generation, which is supplied by three geothermal fields with total installed capacity of 525 MWe.

A major disadvantage is the fact that electricity from some geothermal projects are presently more expensive compared to other types of electricity generation in the country. There have been a lot of discussions as to whether or not other energy sources have been priced 'fairly'.[29]

Nevertheless, several factors have contributed to the high price of geothermal electricity. One reason is a high cost that, among others, relates to inherent difficulty in finding and extracting the energy from the earth that requires special technology and skills as well as adequate financial support. The project requires high initial capital to gather information about the underground reserves as well as to construct the operation facilities. In addition, field works and power plant construction may use up three to

[29] Petroleum-refined fuels have been heavily subsidized, although the government is currently attempting to decrease the subsidy amount. In addition, there has been some concern on the pollution effects of coal and oil, as well as the economic consideration that oil and coal can be exported. Hence, some additional costs (externality and opportunity costs respectively) in comparing coal and oil to geothermal have to be taken into account.

seven years of the project life before any revenue is generated. As such, geothermal development project is a highly specific investment with large capital outlay and long preparation time.

The second disadvantage is the 'non-transportable' nature of geothermal energy, which requires the location of power plant on site or nearby the field. Further, geothermal potentials are commonly found in remote locations with lack of transmission and distribution network. Consequently, these conditions associate such geothermal potentials only to the small local market.

The third shortcoming is that there is no mechanism to effectively represent significant benefits of geothermal development, such as the long-term low cost of operation, low emission of pollutant particulates, and the impacts of diversification of supply from an indigenous, distributed resource (US Embassy, 2002).

Another complication arises from an unfinished process of regulatory reform. In contrast to the previous oil and gas law, the new law that was promulgated in October 2001 excludes geothermal. The problem is that the special regulation for geothermal utilization has not been put in place.

4.2.3 Business Environment

This study focuses on so-called *geothermal total projects.* This terminology is used by the GOI to refer to geothermal projects where the same investor (or consortium of investors) is responsible for both the developments of geothermal field as well as the electricity generation.[30] The final output of an investment in geothermal total project is electricity; therefore the explicit price for output is only for electricity.[31]

Figure 4-2 shows advancement in a geothermal electricity project in Indonesia. Previously, the GOI would provide an estimate on reserve potential and other preliminary data based on some limited surface surveys on the prospective site. In contrast, the Presidential Decree 76/2000 requires more GOI work at this stage, i.e., until the search concludes whether or not the prospect can be upgraded into the 'probable' status.[32]

A proposal that expresses an interest to pursue a geothermal project would include a work plan and a price of electricity to be produced by the project. Once the contract is signed, the investor's tasks in developing the field closely resemble those in oil projects. However, in addition to developing the field, investors would need to develop power-generating facilities as well. The production stage starts following the completion of field development and power plant construction.

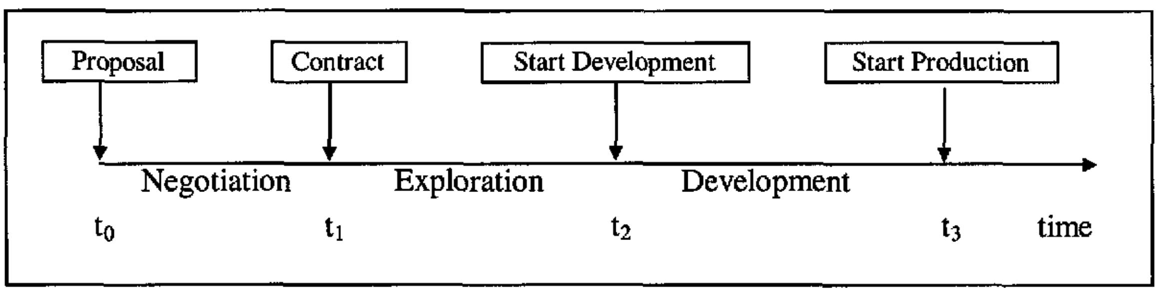


Figure 4-2: Progress in a Geothermal Project

[30] Contrast this to the case where field development and power generation are independent projects or managed and operated by different parties.
[31] If field development and the construction of power generation are independent projects, the output will be steam from one project and electricity from the other. In this case, output price will refer to steam price for the former and electricity price for the latter.
[32] The probable status is determined based on the information from drilling at least an exploratory well.

As highlighted in Chapter 1, the economic crisis that started in 1997 had raised concerns over the role of private participation in the electricity sector. Some of the suspended projects are renegotiating their terms and conditions with PLN, while others choose to enter the arbitration procedure. The problem has been more complex in geothermal development, because unlike other private power generations, private geothermal project involves the utilization of natural resources. Similar to all natural resources in the country, geothermal resources belong to the state.[33]

Based on this view, Presidential Decree 45/1991 determines that private companies may participate in geothermal development as contractors to Pertamina, the state oil and gas company. A Joint Operation Contract (JOC) governs this relationship. Further, Pertamina or the JOC sells either steam or electricity to PLN or other parties for electricity generation. An Energy Sales Contract (ESC) governs the purchase of electricity by PLN, which is usually denominated in dollars and includes a take-or-pay clause. The decree also includes a favorable tax treatment that lumps all applicable taxes into an income tax rate of 34%. Under this arrangement, a severe exchange rate depreciation following the economic crisis has caused enormous financial burden to PLN and GOI.

Presidential Decree 76/2000 was promulgated in May 2000, introducing a new arrangement for private participation in geothermal development. In an effort to improve the initial information for starting geothermal projects, the decree positions the GOI as the exclusive party to conduct exploration activities in determining probable reserves.

[33] Article 33 of The Indonesian Constitution of 1945 stated that all natural resources are under the power of the state, which shall manage those resources to the greatest benefit of the people.

Private corporations can develop geothermal resources for their own use; or if the development is to generate electricity for public use, then they shall proceed under cooperation with PLN. Hence, this arrangement no longer includes Pertamina. Further, the decree states that the electricity prices shall be denominated in Rupiah and removes the one-for-all tax rate by stating that this activity is subject to regular income and other taxes. Although this decree does not affect geothermal project agreements signed prior to May 2000, the existing corporations have been trying to convince the GOI to revise the decree. At the same time they are actively involved in proposing inputs to shape the forthcoming geothermal law.

The above description illustrates the dynamic changes that are taking place in geothermal development. In addition to the regulatory adjustment mentioned above, the following list shows various factors that form a unique business environment and may contribute to the delays of geothermal investments in Indonesia:

a) Legal and Institutional Framework:

Geothermal electricity production involves field activities that are similar to other natural resource extraction activities such as oil and gas or other mining works. Furthermore, the project also includes electricity production. At present, mining and electricity generation are governed by separate groups of regulation. A potential may arise from a longer bureaucratic process such as for acquiring various permits with respect to individual activities; or different applicable taxes as a geothermal total project involves both activities. This situation is prone to conflicting issues and therefore is insecure.

b) Risk Allocation:

i) Proposal and Negotiation Stage:

- To submit a proposal, private firms have to rely on information made available by the GOI. Under the Presidential Decree 45/1991, information about the tract that is generally based on reconnaissance (surface survey) data only. The Presidential Decree 76/200 requires that at least the reserves are offered to potential developers in a 'probable' status. However, limited government budget may suggest that there will not be many geothermal sites available for development in the near future.
- The firm would have to propose a price for the output (electricity) in their project proposal, which is a pre-requisite to go to the negotiation table in obtaining the concession area. The negotiated price will be stated in the contract. This means firms are required to determine part of their project return ex-ante, regardless of limited initial information and uncertainties they must encounter (reserve size and productivity, demand size, the price of other energy in the future).

ii) Exploration Stage:

- To better assess the resource potential, companies will need to undertake exploration activities that includes the drilling of at least 3-5 exploratory wells. This activity may take 3-5 years. Investors have to devote quite a sum of money, since each drilling for preparing a production or injection well would cost $1-3 million.[34] The exploration results indicate whether or not to proceed with development, and at what cost.

- As the consequence of the high uncertainty on the exploration results, external funding is likely to be expensive.

iii) Development Stage:

- In a geothermal electricity project, the development stage covers the development of the field as well as the construction of the power plant. Moreover, both activities are to be conducted in such a way that they will be completed at the same time. The amount of capital to be invested here is therefore much larger when compared to projects that prepare either one of them separately (i.e. the geothermal field or the power plant only).

iv) Production Stage:

- Only one buyer:

  The prevailing regulation states that a geothermal electricity investor, like other Independent Power Producers in Indonesia, can sell their electricity or use it for self-consumption. Although the regulation allows private generated electricity to be sold to both PLN as well as to any other buyers, the transmission system is owned by PLN and there is no legal base allowing the use of this system by parties other than PLN themselves. Other potential consumers or the investors themselves may be willing to build the transmission and distribution facilities. However, the following constraints

[34] Mock, Tester & Wright, 1997. The figure is in 1994 US$.

prohibit this alternative to be pursued, at least for some time in the future. The first problem emanates from the existing regulations that grant the exclusive rights of ownership and management of electricity transmission and distribution system to the state. Even if this restriction is lifted, the second problem is the economic justification for this additional capital requirement. A certain size of demand would be needed to warrant the economic of scale of this investment, since it would need a significant additional capital on top of the huge investment of the geothermal system itself. Therefore, in practice PLN is the only buyer for privately generated electricity.

- Limited market:

  The utilization of geothermal resource is site-specific. If the energy is converted to electricity, it can be delivered to the nearest grid system and therefore can reach distant demand areas. Nevertheless, the electricity generation facility itself is usually in the vicinity of the reserve area. Especially when compared to oil and gas (in the form of LNG or NGL), which can be transported abroad and traded in the international markets, geothermal resource utilization is bounded by their location.

c) Return on Investment:

(i) The project is characterized by a fixed-price contract, since the output price is determined ex-ante for the life of the project. This type of contract puts the firm in a position where it bears the entire loss when there is cost-overruns, as well as enjoy the whole profit in the case of cost-underruns.[35] However, when the project starts, how much money to be spent is as uncertain as the status of the resource size, quality, and productivity. Thus the ex-ante negotiated output price does not guarantee that the investors will recover their costs and that the decision to take the project is worth the risk.

(ii) The above conditions may be economically acceptable for private firms, as long as they can have a return that covers all the expenses and provide a positive yield comparable to other investment opportunities with similar risks. In other words, investors are willing to take the risks if the payoff is sufficiently large. This implies that the more risks left to the investors, the more expensive the output price will be. On the other hand, one of the present problems in the business is that PLN, which is the only buyer, is reluctant to purchase geothermal electricity because of its higher price relative to electricity generated by other types of energy such as hydropower, coal, and oil.

d) Economic Condition:

The lengthy economic crisis that was started in 1997 has caused the currency to depreciate significantly. From Rp.2,500 per US$ then, it has been fluctuating in the range of Rp.8,000-11,000 per US$ during 2002. A continuing major problem is the substantial external debt of the public as well as private sectors. These debts leave Indonesia exposed to interest rate and exchange rate shocks, which implies macroeconomic vulnerability.

---

[35] David, A K and Wong, K (1994)

All the above conditions illustrate the complications that restrict further progress in geothermal development. Considering that there are very limited commercial geothermal sites at present, some significant changes need to be contemplated to encourage further development.

4.2.4 Perspective for Modeling

As illustrated earlier, adjustments in a larger framework of regulatory setting are underway, along with the general issue of restructuring the economy. Correspondingly, some alternative arrangements for geothermal project development had been discussed. It is acknowledged that the changes need to balance the risk and reward for both the GOI/PLN and the private investor. Skilled professionals as well as significant capital requirements to develop geothermal fields are certainly important factors for this venture to be successful. Nevertheless, it is equally important for the proliferation of geothermal resource utilization that the project bears acceptable attributes such as competitive price as well as good quality and reliable supply.

Among the above host of issues, this research focuses attention at the geothermal project itself and less emphasis on the atmosphere. Further, the research concentrates on the significance of natural characteristics of geothermal resources to the project. The benefit of restricting the interest span is to help isolate some inherent issues specific to geothermal electricity projects. On the other hand, a drawback of this approach is an unclear picture of the findings impact on the utilization of geothermal energy resources of the country, since the latter also depends on various other factors beyond the project boundary such as investment climate of the economy. Nevertheless, the research findings point toward specific ways that can be used to facilitate the transaction process between the government and potential private developers.

The costs of geothermal project are highly site and project specific,[36] implying that the economics of geothermal energy extraction are highly variable and wide-ranging. The natural condition of the reserve is one of basic features that affect the other project characteristics. For this reason, this research focuses on the use of better information about the natural characteristics of geothermal resources to the overall project valuation.

---

[36] Major factors to the costs of geothermal power development are temperature and depth of the resource, type of resource, chemistry of geothermal fluid, permeability of the resource, plant size, technology of the plant, infrastructure requirement, climatic condition of the site, topography of the site, environmental constraints, proximity of transmission lines, construction contract, and indirect costs that includes administrative costs, management costs, insurance, permits, financing, taxes, and royalties (World Bank, http://www.worldbank.org/html/fpd/energy/geothermal/assessment.htm#economic)

CHAPTER 5

THE VALUE OF INVESTMENT OPPORTUNITY

This chapter describes an evaluation process for a hypothetical geothermal electricity project using both the conventional DCF approach and the real option analysis. During the conventional DCF analysis, the model setting resembles the present project conditions in Indonesia, where price is set ex-ante and fixed for the project life regardless of the results of the exploration phase. The real options analysis considers the impacts of incorporating some flexibility to the base model.

The first part of this chapter discusses project features through the use of two DCF financial assessments, as these forms of presentation are more widely used. In addition, the methods embrace relevant project information useful in building a case in real options analysis (ROA) setting. The purpose of this section is to further introduce the project structure prior to instigating the real option framework into the analysis.

The second part of the chapter presents the implementation of a real option approach. The project is portrayed as sequential compound options. Copeland and Antikarov (2001) option valuation technique is used, such that the lack of market information does not hamper the application of the theory. The procedure highlights the presence of flexibility in management decisions that are inherent in such structure, and shows that it is indeed valuable. Recognizing such flexibility is appropriately important so that they can be utilized accordingly. A particular interest in this exercise is to examine the relationship between the additional project values to lowering the output price.

Figure 5-1 outlines the interrelationship of research components. The first step is to structure the problem in influence diagram form, fill in the payoff values and calculate the net present value of the project without flexibility. The second step is to examine the project value at the good state, which is the state where exploration is successful and the project enters the production or operation stage. The volatility of the project value (parameter z) is estimated using Monte Carlo simulation. The third step is to generate the structure of the compound options and calculate its value.

The presence of user friendly yet sophisticated modeling and computational software for personal computers provide the means to represent unique characteristics of individual real investment problems as well as perform meticulous numerical exercises of lattice approaches. The exercise involves integrating the utilization of two commercial softwares and two computer models.

The commercial softwares are Microsoft Excel that is used as a platform for the two computer models, and DATA™ (Decision Analysis by Treeage)[37] that is used to construct the structure of the research model in influence diagram format. The two computer models are GEM (Geothermal Electricity Model)[38] and the Compound Options model. The first model is a financial model for geothermal project, which takes into

[37] Decision Analysis by TreeAge (DATA) version 3.5 is a trademark of TreeAge Software, Inc.
[38] Electroconsult of Italy built the original GEM in Lotus for the Directorate General of Electricity and Energy Development of Indonesia in 1996. The model utilized in this research is tailored to accommodate the research needs. Changes include conversion into Excel, revision of some formulas and incorporation of additional features to facilitate the linkages to other research components.

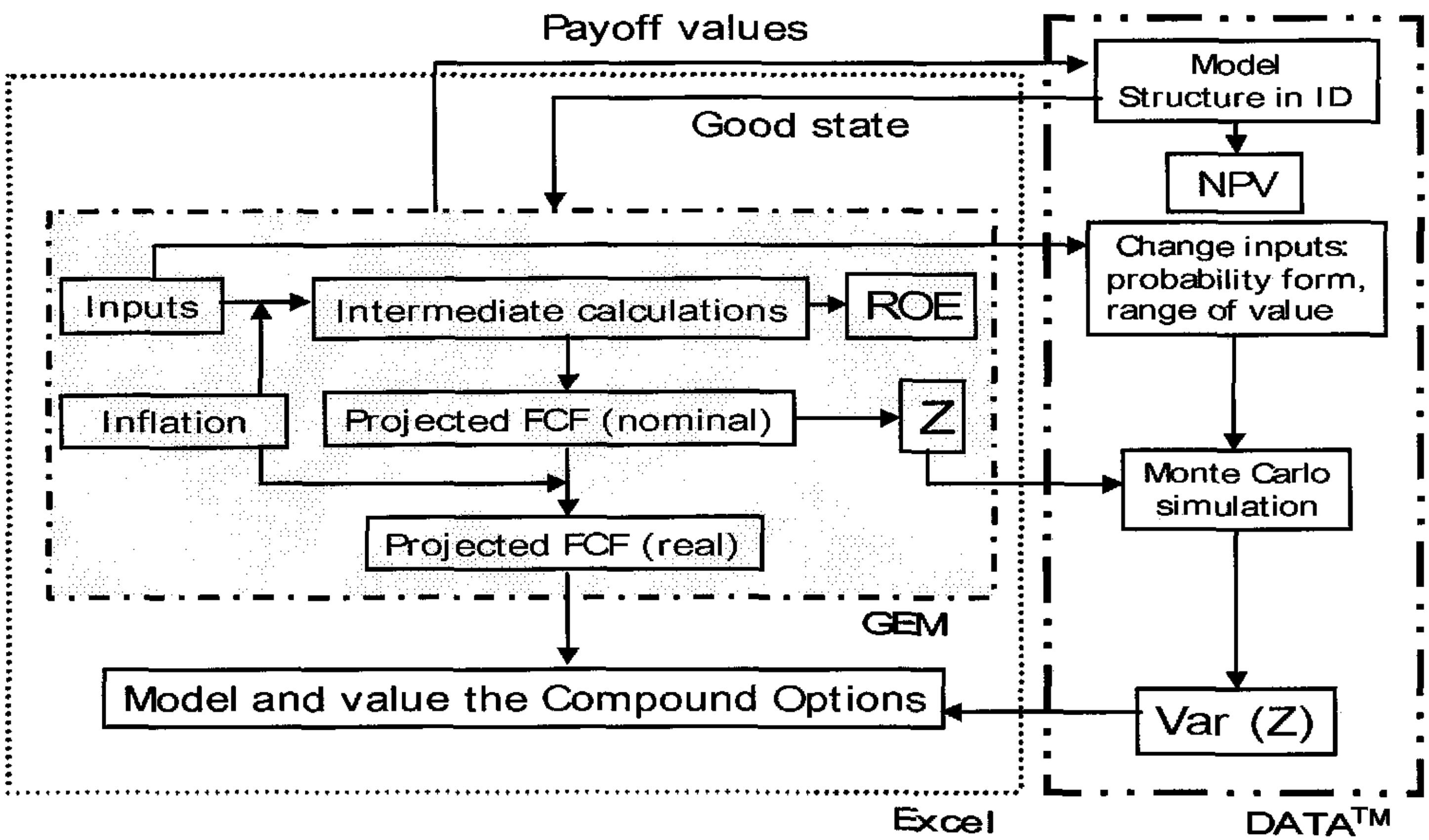


Figure 5-1. Research Outline

account field development as well as power plant operations. The second model is developed following the technique introduced by Copeland and Antikarov (2001).

Steps 1 and 2 of the research procedure integrate the utilization of GEM and DATA™. Step 3 uses GEM and the Compound Options Model to obtain the price implications and the option values. The exercise considers a hypothetical geothermal prospect located in West Java. The description below uses a corporate point of view since the developer is assumed to be the party that undertakes the activities. Nevertheless, in essence it can be seen as an investment decision problem by either the government or the developer.

5.1 NET PRESENT VALUE ASSESSMENTS

A preliminary government study estimates such prospect has a 110 MWe potential capacity. The nearest transmission grid is a few kilometers away, and there are several small cities and industry complexes around the district. This prospect seems very attractive, however the project proposal would need a careful examination since it involves a large initial capital outlay and several years to complete the facility. Moreover, the present regulation does not allow private companies to sell electricity directly to consumers. Rather, it has to be sold to the state utility company, which would buy only if their price could compete with other electricity generation companies. The future price of electricity produced by the facility has to be determined before the project starts. For this purpose, the project profile is estimated based on available information.

The first part of this section identifies project components and their interrelationship, while the second part incorporates available data and information into the structure.

5.1.1 Model Structure

Figure 5-2 illustrates the prevailing system of geothermal development, highlighting the interrelationship of project decisions and major variables affecting such decisions in an influence diagram representation. A brief note about the components of this model structure and interrelationship among them are illustrated below. A more detailed description can be referred to section C.7 of Appendix C, which also contains background information about influence diagram and its symbols.

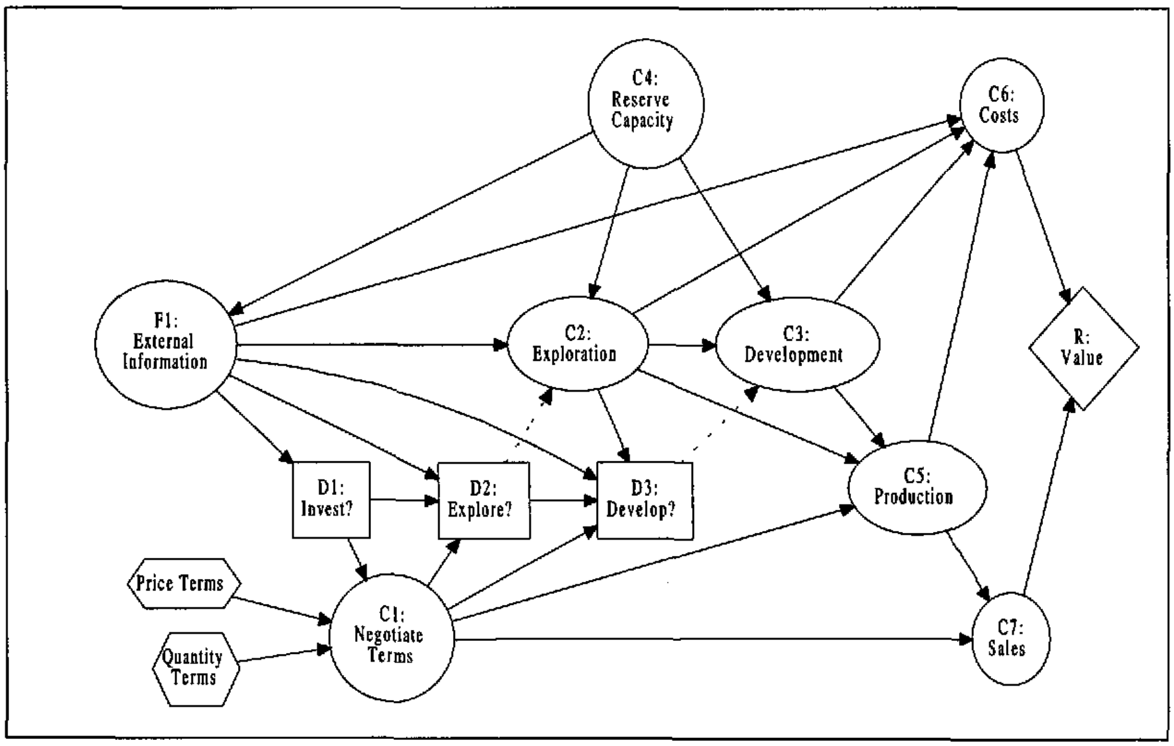


Figure 5-2. Uncertainties and Major Decisions in the Base Case Model

There are three major decisions to be made, which are indicated by rectangles on the picture: (i) whether to invest in the venture, (ii) whether to continue with exploration after the negotiation on project terms is concluded, and (iii) whether to continue with field and power plant development, which leads to electricity production. The ovals and circles represent uncertainties surrounding the resources existence and characteristics, the project terms to be negotiated, the outcome of the series of activity to learn about the reserves, and the actual sales of electricity. The double-lined circles stand for deterministic variables, which are parameters that have a single, fixed value in the model. The hexagons symbolize a group of deterministic nodes that belong to the same logical group, incorporated to simplify the diagram appearance. The arrows indicate flow of influence among the nodes.

No arrow pointing toward node C4 indicates that the actual size and condition of the reserve capacity will never be known with certainty. However, its size can be estimated by conducting a series of studies. The government or a third party conducts the reconnaissance survey. When such survey indicates that the area is prospective (node F1), this result becomes the primary information for the government to invite potential investors. The company has no control over such forecast or estimate figures; hence there is no arrow from any decision node into node F1. In contrast to F1, the company controls the other two studies at node C2 and C3. The order of occurrence of F1, C2 and C3 reflects time sequence and quality of results. A later study would yield more accurate estimate, but at a higher cost.

A contractual negotiation takes place after a decision to pursue the investment opportunity, but before any field activities commences. This negotiation would yield a certain pricing and supply figures embraced by node C1, which is set for the lifetime of the project. The arrows emanating from C1 into D2, D3, C5 and C7 show direct influence of this agreement, while it indirectly influences C2 and C3 through D2 and D3 respectively. The amount of sales and the accumulative expenditure during the preparation of geothermal field and power plant facilities would dictate the total value of the project.

Table 5-1 summarizes the classifications underlying the use of arcs on the model structure. The use of DATA™ 3.5 allows exclusion of some arcs, such as those assigned for the 'no-forgetting property',[39] because the software has an internal mechanism to automatically recognize an appropriate structure. However, Figure 5-1 presents the whole sets of these arcs for the general readers.

5.1.2 Information and Data for the Base Case Model

(a) Data Sources

Data on the Indonesian geothermal electricity projects are obtained from the following sources:

(i) Directorate General of Geology and Mineral Resources: a map depicting locations of geothermal prospects in Indonesia.

[39] Refer to Appendix C for description of this terminology.

Table 5-1. Notes for The Arcs[a]

Reason for arc assignment	Relevant nodes
Single decision-maker property[b]	D1 → D2 → D3
No-forgetting property[c]	F1 → D2 F1 → D3
Imperfect information (in the form of forecasts, estimates, or tests) that will be used to represent the true state, since they are observed earlier	C4 → F1 C4 → C2 C4 → C3
Input for a decision	F1 → D1 C1 → D2 C1 → D3 C2 → D3
Cost components of ROI calculation	F1 → C6 C2 → C6 C3 → C6 C5 → C6
Revenue component of ROI calculation	C7 → R

[a] Specific description, in addition to the generic remarks stated on Table C.2. Pairs of nodes and arc that are not listed only have the applicable generic remarks.
[b] *Definition1-(ii), Section* C.2, *Appendix* C
[c] Definition 1-(iii), Section C.2, Appendix C

(ii) Electroconsult et al. (1996):

The final reports on Geothermal Private Power Development project for the Directorate General of Electricity and Energy Development of Indonesia, in particular the following parts of the set:

- Geothermal Electricity Model, which is a financial model for geothermal project in spreadsheet format and the respective user's guide.
- Evaluation Technique, which is a guideline to assess investment proposals from private investors.

(iii) Enerindomurni (1999):

Final report of *Studi Pengurangan Resiko Eksplorasi dan optimasi Pembiayaan Pengembangan Panas Bumi* (study for exploration risk reduction and geothermal development cost optimization), for the Directorate General of Oil and Gas of Indonesia. The report provides average figures of qualifications and general characteristics of Indonesian geothermal prospects. The report also includes a simulation model named *Sistem Analisa Resiko* (SAR, risk analysis system), which contains database of several Indonesian geothermal fields.

(iv) Indonesian Geothermal Association: files describing the present business structure and ideas to improve the sector's condition.

(v) Ministry of Mines and Energy: contracted prices of geothermal projects.

(vi) PLN: load duration of Java-Bali system in 2000.

(vii) US Embassy Jakarta (2002):

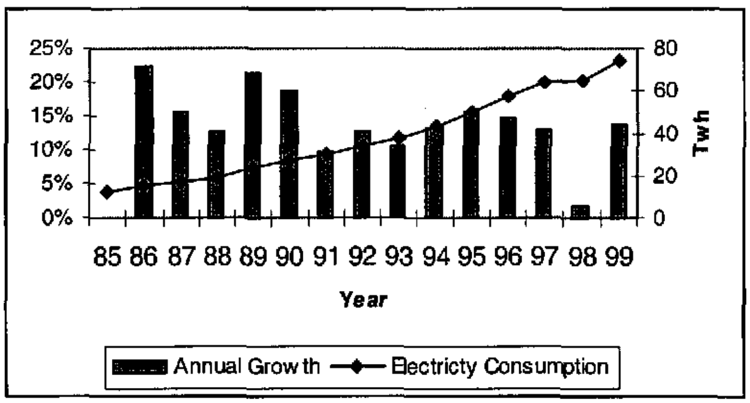
A report on Indonesia's geothermal development, which is the source for contracted prices data and the status of geothermal development projects.

(viii) Other sources:

- Web pages on financial parameters, options, and geothermal.
- Articles by Indonesian scholars and geothermal practitioners concerning generation costs of various power plants and ideas to improve the present condition.
- Personal interviews concerning financial indicators and country performance in financial market.

(b) Electricity Demand

The national demand for electricity has been growing at an average of 14% per year since 1985, as shown in Figure 5-3. This growth rate is expected to continue for the next couple of decades, considering the existing electrification ratio of 53%.[40] In addition, the prolonged economic crisis has caused infrastructure development to slow down significantly, which adds more pressure to the unfulfilled demand potential for electricity. Therefore, future demand is expected to be strong.



Source: Biro Pusat Statistik, 2002.

Figure 5-3. Electricity Consumption

(c) Reserve Potential

The presence and size of economically feasible reserve in the prospect area is yet to be studied. Initial information from surface examination is not a reliable estimate,

[40] Ariati (2001)

since among others, geological structure and hydro-geological conditions beneath the surface have a major influence on the feasibility of the prospect. This uncertainty can be resolved only by investing in a series of activities to study the underground characteristics of the geothermal system in the area, which requires drillings of some wells.

(d) Project Time Plan

The examination and preparation period would take about five years. Exploration surveys and drilling activities would need one year respectively, while the development of both the fields and power plants requires three years. The lifetime of the completed facility is estimated to be 35 years, where a full capacity operation is expected to take place during the first 30 years and a declining capacity during the last 5 years of its lifetime.

(e) Estimated Costs

The initial estimate indicates that the geothermal potential under study has a 110 MW potential capacity. As a reference, the unit costs for various types of geothermal project in developing countries are shown in Table 5-2, which indicates that the total cost per unit of power generated by the facility is likely to be in the range of US$2.5-6.0 cents/kWh. However, the capital costs of geothermal projects are highly site and project specific (World Bank, 2002). Some information on the average costs of geothermal project in the country may provide additional information.

Table 5-2. Unit Cost of Power

US cents/kWh

	High Quality Resource	Medium Quality Resource	Low Quality Resource
Small Plants (<5 MW)	5.0 - 7.0	5.5 – 8.5	6.0 –10.5
Medium Plants (5-30 MW)	4.0 – 6.0	4.5 – 7.0	Normally not suitable
Large Plants (>30 MW)	2.5 – 6.0	4.0 – 6.0	Normally not suitable

Notes: Assume 10% discount rates and 90% capacity factor.
Estimates are based on geothermal projects in developing countries, where indirect costs are at the higher end of the scale.
Source: World Bank, 2002.

The following cost estimates are based on the Indonesian figures reported by Electroconsult (1996). The economical size for the best available technology at the moment calls for a minimum of 55 MW commercial power generation capacities. This implies that the facility needs two 55 MW electricity generating units, which would cost US$95 million in total.

The company needs to do some fieldwork to examine the available resource potential, as well as develop the fields to supply the power plant of the planned size. The fixed costs of this project are estimated to be US$3 million for surface exploration and studies, and US$5 million for establishing land access and rights.

Usually a project of this size requires 5 exploration wells that cost US$2.3 million each. At least 3 good exploratory wells are expected to be good enough to be used as production wells. Historical company performance suggests that their success in drilling can be represented in a ratio of productive to unproductive well of 4 to 1, provided that the area contains the amount of energy as estimated by the government.

Assuming that the average initial performance of production wells is 7 MWe and the required reserve capacity is 5% of the full capacity, this facility would need 16.5

production wells to supply the 110 MW power plants in its first year of operation. However, the 4:1 drilling performance suggests that the company would need to drill 22 wells to obtain the necessary supply of geothermal energy. The unproductive wells are commonly used as re-injection wells, and one re-injection well is required for every three production wells. Although the cost of a development well is not as much as an exploration well, the expenditure is still significant. The company expects to spend US$1.5 million per well.

In addition, the company estimates that the well productivity rate could decline at 2% per year.[41] Therefore, during the operation stage the facility needs additional drilling of the so-called 'make-up' wells to maintain the rate of steam supply to the power plant. The company plans to drill one make-up well every two years, and the estimated cost is US$1.5 million per well.

A gathering system is required for connecting productive as well as make-up wells. The establishment of this system is estimated to be around US$0.72 million for each productive well, and US$0.38 million for each make-up well.

Administrative and engineering costs during exploration and development are around 10% of investment costs, while during operation it is estimated to be 10% of yearly costs. Operation and maintenance costs during operation are estimated to be 2% of total investment.

---

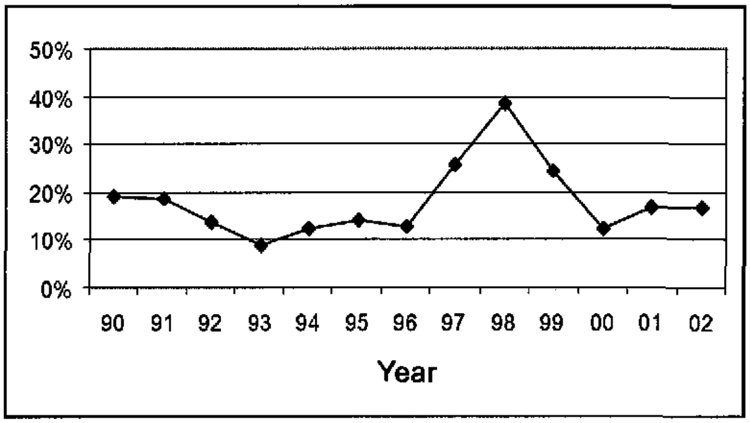
[41] In this respect, geothermal resource is not renewable. Exploitation triggers certain physical and chemical process underground, and added to naturally occurring process, will lead to depletion of the geothermal resources (Dickson and Fanelli, 1995). Mock et al. (1997) views geothermal as renewable in the sense that a complete recovery of original temperature will occur within a period of less than 10 times the production period.

(f) Financial Parameters

The company also incorporates the following parameter values in the investment proposal:

- 20% discount rate for both field and power plant developments and a 30% target for the return on equity. The discount rate figures over the past decade are shown in Figure 5-4. Erb et al. (2002) calculation shows that based on credit ratings that reflect the systematic risk of the country, the expected return for average risk investment in Indonesia range between 21%-25%. Since geothermal project is considered risky, as also supported by the common observed rate used by business participants, the minimum ROE for this model is set at 30%. Economic crisis, unsettling political issues, weak law and regulatory enforcement, contract breaching and financial difficulties in numerous power projects, as well as less international involvement in the Indonesian financial market has led to high premium requirement for capital investment. Some disruptions and instabilities in the trading of government bonds during recent years led to inactive trading, suggesting that the bonds may not be used as an indicator for country risk anymore.
- Funding during exploration period comes solely from the shareholders, since high degree of uncertainty on project existence during its initial stage commonly discourage commercial lenders to participate in the project. During the development stage, the majority of capital requirements shall be funded from commercial loans. The total equity funding during exploration and development is 40% with minimum

30% rate of return. Commercial funding is estimated to bear 8% interest in constant value and payable in 10 years period.



Source: Bank Negara Malaysia, 2002.

Figure 5-4. Indonesia Discount Rates

- Income tax rate and royalty are 30% and 4% respectively. Presidential Decree No. 76/2000 promulgates a new tax rate replacing the 30%-4% pair. This model uses the previous tax and royalty settings since this exercise is used later to compare this model with the existing business arrangement. Moreover, a draft of geothermal law, which is of higher legal status than the decree, is currently being prepared. This activity indicates that the decree may not be sustained. Further, there has been no new geothermal projects following the promulgation of the new decree.

(g) Estimated Revenue

Assume that scheduled and non-scheduled maintenance would reduce plant operation by 10% of its gross capacity. This means power plant availability is 90% of its gross capacity ('gross availability factor', GAF). Additional downtime due to lack of system demands and economic dispatch considerations is estimated to cause the plant runs at 85% of its availability factor ('discretionary factor', DF). Further, internal electricity consumption for the power plant and field operations is estimated to take around 5% of its gross energy production. Taking all these factors into account, the facility is expected to sell 700 GWh[42] per year throughout its full-production period of 30 years.

The payment of purchase consists of several components. They are 'generation component' that relates to generating capacity of the facility, and 'resource component' that reflects the amount of energy sales during the period. In other words, the first part is the fixed components and the second part is the variable components of the price. In addition, there are operation and maintenance charges attached to each of these components.

As previously indicated by Table 5-2, the initial estimate for the output price of the project is between US$2.5-6.0 cents/kWh. However, subsection (f) shows that the project uses higher discount rates and lower capacity factor than the level used to construct Table 5-2. Therefore, it is likely that the price range for the project is skewed

[42] (110 MW x 8,760 hours per year x GAF x DF x (1-internal consumption))/1,000

toward the upper range of the World Bank estimates, and probably more than US$6.0 cents/kWh.

There are many values of the price components that can produce a unit cost of around US$6.0 cents/kWh. The Base Case in this exercise uses the figures calculated by Electroconsult (1996), which is in line with the World Bank figures plus the above-mentioned adjustments. Based on the expected return on equity (ROE) target of 30%, the following example of input set yield a unit cost of US$6.19 cents/kWh and is used as the benchmark figures for the other scenarios:[43]

- Capacity Charge Rate (CCR): US$20/kW per month
- Operations and maintenance for CCR: US$2/kW per month
- Energy Charge Rate (ECR): US$0.0331/kWh
- Operations and maintenance for ECR: US$0.0071/kWh

In addition to the above pricing terms, one must consider an additional stipulation that specifies a minimum amount the utility is required to purchase. Usually referred to as the 'take-or-pay' (TOP) clause, it says that if the purchase were greater than the TOP level then the company would offer to reduce the ECR by 50% for the extra purchase. However, if the purchase is lower than TOP then the company still receives payment for the TOP amount. Based on the above price figures, the expected revenue from selling 700 GWh of electricity is therefore around $65 million per year.

[43] The existing geothermal projects are used as references. Appendix D lists other parameter values that relate to this calculation.

5.1.3 Decision Tree Assessment

Table 5-3 through Table 5-5 provides additional layers of information to the influence diagram of project structure shown in Figure 5-1. The tables reflect some judgments and estimates based on existing similar activities and the assessments of company experts. These figures may vary among prospect areas and with the knowledge and expertise of the respective company.

DATA^{TM} 3.5 facilitates the conversion of influence diagram into tree representation as part of its solution procedure. Modeling the project as influence diagram structure using the decision analysis software eases the implementation of Bayes' Theorem in translating the estimates of conditional probabilities in Table 5-1 into appropriate joint probability figures. The inferred probability interrelationships in the model can be seen in the form of formulas below some of the tree branches.

The model incorporates the following asymmetry assumptions to exclude irrelevant conditions and therefore avoids unnecessary branches of the tree:

(i) No investment will take place in states of nature where it makes no sense to do so.

(ii) If the company declines to invest at node D1, or does not reach an agreement at node C1, or decides not to explore at node D2, or decides not to develop the field at node D3, then there will be no production of electricity and consequently no sales.

(iii) If the reserve is not feasible, then development activity will definitely result in 'fail'.

(iv) If development activity is successful, then the project proceeds to production stage.

Table 5-3. Chance Nodes

Node Identifier	Possible Outcome	Probability
F1 External Information	Good info Bad info	p(Good info/Reserve is Feasible) = 1 p(Good info/Reserve is Not Feasible) = 0.5 p(Bad info/Reserve is Feasible) = 0*
C1 Negotiate Terms	Agree Not Agree	0.5 0.5
C2 Exploration	Success Fail	p(Success/Reserve is Feasible) = 0.7 p(Success/Reserve is Not Feasible) = 0.1
C3 Development	Success Fail	p(Success/Reserve is Feasible) = 0.8 p(Success/Reserve is Not Feasible) = 0
C4 Reserve Capacity	Feasible Not Feasible	0.6 0.4
C5 Production	Production No Production	p(Production/Success at Development, Success at Exploration, Agree on Terms) = 0.9
C6 Costs	Costs	1
C7 Sales	Sales	1

Note: * Statement (Bad info/Reserve is Feasible) says that the prospect is not feasible. Regardless of the actual condition of the reserve, the 'non feasible' evaluation result means that the area would not be offered to investors in the first place.

Table 5-4. Decision Nodes

Node Identifier	Alternatives
D1 Invest?	Invest Don't invest
D2 Explore?	Explore Don't explore
D3 Develop?	Develop Don't develop

Table 5-5. Deterministic Nodes

Node Identifier	Value Definition	Remarks
Charge_CCR	20	Grouped within the "Price Terms" sub model
Charge_OM_CCR	2	
Charge_ECR	0.0331	
Charge_OM_ECR	0.0071	
Reduce_ECR	0.5	
Capacity	110	Grouped within the "Quantity Terms" sub model
TOP	0.8	
DF	0.85	
Inflation	0.03	
Company Discount Rate	0.2	

Utilization of another software product, Geothermal Electricity Model (GEM), facilitates the calculation of the payoff value for each path on the tree. GEM is a financial model that takes into account exploration and field development activities in a geothermal electricity project. Both models are linked in the following way:

(i) The payoff values for various states of the model is calculated in GEM, and exported to DATA as inputs to calculate the project value without flexibility.

(ii) GEM undertakes necessary calculations to produce the rate of return on project value, and exchanges the information back to DATA,

(iii) DATA calculates the volatility of the rate of return parameter by performing Monte Carlo simulation in cooperation with GEM. This procedure asks DATA to vary the values of several parameters, transfer a new set of values to GEM as inputs for item (ii) above, and GEM transfer back the results to DATA. This exercise employs DATA to manage item (iii) for 1000 iteration.

Figure 5-5 shows a decision tree that embodies the influence diagram structure in Figure 5-2 and all of the information stated in Tables 5-3 through 5-5. Figure 5-6 shows a rollback decision tree which uses expected net present value to find the optimal decision policy. There is only one possible path with positive payoff and has only 16.8% probability, which is the all-good state path that lead to production. Other alternative paths either give zero or negative payoffs. The resulting expected value for the overall project is positive but very small. Considering the required large amount of capital and lengthy pre-production time, this result puts the project at threshold.

Figure 5-7 shows sensitivity analysis of ± 20% changes in the parameter values to the expected project value. In decreasing order, major impacts are from the discount rate, the first four probability figures at Graph 1, the fixed components of the price (Charge_CCR and Charge_ECR), and well productivity. Low discount rate (Graph 3, right wing of the first bar) yields the strongest impact. Low well productivity has a stronger effect than otherwise, as indicated by a longer left wing of the first bar at Graph 2. The absence of a bar for inflation at Graph 3 shows that the model is inflation neutral.

5.1.4 NPV of The Upside Potential

Although a decision tree assessment for the overall project gives a minuscule figure, the company knows that it is typical for this kind of risky venture. Further evaluation is deemed necessary to examine what the upside potential would offer. Even a small

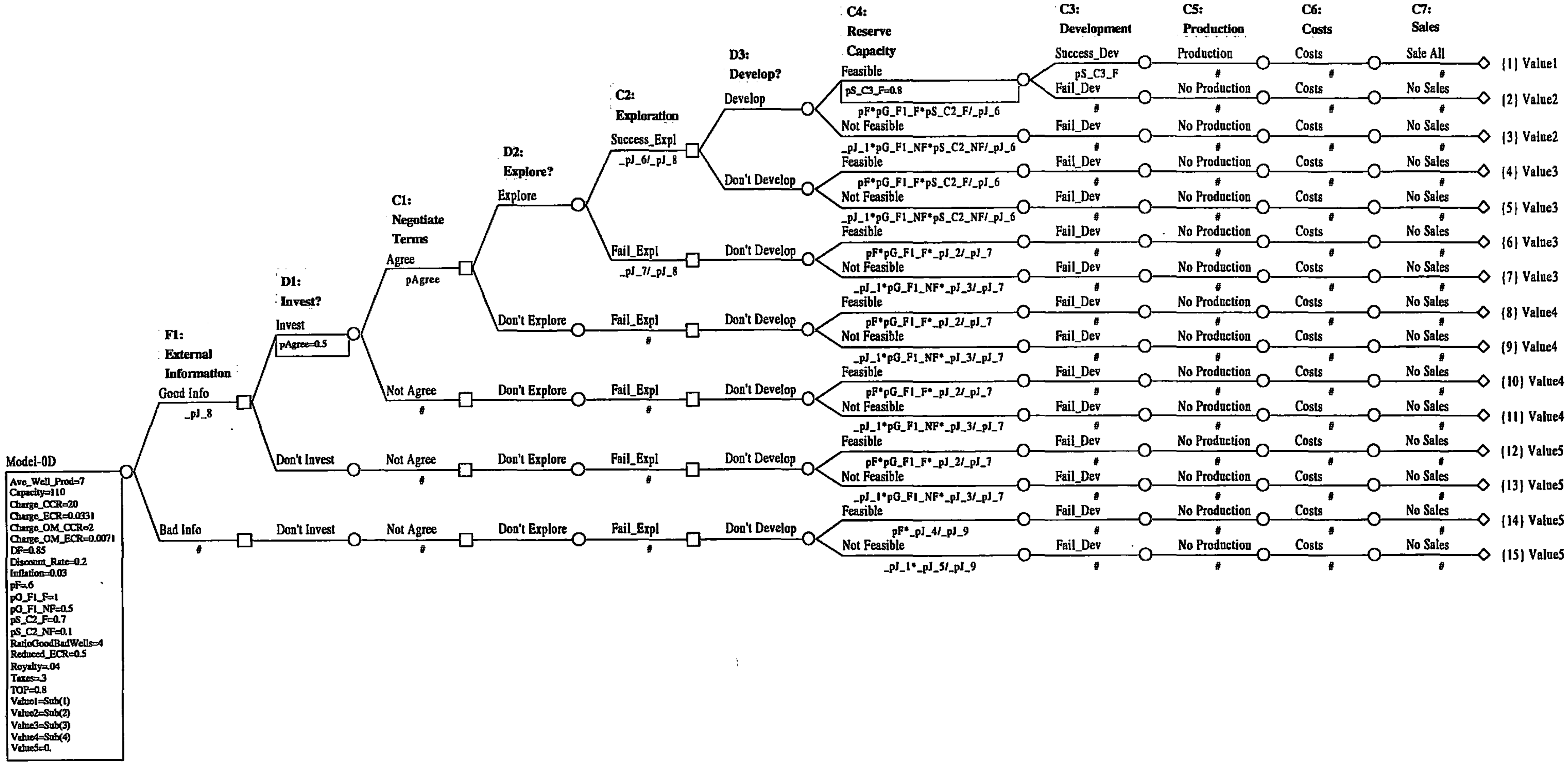


Figure 5-5. Project Decision Structure in Tree Representation

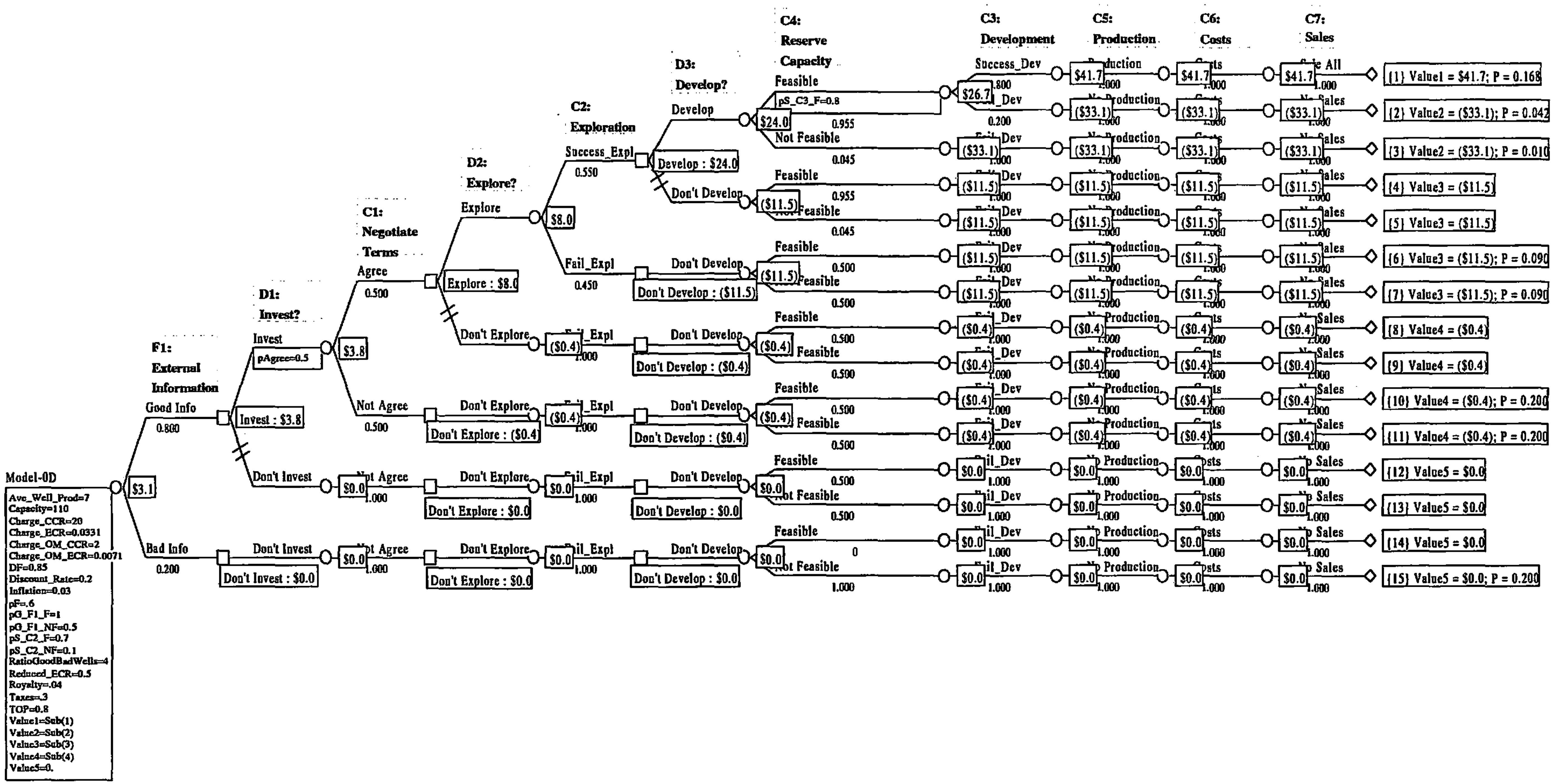


Figure 5-6. Expected Value Assessment for Project Without Flexibility

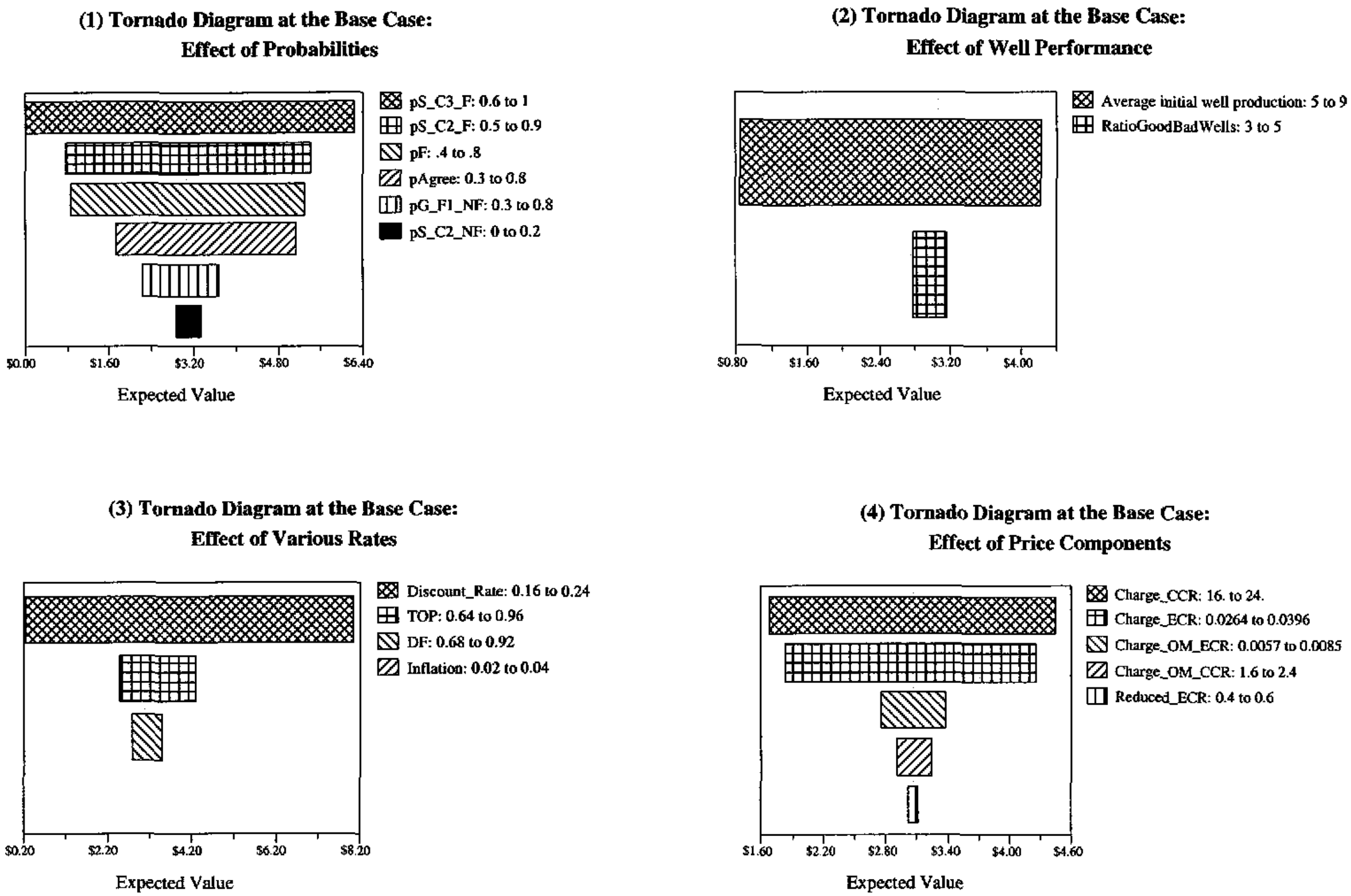


Figure 5-7. Base Case Sensitivity Analysis

possibility of success can lead to a profitable business, provided that there is a feasible reserve in the prospect area. Given that the reserve is feasible, and that the exploration-development-production stages are successfully completed, a projection of financial performance over the project lifetime can provide a more detail feature of the project characteristics and value.

Figure 5-8 illustrates the pattern of revenues and expenditures of the project overtime. The project financial figure is good starting at the operational stage. The Base Case column of Table 5-6 shows major results,[44] while Table D.2-1 of Appendix D presents the details.

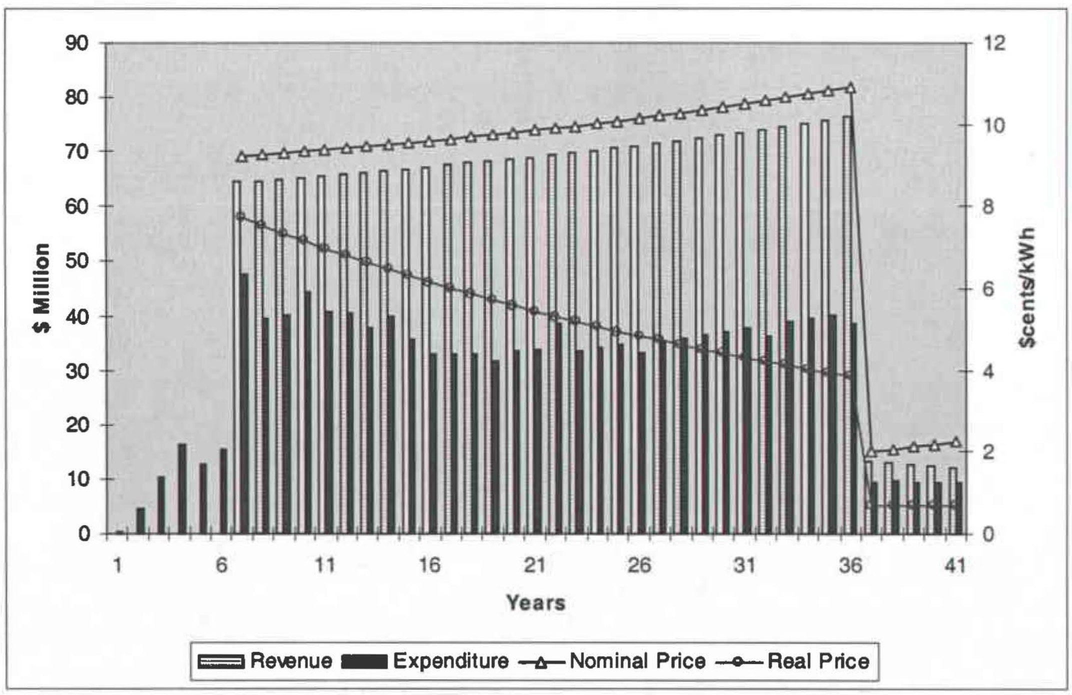


Figure 5-8. Some Project Indicators

[44] Calculated using GEM with previously stated inputs.

The project would give positive net income with an expected return on equity higher than the desired requirement of 30%, and the corresponding unit cost (which can be regarded as the levelized[45] electricity price by the buyer) for this project would be $6.19 cents per kWh. After taking into account the losses carried forward, a positive net profit would start at the third year of operation or year 8.

This encouraging outcome reflects the best possible state of the project, which may come as a consequence of the combination of an upstate outcome of nature and favorable values of the parameters. Relative contribution of good outcome possibilities to the overall project value has been evaluated at the previous subsection by incorporating possibilities of the other extreme. The next discussion takes a closer look at the selection of parameter values and its potential impacts on project value. An important concern is reserve feasibility and size.

For this good outcome scenario, the company implicitly assumes that the prospect indeed contains sufficient energy to supply the 110 MW facilities. Note that this optimistic view is made in a state where no exploration drilling has taken place, while in reality it is also possible that the prospect is dry or contains less than expected amount of energy. The assessment of a dry possibility or a non-feasible reserve has been taken care of at the previous subsection. The other possibility, less than expected amount of energy but is still considered feasible, may reflect in a lower production rate per well. This

[45] It is a constant charge per kWh needed to yield an annual cash flow sufficient to cover all capital costs and expenses acquired by the operation of the plant and maintaining an acceptable rate of return on capital invested in the unit (Blair et al., 1982).

condition consequently requires more wells to support the facility, which translates into higher capital outlay for the venture.

The industry average for standard wells in Java[46] is 6 MW in a steam-dominated field and 5 MW in a water-dominated field. Hence, the company estimates for the average initial well productivity of 7 MW is higher than average, reflecting an optimistic expectation on the field performance. The last column of Table 5-6 shows major project indicators if well productivity turns out to be, say, 6 MW. The set of figures show that the company would need to propose a higher price in order to obtain the minimum required ROE. In other words, if the company proposes the previously estimated price of US$6.19 cents/kWh, then the project would not meet the ROE requirement. Since the price needs to be agreed upon before the project starts, this problem is not trivial.

Table 5-6. Major Results of Upstate NPV Assessment

	Unit	Base Case	6 MW Well Productivity
NPV	$Million	41.40	40.93
ROE	%	30.01	30.01
Levelized Price	$ cents/kWh	6.19	6.43

The DCF method requires separate analysis for accommodating these uncertainties. Individual scenarios are developed for these states of affairs, and each of them is analyzed in the absence of the other. As a result, capital expenditures in the proposal are not linked to strategic and operating plans that embody management responses toward uncertain future state and the arrival of new information. Hence, the

[46] The range of productivity for standard wells in Java is: 1.5-11 MW for steam-dominated field, and 2-9 MW for water-dominated field (Enerindomurni, 1999). However, some drillings reportedly obtain well productivity as high as 15 MW (information from personal interviews).

opportunity to select optimal decision policy under updated information is commonly understated and even unrecognized during initial project planning.

5.2 REAL OPTION PERSPECTIVE

As highlighted previously in Section 2.2, real option analysis does not assume a now-or-never decision process. An option framework allows management to make a later decision based on the most recent available information, i.e. there is flexibility in the project decision process. This sub section discusses an implementation of real option perspective to value managerial flexibility in a geothermal project with this particular setting.

A series of exploration-development–production activities can be seen as *compound options* or option on option. The first option is an exploration option that gives the company a right but not an obligation to hold the second option, which is a development option. When exercised, the payoff of an exploration option is not directly dependent on the value of the underlying project, rather on the value provided by the option to invest at the next stage.

The second option, a development option, gives the company a right but not an obligation to proceed to the production stage. Its payoff is an income stream resulted from the production activities that reflect the value of the underlying project. The second option is alive only when the first option is exercised, which means these two options are *sequential compound options.*

The option theory requires a market to be able to evaluate the stochastic behavior of change in value of the underlying asset. This means the underlying asset needs to be actively traded. A geothermal electricity project is not actively traded, while the product is traded in a regulated market. The government sets the electricity prices and adjustments used to be once in two-three years. During the past several years however, due to the financial crisis of the utility company, price adjustments occurred two-three times in one year. Nevertheless, volatility is almost negligible in this pattern of price changes. This research adopts the approach proposed by Copeland and Antikarov (2001), which uses the projected cash flow of the project as the underlying asset.

Table 2-5 of Chapter 2 illustrates a general guideline to proceed toward real options analysis. As stated in subsection 2.4.4, there are two necessary assumptions: (i) Marketed Asset Disclaimer, which states that the present value of any asset, whether it is traded or not, can be used as the underlying value without flexibility, and (ii) properly anticipated prices (or cash flows) fluctuate randomly, which implies that changes in the asset's present value will follow a random walk. This approach uses Entity Free Cash Flow (Entity FCF) that is discounted at WACC to represent the gain in shareholder's wealth, or the value of the underlying risky asset, without flexibility.

The explicit planning period covers exploration and development years only, since beyond the development stage the compound options are 'expired' if it is not exercised. In this case, the model assumes that after the development stage there is no additional flexibility in management decisions that can add to the project value. Therefore, the event tree of project value covers only the exploration and development stages. The following exercise implements the four-step procedure outlined in Table 2-5 of Chapter 2.

5.2.1 Step 1: Compute the base case present value of the project

The base case present value (V_0) represents the value of the project without flexibility, computed using a standard discounted cash flow of the Entity FCF. The present value calculated in the previous sub-section 5.1.2 resembles the result of this step (refer to line 51 at Table D.2-1 of Appendix D).

5.2.2 Step 2: Model the uncertainty of project value using event trees

Modeling the uncertainty of project value requires an estimate on the volatility of the underlying risky asset. Copeland (2000) notes that volatility of a project is not the same as the volatility of any of its input variables, nor equal to the volatility of the company's equity. Rather, assuming that multiple sources of uncertainties affecting the project value is correlated and therefore can be consolidated into one measure, the volatility of a project value is the standard deviation of the percent changes in the value of the project from one time to the next. In other words, the relevant volatility is the standard deviation of the rate of return on the project value.

This measure of volatility is then used to model possible values of the project over time. As discussed earlier in section 2.4.4, this is possible under the second assumptions introduced by Copeland et al. (2001) following a theorem by Paul Samuelson (1965), which implies that for any pattern of cash flows that a project is expected to have, the changes in its present value will follow a random walk.

Let z represent the rate of return on the project value:

$$z = ln\,((PV_1 + FCF_1)/(PV_0)) \tag{5-1}$$

where,

FCF1 is the free cash flow at year 1

PV_0 is the present value of the project calculated at time zero

PV_1 is the present value of the FCF of year 2 onward calculated at time 1, which is:

$$PV_1 = \sum_{t=2}^{T} (FCF_t /(1+WACC)^{t-1}) \tag{5-2}$$

The volatility of variable z can be measured by iterating the input variables to vary PV_1 while holding PV_0 constant in a Monte Carlo simulation. The variability of the input variables affecting z can be derived from, (i) historical data, assuming that the future follows the past, or (ii) subjective, but forward looking, estimates made by management (Copeland, 2001). This model uses the second method, incorporating expert assessment on the profile of the Indonesian geothermal prospects in the reference documentation.

An application of the above method to the hypothetical geothermal project is as follows. Either individual or a combination of variations in resource uncertainty, the agreed price terms, and the take or pay level can affect project value. Their combined uncertainty can be estimated using a consolidated approach described in Copeland et al. (2001).

The value of forecast variable in the base case setting is $z = 0.19$ (refer to line 59 at Table D.2-1 for the value of its components). Table 5-7 shows the variables and their range of variations that are used in estimating the volatility of the forecast variable z. Resource uncertainty can be represented by two variables, (i) the average initial well production rate, and (ii) the ratio of productive/unproductive wells. Each of these leads to a different amount of well requirement for the project, therefore affecting project costs and consequently project value. The value of average initial well production varies by 3 MW, while the ratio of good/bad well differs by one well and the price components change within 10% range. Running a 1000-steps Monte Carlo simulation on z while varying the value of these variables yields a standard deviation of 14%.

The information on the volatility of z is further used to calculate the upward and downward movements of the project value at the event tree:

$$u = e^{\sigma\sqrt{(T/n)}} = 1.150$$

$$d = e^{-\sigma\sqrt{(T/n)}} = 0.869$$

where T is the years in planning period and n is the subintervals that divide the planning period. The resulting event tree is shown as Figure 5-9, which represents the stochastic process for the value of the underlying asset or the project without flexibility. Note that an event tree does not have any decisions built into it, since it is used to model uncertainties that influence the value of the risky asset over time.

Table 5-7. Parameter Values for Monte Carlo Simulation on z

Variables	Distribution	Values
Average initial well production	Triangular	Min = 4; Likeliest = 7; Max = 10
Ratio of Productive/Unproductive wells	Triangular	Min = 3; Likeliest = 4; Max = 5
Capacity Charge Rate	Triangular	Min = 19; Likeliest = 20; Max = 21
Energy Charge Rate	Triangular	Min = 0.0030; Likeliest = 0.033; Max = 0.036
O&M CCR	Triangular	Min = 1.98; Likeliest = 2; Max = 2.02
O&M ECR	Triangular	Min = 0.0063; Likeliest = 0.007; Max = 0.0077
Take-or-Pay	Triangular	Min = 0.7; Likeliest = 0.8; Max = 0.85

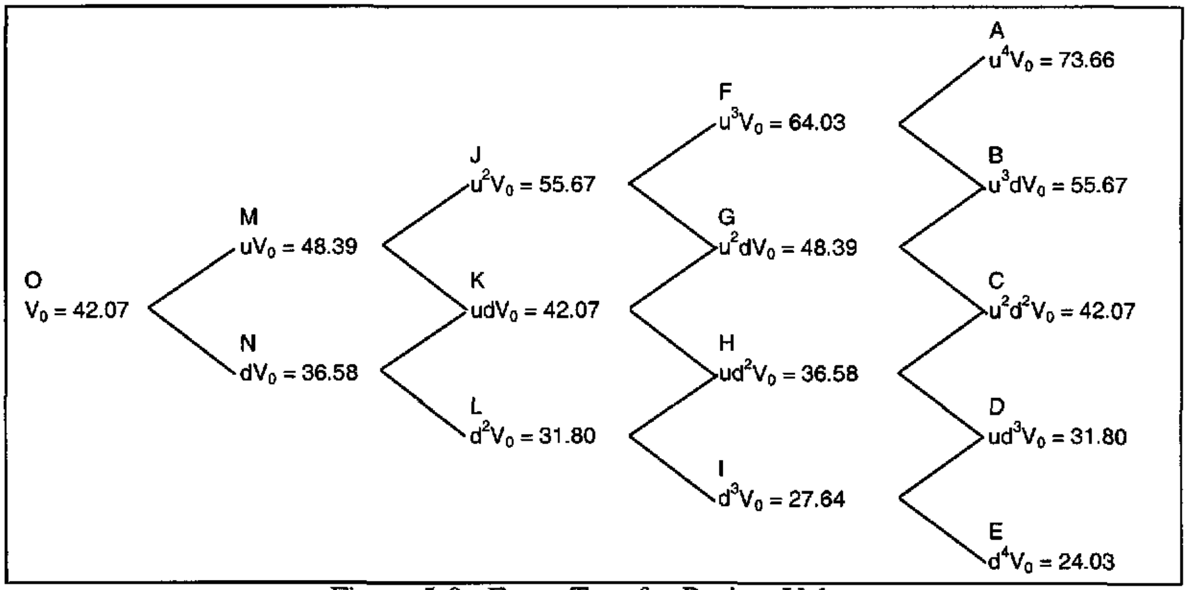


Figure 5-9. Event Tree for Project Value

5.2.2 Step 3: Identify and incorporate managerial flexibility

The compound options with this project imply the following relationships. The first option has an exercise price of $X1$ = US$11.06 million, which is the investment required to proceed to the development phase. This option expires at the end of year 2, which allows the management to decide whether to abandon the project, or to defer investment, or continue to the next phase by making an additional investment. The second option has an exercise price of $X2$ = US$21.61 million and expires at the end of year 5.

At any node, the decision principle is to select which is larger, either exercising the option, or keeping the option alive. However, this principle manifests in different ways throughout the tree according to distinctive situations at the respective nodes. For example, the value of keeping an option alive at its termination time would be worth 0. This is simply because the option expired at the end of that period, therefore it has no value at the next period. This means that at the terminal time of each option, the decision would be to select the maximum of exercising that option and a zero value.

ROA starts the analysis from the end of period concerned. In this project, the option at the last portion of the planning period is Option-2 with life spans from year 3 through year 5. Option-2 is available only if the company obtains Option-1, which life spans from year 1 through year 2. In sequential compound options, the order of economic priority is the opposite of the time sequence because the first option will be exercised contingent on the value of the second option. Hence, the value of Option-2 needs to be calculated before the value of Option-1 can be evaluated.

Using the value tree in Figure 5-9 as the value of the underlying risky asset, the resulting decision tree of the problem is shown in Figure 5-10 that combines the value tree of Option-2 in Figure 5-11 and that for Option-1 in Figure 5-12. Table D-3 of

Appendix D shows the procedure result in relevant sequence, including the replicating portfolio tables when applicable.

(a) Valuing Option-2:

At the end nodes A, B, C, D, and E of Figure 5-9, the choices are to exercise the second option or to stop the project. The option would worth 0 if it was not exercised, since this is the last period of the option horizon. For example, at node A these choices are represented as:

Max [(Value of the underlying asset at A) – (Exercise price of Second Option), 0]

$$= \text{Max}\ [u^4V_0 - X2, 0] = \text{Max}\ [73.66\text{-}21.61, 0] = 52.05.$$

The optimal decision at node A indicates that the project is better off when the management decides to invest US$21.61 million, rather than to stop the project. The decision tree shows that based on the volatility of the project value characterized by the value tree in Figure 5-9 and the stated amount of expenditure above, it is not worthwhile to abandon the project at any state of nature since the optimal decision at all of the end nodes A, B, C, D, and E is to spend the development cost.

The value of project at nodes F, G, H and I is determined by selecting which has a larger value, to exercise the option or to keep the option open:

(i). The payoff from exercising the option is the difference between project value of the respective nodes at Figure 5-9, and the exercise price of US$31.1 million.

(ii) The payoff from keeping the option open is calculated using the replicating portfolio approach as follows:

- As flexibility is incorporated into the event trees, the resulting decision tree reflects different risk characteristics of the project. Therefore, the WACC as the cost of capital that as previously used in calculating the underlying asset value can no longer be applicable. The new cost of capital can be determined by either using replicating portfolio approach, or risk-neutral probability approach (Copeland, 2001).
- Using the MAD assumption (section 2.3.4), the payoffs of the twin security are the same as those of the project itself. For example at Node F, the up state value of the underlying asset is 73.66 and the down state value is 55.67.
- The replicating portfolio approach says that to prevent the arbitrage profits, two assets that have exactly the same payoff in every state of nature are perfect substitutes and therefore they must have the same value. The portfolio that can be used to replicate the end-of-period payouts is *m units of the* underlying asset (i.e. mV_0) plus *B* bonds. The value of the replicating portfolio for node F is as follows:

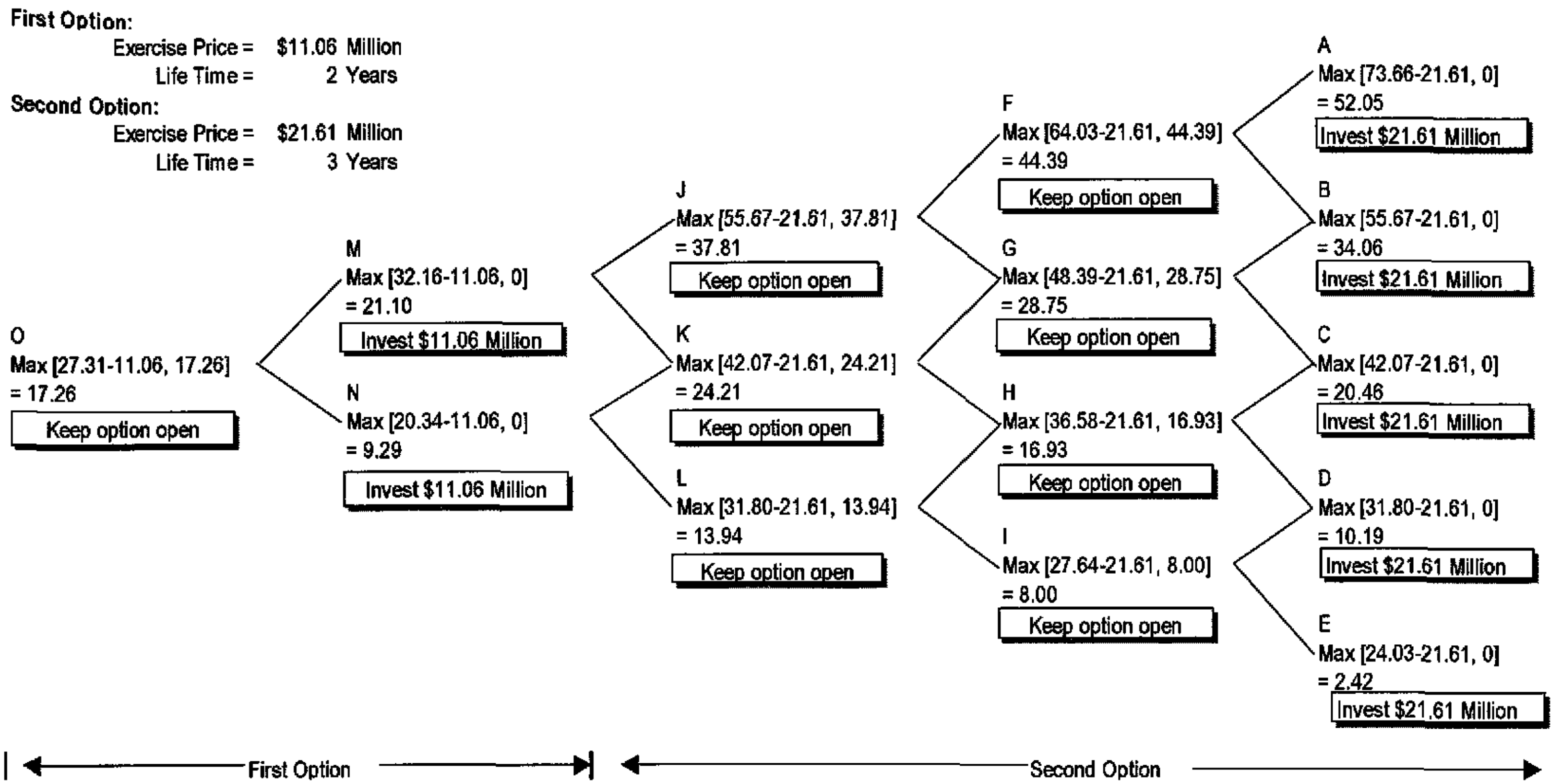


Figure 5-10. Sequential Compound Options

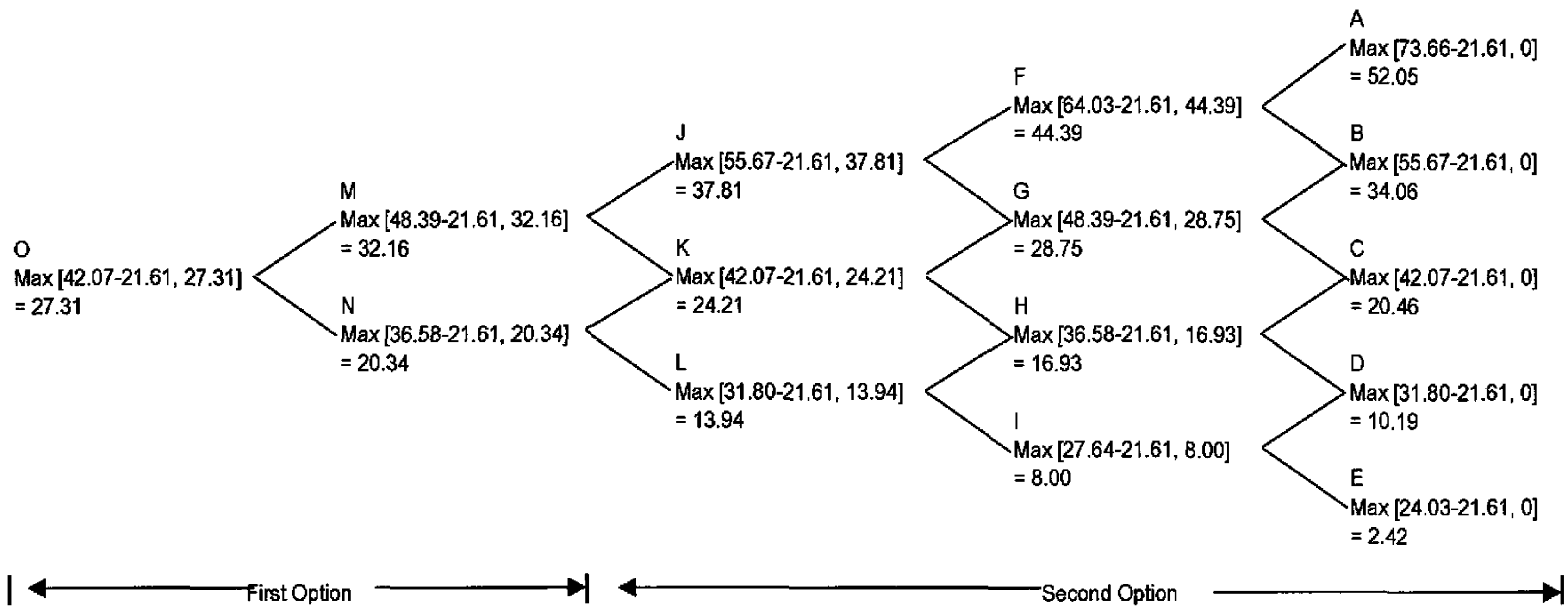


Figure 5-11. Value Tree of the Second Option

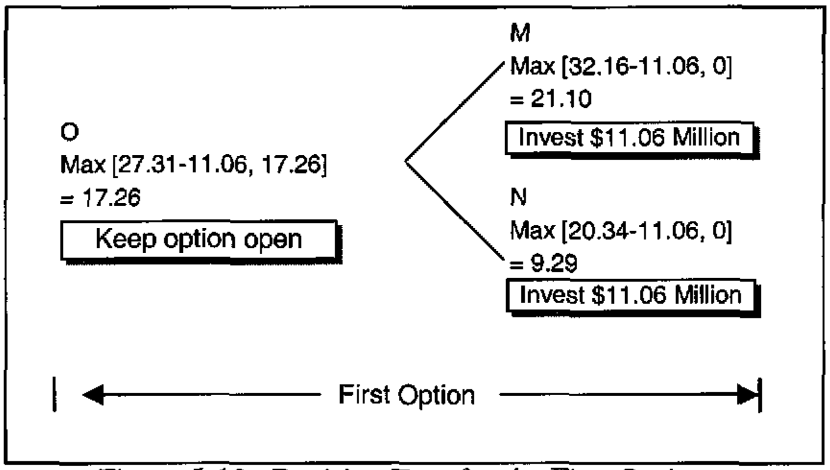


Figure 5-12. Decision Tree for the First Option

Replicating portfolio in the up state: $m\,(64.03) + B\,(1+rf) = 73.66$

Replicating portfolio in the down state: $m\,(64.03) + B\,(1+rf) = 55.67$

Solving the two equations for the two unknowns, we have m = 1 and B = -19.64

The present value of the flexibility option at Node F is equivalent to the value of the replicating portfolio for this node, which is

$$(mV_0 + B) = (1 * 64.03) - 19.64 = 44.39$$

Selecting which is larger between (i) and (ii) for Node F is to solve the following:

$$\text{Max}\,[\,(u^3V_0 - X)\ ,\ (mV_0 + B)] \tag{5-3}$$

$$= \text{Max}\,[\,64.03 - 21.61, 44.39\,] = 44.39$$

This result indicates that it would be better to defer investment at this point of time. Applying the procedure to nodes G, H and I give similar results.

Evaluating nodes J, K, and L also suggest the same decision. These nodes are the initial points that the second option directly influences the project value. Columns 3 to 5 of Figure 5-10 show the values of Option-2 at various nodes. Prior to nodes J, K, and L, it is Option-1 that directly influences the project decision.

(b) Valuing Option-1:

The first option expires at the end of year 2, therefore either it must be exercised by investing US$11.06 million, or left unexercised (expire) at no cost. The payoff from exercising the first option is the value of the second option. Therefore, before we proceed to valuing the first option, the value of the Option-2 at nodes M, N, and O are also required. The whole value tree for the second option is shown as Figure 5-11, while Figure 5-12 represents the value tree of Option-1.

The value of management flexibility in Option-1 at end of year 2 is:

Max [((Value of the Second Option) – (Exercise Price of First Option)), 0] (5-4)

For example, at Node M the option value is: Max [32.16-11.06, 0] = 21.10

Since the payoff of Option-2 is larger than the exercise price, then the optimal decision is to spend the exploration cost in order to obtain the right to the development stage. Similar decision is also applicable at node N.

The value of Option-1 at node O is:

Max [((Value of the Second Option) – (Exercise Price of First Option)),

(Value of the Replicating Portfolio)]

= Max [(27.31-11.06) , 17.26] = 17.26 (5-5)

At node O, the value of exercising the option is less than the value of keeping it alive. Therefore, the optimal decision at this point is to keep the option open.

5.2.4 Step 4: Analysis

A positive US$17.26 million net result of the ROA procedure can be interpreted in the following ways:

a) Such figure represents the net present value of a project that has PV of US$42.07 million today, with a standard deviation of 14% per year and requires the completion of two-stage investments of US$11.06 million and US$21.61 million respectively. If the start-up cost (if any, in addition to the expenditure items already considered) were greater than US$17.26 million, the project would be rejected; otherwise it would be accepted.

b) This result also suggests that incorporating flexibilities in project assessment would improve the project value as compared to its value without flexibilities.

Incorporating a wider range of parameter values for the estimation of standard deviation of z results in a higher flexibility value. For example, some changes in a few parameter values as listed in Table 5-8 produce a standard deviation of 25% for z as shown by Figure 5-13. Applying the higher standard deviation of z gives flexibility option value of US$17.34 million, slightly higher than the previous flexibility value (refer to Table D.4 at Appendix D for the calculation). This result confirms Table 1-2 at Chapter 1, which indicates that higher uncertainty implies higher option value or flexibility value.

Table 5-8. A Wider Range of Parameter Values

Variables	Previous Range			New Range		
	Min	Likeliest	Max	Min	Likeliest	Max
Average Initial Well Productivity	4	7	10	3	7	11
Ratio of Productive/Unproductive Wells	3	4	5	2	4	5

One source of the improved condition is the reduction of the effect of unfavorable outcome at some future state by selecting a better payoff through either exercising the option or otherwise. As this approach allows the management to take into account the most recent conditions and updated information, it shows the benefit of flexibility over pre-commitment decisions.

The option decision function of *Max [.. , 0]* at the terminal nodes and *Max [.. , ..]* at non-terminal nodes would avoid negative value and therefore, improve the maximization of project value. Further, since this criterion is embedded in each decision steps, ROA does not need to discriminate some future states by eliminating their presence in the evaluation. This is in contrast to the naïve DCF method that tend to weigh down project value excessively because of the presence of possible bad states, and also different from the scenario-based DCF method that single out certain states of future outcome in the analysis.

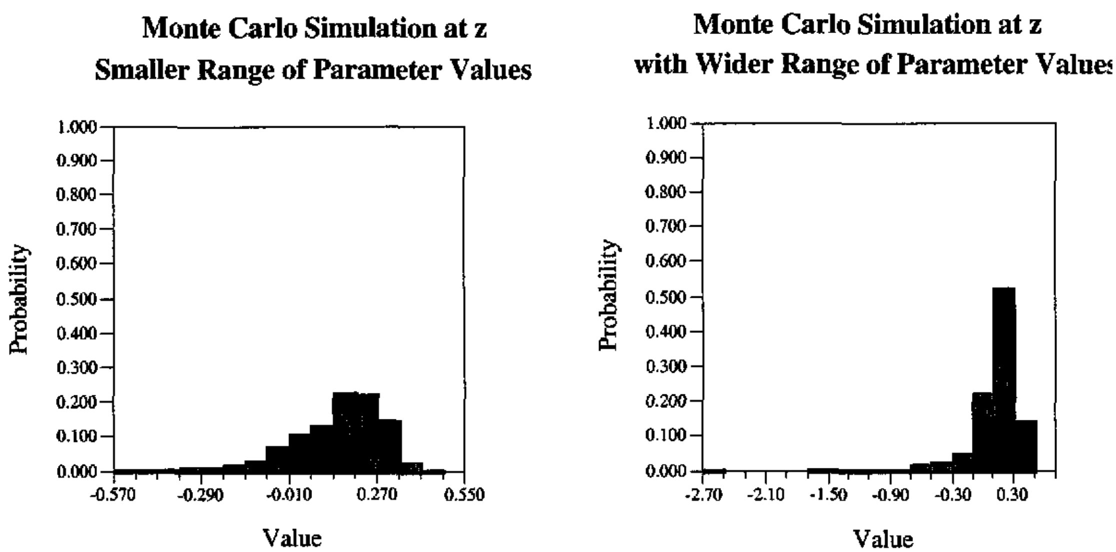


Figure 5-13. Impact of Parameter Value Range to Probability Distribution of z

However, the optimal decision of generally deferring investment until the terminal year of each the option might not be strictly viable. This outcome may have been induced by the consolidated approach of assessing the uncertainty (refer to sub section 5.2.2). In this approach, there is no differentiation on the effect of technical uncertainty and market uncertainty on the project value. Since alleviation of technical uncertainty can only occur through investing in the field studies, deferring investment until the terminal year could be counter-productive as the same amount of work to uncover the uncertainty still have to be done but in a shorter time period. The first constraint may be due to natural characteristics of the work. For example, drilling an exploration well of 1,000 meters depth require a certain minimum time to be completed. In addition, since a project requires numerous well drillings, a shorter time period implies simultaneous drilling for the same amount of wells. This may lead to the second constraint of higher cost for mobilization of capital and other resources for this grander work may. For example, equipment rentals might cost more for a shorter rental period; mobilization of separate deployment of field workers is usually more expensive. As such, this strategy would have a negative impact on project value that outweigh the benefit from deferring expenditure. Nevertheless, the general strategy can still be applied in the sense that expenditure shall be dispensed at an increasing amount over time. That is, spending at the initial year of each option is less than of the later year.

5.3 EXPANSION OPTION

It can be stated intuitively that better knowledge of the underground characteristics of the prospect area can reduce technical uncertainty and a consequent business risk of inappropriate output pricing. The proposition to be evaluated here suggests a price determination following the completion of the exploration phase. Under the assumption of symmetrical information and a simple self-interest behavior, the proposition is Pareto improving as compared to the ex-ante price determination system.

5.3.1 Exploration Information

The exploration stage is selected as the point of review since it is considered the most crucial step in a geothermal project for the following reasons:

a) An exploration undertaking is normally risky, since at the beginning investors do not have enough information to know whether or not the tract can be economically exploited. The availability of information depends on survey activities at that particular area, where more exploration and development activities would result in more information and better accuracy of the data.

b) Exploration projects do not generate income for years until it reaches the production stage, while expenditures begin to flow right from the beginning. That is the reason for conducting exploration activities in several steps, where earlier activities cost less than the rest. More expensive examinations are called for when the prospects show promising results.

c) The good outcome or good state of an exploration result is a proven reserve, which provides highly reliable information for planning of further project activities. A bad state would yield to a decision of project abandonment.

d) In the case of geothermal electricity projects in Indonesia, the above conditions of the exploration stage is aggravated by the requirement to lock in a price of future output as a precondition to obtain the project, together with limited preliminary data about the resource.

A price determination after the exploration phase can be referred to as 'the ex-post structure,' in contrast to the ex-ante system that presently prevails. An ex-post structure is expected to improve project viability through the following chain of effects, (i) reduction in technical uncertainty, (ii) possibility of larger plant capacity, and (iii) possibility of lower unit price. Each of these effects is illustrated below.

First, the exploration stage includes initial drillings that reveals information about the underground geothermal systems and other reserve characteristics in the prospect area. Hence, the completion of an exploration phase is expected to yield estimates on reserve feasibility with a higher degree of confidence.

Second, in addition to lessening reserve uncertainty, price determination after the exploration stage may also improve project value due to the possibility of finding a better realization of reserve characteristics than initially estimated. This condition may be due to a higher productivity of wells, or lower costs, or a larger reserve, or a varying degree of their combinations. This research focuses on the impact of a possible expansion of project capacity. Table 5-9 illustrates the difference between initial development capacity and the expansions at three operating private power facilities and two geothermal projects that are not operating but have completed construction. The initial capacity can be considered as reserve estimate before exploration, since in the present pre-commitment system this is set before the project starts along with the forthcoming output price of the facility. The 'expansion' columns show additional increase in capacity due to the fact that the reserves contain more power potential than the initial estimate. Although based on a limited sample, these figures suggest that the initial development, which reflects a preliminary estimate of the reserve size, tends to be lower than the size revealed after exploration.

A larger reserve than initially expected allows larger capacity to be built on the area, which means higher possible production and higher expected revenue from the same field operation. From the cost side, it is clear that a larger plant size needs at least more production, re-injection and make up wells, which implies that development cost would be larger parallel to the increase in capacity size. However, the cost for exploration would stay the same, as this stage does not need to be repeated. Therefore, higher expected revenue would yield a better project return.

Table 5-9. Reserve Estimate Before & After Exploration

Fields	Initial Capacity	Expansion[a]	
		Capacity	Remarks
Darajat	1 x 55 MW	5 x 55 MW	1 under construction, 4 planned. Field potential at least 400 MW
Dieng	1 x 60 MW[b]	3 x 60 MW	Planned. Field potential 350 MW
Kamojang	1 x 30 MW	3 x 55 MW	2 operating, 1 planned. Field potential 240 MW
Salak	2 x 55 MW	4 x 55 MW	All operating. Field potential 400 MW
Wayang Windu	1 x 110 MW	1 x 110 MW	Planned. Field potential 400 MW

[a] In addition to the initial capacity
[b] Not currently operating
Source: US Embassy Jakarta, 2002

The third effect from the proposition is due to a possibility of lower unit price of electricity produced by the facility, as shown by the exercise at the following subsection. The output price depends heavily on reserve size. Continuing the argument for the second effect above, a better project return from a larger plant capacity allows the company to have a wider range of feasible prices. This means more flexibility in determining the output price. Further, within this feasible price range, even the lowest price still meets the minimum required rate of return. The implication is that this flexibility will be in a stronger position to compete with the other base load suppliers.

5.3.2 Expansion Simulation

The results of some examples underlying the observation stated as the third effect above are summarized in Table 5-10, while detailed figures are located in Tables D.2-1 to D.2-6 at Appendix D. The second and third effects discussed in subsection 5.3.1 above can be shown by simulating the projected financial performance for 110 MW, 165 MW, and 220 MW geothermal project using GEM.

Table 5-10. Simulation on Plant Size and Output Price

	Unit	Base Case	Case 1	Case 2	Case 3	Case 4	Case 5
Inputs:							
Capacity	MW	110	165	220	220	220	220
CCR	$/kW/month	20	16	14	14	15	20
O&M CCR	$/kW/month	2	1.75	1.25	1.25	1.25	2
ECR	$/kWh	0.0331	0.025	0.01977	0.0215	0.0256	0.0031
O&M ECR	$/kWh	0.0071	0.00334	0.00325	0.00342	0.0052	0.0071
Outputs:							
Unit Price	$cents/kWh	6.19	4.64	3.89	**4.03**	**4.64**	**6.19**
Good State Worth	$ Million	42.07	40.6	39.44	43.68	61.24	105.44
ROE	%	**30.01**	**30.01**	**30.01**	31.41	36.62	47.39
Expected Value	$ Million	3.1	2.4	1.6	2.3	5.3	12.7
Z*	%	18	16	15	23	57	111
Std Dev of Z	%	14	24	35	31	20	10
ROV	$ Million	17.26	16.25	15.6	19.05	37.01	81.03

Notes: *Z is the rate of return on the project value (refer to equation 5-1).
Bold numbers indicate the targeted value to be achieved by the respective scenario.

Assume that the main concern of the company is to obtain a return on equity (ROE) of at least 30%. For the above simulations, the only changes in the input variables are the capacity and the charges components. The figures in the 'Base Case', 'Case 1' and 'Case 2' indicate that a higher capacity would allow the company to offer a lower unit price while keeping the ROE at the minimum required level of 30%. If the reserve would support a 165 MW power plant then the project can offer US$4.64 cents/kWh, instead of US$6.19 cents/kWh for a 110 MW plant. If the reserve would support a 220 MW plant capacity then the unit price can be lowered to US$3.89 cents/kWh while the project can still meet its minimum required ROE.

Columns 'Case 3', 'Case 4'and 'Case 5' represent the project profile where the reserve can support a 220 MW plant but the company does not lower the offered price as low as in 'Case 2'. 'Case 3' shows that the geothermal project can produce electricity at a price comparable to the average production cost of the other power producers supplying the base load (refer to Table 5-13), and yet acquires a higher than 30% rate of return. In 'Case 4' the offer price is set to match that of 165 MW, and this would increase the ROE by 6% above the minimum required level. 'Case 5' illustrates that the project earns nearly 50% rate of return when the reserve can support 220 MW but the company keep the ex-ante price, which is the price of the 110 MW project. The unit price of 'Case 2' until 'Case 5' suggest the range of feasible prices for doubling the capacity of the project. These exercises suggest that it is possible to relate a profitable geothermal project with lower electricity prices, especially when comparing the Base Case with 'Case 3'.

The benefits of taking into account the flexibility of future decision into the present investment decision can be summarized as follows:

- The options to defer and abandon increases project value, which implies that *flexibility is valuable in this project structure*, as shown by the positive ROV of the Base Case.
- Combining expansion options with a restriction on the return on equity can reduce the unit price, such as a decreasing trend of the unit prices of the Base Case, Case 1 and Case 2. On the other hand, releasing the restriction on ROE is associated with higher values of the good state condition, the overall expected value of the project, and the real option value. As the unit price increases, the real option value increases faster than the value of the good state as well as the expected project value. This implies that flexibility is more important as the project value improves.
- An expansion option allows the project to achieve both an improvement in the project value as well as lower unit prices.
- Combining the expansion option with the ex-ante price estimate yield a significant profit. On the other hand, this figure also shows that this unit price is excessively burdensome for the utility company.

Taking one step further, suppose the Base Case price of US$6.19 cents/kWh is the amount paid by the utility company to geothermal power producer for the purchase between 2000-2002. Suppose there is only one private geothermal producer, which sells 8.9 TWh electricity to the utility company during the period. Assume that the Base Case price is a contractual price that was pre-determined before the project started. Then later, if the reserves turn out to be larger and the project size increases accordingly, the company can still get the same level of ROE by charging 37% less price per unit of sales. This means that such a lower price still allows the geothermal producer to meet the required return on their investment.

Table 5-11 illustrates that imposing the Base Case price and compare it with the Case-2 price would show a disparity of US$205 million in three years. From the point of view of the utility company, this means a significant amount of savings. This can be thought of as one of the potential social benefits of avoiding unnecessary burden of high prices due to restrictive business arrangement. Of course, on the other hand, this means thinning the hefty profit obtained by the investor under the ex-ante price determination system. Nevertheless, as the present halted status of geothermal project shows, charging excessive prices cannot be sustained.

Table 5-11. Potential Savings from Flexible Arrangement in Geothermal Project

Power Generation	Production (GWh)			
	Actual 2000	Interpolation 2001	Planned 2002	Total 2000-02
PLN-Geopower	2,219.97	2,514.99	2,810.00	7,545
PLN-Other Generations	64,441.23	64,175.62	63,910.00	192,527
PLN-Total	**66,661.20**	**66,690.60**	**66,720.00**	**200,072**
IPP-Geopower	2,241.46	2,973.23	3,705.00	8,920
IPP-Other Generations	6,093.95	9,278.98	12,464.00	27,837
IPP-Total	**8,335.42**	**12,252.21**	**16,169.00**	**36,757**
	Estimated PLN Payment for IPP-Geopower ($)[a]			
Based on P=6.19 $cents/kWh[b]	138,746,622	184,043,061	229,339,500	552,129,182
Based on P=3.89 $cents/kWh[c]	87,192,950	115,658,725	144,124,500	346,976,174
Potential Savings[d]	**51,553,672**	**68,384,336**	**85,215,000**	**205,153,008**

Notes:

(a) Estimated payment = (production of IPP Geopower) x price x 10^6
(b) Base Case Model: 110 MW, meet ROE 30% (refer to Table 5-9)
(c) Case 2: potential expansion to 220 MW, meet ROE 30% (refer to Table 5-9)
(d) Gap between estimated payments based on (a) and (b)

Source: PLN: power production data for 2000 actual and 2002 planned

Figure 5-14 illustrates average prices from some power plants in the system, showing a disparity in prices and the merit of the system. The chart reflects the average of the first step price of geothermal projects at Table 5-12, and an average of typical plants serving the load system shown in Table 5-13. Although electricity prices from several geothermal projects decrease at some future years, the first step price is considered in this analysis because this is the price level to be compared to other base load suppliers at the present time. Note that the capacity factor for the simulation figures in Table 5-10 is 76%, which implies that the unit price from the simulation would have been higher if a 70% capacity factor was used as in Table 5-13.

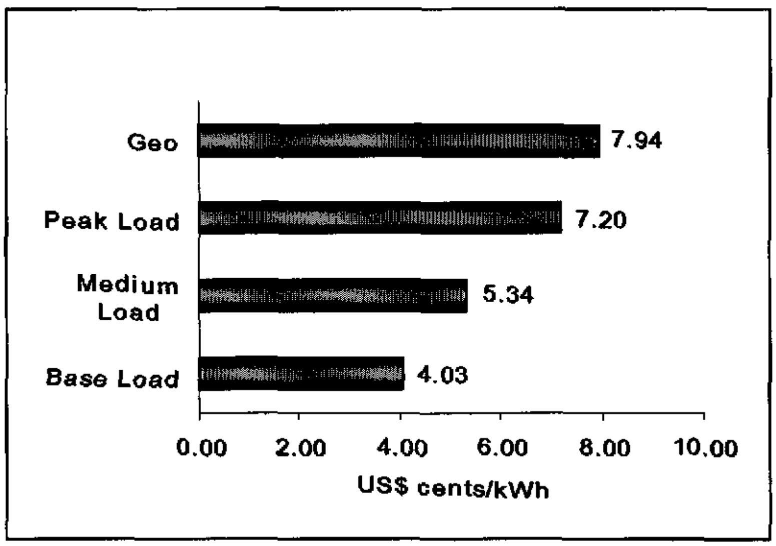


Figure 5-14. Geothermal Price and Average Production Costs of the Load System

The above exercises indicate that a better knowledge on reserve size and quality would allow geothermal electricity price to compete better in the system. As shown by the base case figures, the presently high price reflects the severity of impact of high capital outlay requirements in geothermal project and the fact that these expenditures have to be committed upfront. The expenditure designated for development wells can be thought of as a commitment to purchase a large portion of the eventual fuel supply at the project start-up (US Embassy Jakarta, 2002). Simulation results in Table 5-9 implies that a pre-commitment on output prices where reserve feasibility is still in question adds more upward pressure to the output price, since these prices are set with a smaller reserve and plant capacity in mind. Further, this setting may induce opportunism behavior that tends to increase the upward pressure to the price.

Table 5-12. Geothermal Power Plant Development Project

Power Plant		Year	Contracted Tariff US$ cents/kWh
1	Bedugul		7.15
2	Cibuni		6.90
3	Darajat		6.95*
4	Dieng	1-14	9.81
		15-22	7.41
		23-30	6.21
5	Kamojang 4,5		7.03
6	Karaha 1-4	1-14	8.46
		15-22	6.57
		23-30	5.63
7	Patuha 1-4	1-14	7.25
		15-22	5.63
		23-30	4.82
8	Salak 4,5,6	1-14	8.46
		15-30	4.94
9	Sarulla 1-6	1-14	7.60
		15-22	5.75
		2-30	5.21
10	Sibayak		7.1
11	Wayang Windu	1-14	8.39
		15-22	6.51
		23-30	5.57

*Reduced to 4.2 cents following a renegotiation in April 2000
Source: US Embassy Jakarta, 2002; PLN; Ministry of Mines and Energy

Table 5-13. Production Cost (US$ cents/kWh)

Plant Type	Fuel	Total Production Cost		
		Base Load	Medium Load	Peak Load
Steam	Coal	4.195		
Steam	MFO	3.745		
Closed Cycle Gas Turbine	Gas	4.303		
Closed Cycle Gas Turbine	HSD	3.891		
Diesel	HSD		5.436	
Diesel	MFO		5.238	
Open Cycle Gas Turbine	Gas			7.234
Open Cycle Gas Turbine	HSD			6.673
Hydro				7.699
Average		4.0335	5.337	7.202

Note: Capacity factor for base load is 70%, medium load 50%, peak load 30-40%
Source: Akmal et al., 2000.

5.4 EXERCISE SUMMARY

The Option Theory calls for information on the volatility of the change in price or value of the underlying asset. This requirement implies that the underlying asset shall be actively traded, such that the market provides sufficient data on price changes allowing the respective volatility to be measured. The existing Indonesian capital market does not permit a direct implementation of Real Option Valuation to geothermal electricity project, since there is no electricity- or extraction- project related products in the market. Further, the electricity sector is regulated, such that prices are stable at a certain level for a long time with infrequent adjustment. Therefore, the volatility measure of the underlying asset is nearly zero.

Copeland and Antikarov (2001) propose to represent the underlying asset value by a properly anticipated stream of cash flows of the respective project. The change in project value is represented by the rate of return of the cash flows. The variations in the rate of return are due to changes in parameter values affecting the cash flows, such as natural conditions of the reserve, financial parameters and the price components. This approach makes possible an application of real option valuation to non-tradable real assets.

The project is modeled as compound options, namely exploration option and development option. Exercising the development option is by undertaking exploration activities, which means spending the exploration costs (representing the strike price of the option) to obtain the second option, which is the development option. Similarly, exercising the development option is by undertaking development activities, which means spending the development cost (representing the strike price of the option) to obtain a project that generates revenue over the rest of the project life. At every time period, the management can choose to continue investing, or delay investment decision (option to wait), or stop the project to respond to unfavorable conditions (option to abandon).

The exercise in section 5.2 describes an implementation of Copeland and Antikarov approach to value managerial options in a hypothetical 110 MW geothermal electricity project at the Indonesian business setting. Table 5-14 summarizes the results of the exercise. ROA takes into account flexibility in the project investment decision, and reflects the worth of this added feature at the time of valuation period, which is at the start of the project. The options to defer and abandon investment show that flexibility value in this exercise is positive, increasing the value of a good state by 41%. This implies that the conventional NPV undervalues the project.

Table 5-14. Results Summary

Method	Value ($ million)	Relative
Conventional NPV:		
• Expected Total Value of Project	3	
• Value of Good State*	42	Base
Project with Flexibility: Additional Value at the Good State		
1. Options to Defer and Abandon Investment	17	(+41%)
2. (1) & Option to Expand; targeting the Base Load Prod Cost	19	(+45%)
3. (1) & Option to Expand; using the ex-ante price set	81	(+193%)

Note: a good state refers to the condition when the reserve feasibility and size are sufficient to support electricity production, such that the project earns revenue.

Section 5.3 examines the possibility of realizing that the reserve is better than previously estimated, which may mean higher productivity of wells, or lower costs, or larger capacity of the reserve, or a varying degree of their combinations. The analysis considers the impact of having an expansion option, in addition to the circumstances described in section 5.2. The example examines twice as large capacity than initially estimated, and the results show that real options consideration improves project value by 45%. It also provides information to allow managers decide an output price that can compete with other base load suppliers and yet relates to a profitable project.

Further, exercising the expansion option and applying the ex-ante price yields a highly profitable business. However, the latter also means an excessive burden to the state utility company. The range of feasible prices associated with these conditions indicates that there is a room for an improvement in the distribution of profit. The flexibility value is almost twice as much as the conventional value of the project.

The above exercises show that price determination following the conclusion of exploration activities provides both the possibilities of securing a profitable business and at the same time relates the project with a competitive price. This outcome is a consequence of focusing on the impact of having new information on the reserve characteristics as a result of completing exploration activities. Nevertheless, the model in this chapter is bounded within the private developer's internal decision assessment without recognizing the presence of other active participants. In other perspective, the model implicitly assumes symmetric information and a simple opportunistic behavior of the market participants. Therefore, it is important to note that the results from this exercise are based on those assumptions. Removing these assumptions opens a new array of possible difficulties related to incomplete and asymmetric information, as well as opportunistic behavior of the market participants. Chapter 6 proposes an arrangement to addresses this issue.

CHAPTER 6

POLICY IMPLICATION

As stated previously, the model in Chapter 5 concentrates on the consequences of natural characteristics of geothermal resources to the project. This implies less emphasis towards the behavior of the parties. While the importance of their roles is considered, strategic interrelationships among them are not critically important. The implicit setting of the model can be described as follows: (i) agents inside the firm and the states of nature determine the project value, which belongs to group 2 of investment literature categories following Brennan and Trigeorgis (2000), (ii) the third party, who is assumed to be the government, plays a role as regulator that provides laws and order to govern the business. In addition, the model also employs two implicit assumptions, which are: (iii) complete and symmetric information, and (iv) simple self-interest behavior of the market participants. The exercise results suggest that an ex-post price determination is Pareto improving.

In contrast to the previous setting, this chapter assumes incomplete and asymmetric information, as well as opportunistic behavior by market participants. Under this condition, an ex-post price determination may not work. Incorporating these assumptions implies that the boundary of the problem has moved outward, incorporating several participants and the impacts of their interaction with each other. Although the research does not cover the institutional arrangement analysis in a formal way, the following assessment highlights important features of the setting and the need for institutional changes are indicative. The first section of this chapter reviews some literature to describe the relationship of the parties. The second section illustrates the possible difficulties related to the ex-post price determination. The third section proposes a two-phase price determination to attenuate the difficulties associated with opportunistic behavior as well as incomplete and asymmetric information.

6.1 INTERRELATIONSHIP OF THE PARTIES

For the purpose of simplicity,[47] let us assume that the parties involved in this case are: (i) the government, which represents the people of Indonesia as the legal owner of geothermal resources in the country, and (ii) a private developer, who has special skills, expertise and financial support to develop a geothermal prospect.

A geothermal development project can be seen as a delegation[48] of task from the government to a private developer. The task is to develop a geothermal prospect such that it can generate electricity and transfer the electricity back to the government at a price. The government then distributes the electricity to the public at another level of price.

Following the terminology of the institutional economic literature, in this context the government is the 'principal' and the private developer is the 'agent'. Laffont and Martimort (2002) state that, "the essential paradigm for the analysis of market behavior by economists is one where economic agents pursue, at least to some extent, their private

[47] In practice, the developer represents a consortium of companies, while project financing involves a consortium of banks and other financial institutions.
[48] The motivation to delegate can be the possible benefit related to the division of tasks or the lack of time or ability to perform the task (Laffont and Martimort, 2002)

interests," which in different literature this paradigm is referred to as opportunism or strategic behavior. From the point of view of *The Incentive Theory*, the task delegation has two basic characteristics, namely conflicting objectives and decentralized information. In terms of a geothermal project, these two characteristics can be described as follows:

(i) Conflicting objectives: the principal would like to be able to have a developed geothermal resource and to provide low price electricity for the public, while the agent would like to maximize profit.

(ii) Decentralized information: by doing the task, the agent may get access to information that is not available to the principal. Such information may include the exact opportunity cost of this task, the precise technology used, as well as the match between agent's ability and the technology used. In addition, accomplishing a geothermal project development task also make available very specific and valuable information about the underground resource condition. Even if there is a regulation stating that this data shall be provided to the principal, the opportunism behavior paradigm stated above indicates that there remains a possibility that not all findings are reported.

Laffont and Martimort (2002) suggest that the implication of these informational problems in task delegation generally prevent society from achieving the first-best allocation of resources that could be possible in a world where all information would be common knowledge. This means that the condition of asymmetric information lead to incentive compatible contract that involves a trade off between information rent and the allocative efficiency. As they put it:

> "..the information gap between the principal and the agent has some fundamental implications for the design of the bilateral contract they sign. In order to reach an efficient use of economic resources, this contract must *elicit* the agent's private information. This can only be done by giving up some *information rent* to the privately informed agent. Generally, this rent is costly to the principal." (note: the original text do not include underlines)

Williamson (1985) refers to this cost as transaction cost, which is defined as "the cost of running the economic system." *The Transaction Cost Theory* recognizes that there are three principal dimensions that distinguish transactions (or contractual relations), which are asset specificity, uncertainty, and frequency. Asset specificity refers to distinctive skills, unique choice of locations, or special purpose investment. Uncertainty may arise due to acts of nature, lack of communication, or strategic behavior. Frequency of transaction matters since repeated transaction provides experience, which is information that can be used as a reference in making decisions.

With respect to the above transaction dimensions, a geothermal project is an idiosyncratic or highly specific investment. The geothermal wells drilled for the project are location-specific and have a specific purpose, i.e., to transport the heat of the earth to the surface. Moreover, undertaking the task requires special skills. The source of uncertainty in the project is due to the course of nature, which determines whether the prospect contains sufficient quantity and quality of energy. The task assignment takes place only once, which is at the start of the project.

Williamson (1985, 1986) stated that once such idiosyncratic transaction has entered into a contract, there are strong incentives to see the contract through completion.

Further, the interests of the parties to sustaining the relation are especially great for highly idiosyncratic transactions. This is because in highly specific investment the agent is effectively 'locked into' the transaction because the asset is not suitable for other purposes. The principal is also committed to the transaction because of the skill requirement for undertaking the task mastered by the agent, as well as possible costs associated with any delay of production should the contract is interrupted or terminated. Another implication of asset specificity is a fundamental transformation of the market once the contract is signed. An ex-ante competition to enter a contract for an idiosyncratic investment is effectively transformed into one of bilateral supply. This is because economic values would be sacrificed if the ongoing supply relation were to be terminated, except when such investment is transferable to an alternative party at low cost.

Williamson (1986) suggests that 'Trilateral Governance' is an efficient governance structure for such transaction, which is where the principal and agent enter a not-so-comprehensive contract that facilitates transaction and the contract also includes third party assistance. The third party function is to incorporate flexibility and to fill the gaps in the contract, such as to solve dispute and evaluate performance. Further, he also suggests that idiosyncratic investment can benefit from adaptive–sequential-contract since it can attenuate opportunism.

6.2 EX-POST PRICE DETERMINATION

The research findings at Chapter 5 are important information to be considered in determining the output price. Since expansion option is known after the exploration works have been concluded, this finding also suggests that it is worth to consider deciding the output price after the exploration stage. A price determination after the exploration phase can be referred to as 'the ex-post structure,' in contrast to the ex-ante system that presently prevails.

Assuming symmetrical information and a simple self-interest seeking behavior[49] by both parties, the ex-post structure offers a set of incentives to develop geothermal resources. From the company's point of view, this structure provides information to consider a lower feasible price than the level dictated by the ex-ante price. These lower and yet feasible prices would improve the chance of the company to compete with the other base load suppliers, and therefore, securing their positions in the merit order of load dispatch.

The ex-post structure is also of interest to the utility company, since (i) having geothermal power plants supply power at competitive prices would reduce the financial burden that is presently imposed to the utility due to the 'must-run' policy, and (ii) having geothermal plants in the system means a diversification of supply base that could increase reliability of the system.

From the point of view of the government, the ex-post structure would be able to serve as a self-generating motivation for geothermal development that would hopefully

[49] Information is fully and candidly disclosed upon request, accurate state of the world declaration, and oath- and rule-bound actions (Williamson, 1985).

attract more parties to participate. In addition, development of geothermal resources would help ease the pressure on domestic demand for energy.

The above results show that under the assumption of symmetrical information and minimal opportunistic behavior, the ex-post structure is Pareto improving. This improvement would also be socially desirable, especially for many regions where geothermal potentials have been identified and plans to develop the resources have not materialized due to the existing problems.

However, the two assumptions above imply that the results are applicable in a simple world. When such assumptions are relaxed, then the ex-post arrangement has to deal with consequences of asymmetric information and opportunistic behavior of the parties. The possible problems from the private developers' point of view are, (i) lack of interest from private developers, since exploration spending does not guarantee access to the development and operational stages, and (ii) if private developers are willing to take the risk, their opportunistic behavior may lure them to charge excessive prices for the private information they have from investing in the field study. The reciprocal problems from the point of view of the government and the electric utility company are, (i) opportunistic behavior by the government to take over the project, as better information is available without any investment or obligation from their side, and (ii) hesitation from the government and the electric utility company due to uncertainty on the output price to be charged. These difficulties show that the ex-post structure is likely to fail.

6.3 TWO-PHASE NEGOTIATION

Some scholars and practitioners have suggested the price negotiation after exploration, such as Enerindomurni (1999) and Electroconsult (1996). Nevertheless, an implementation of this setting is likely to be difficult since there would be large expenditures for the exploration phase that require the company to look for commercial financing. Without any agreement concerning prices that reflect the expected value of the project, it would be difficult to finance the project with outside funding.

Partowidagdo (2000) suggests coupling the ex-post structure with an exploration insurance that reimburses the developer should the exploration fail to produce electricity at a competitive price, while the fund comes from taxing the existing geothermal fields or collecting a depletion premium from oil and gas extraction. This scheme may induce participation in geothermal development. But again, in a world with incomplete and asymmetric information as well as opportunistic behavior, the private information on the cost size and structure to undertake the exploration are not observable and therefore, may motivate opportunistic behavior to overcharge the cost. Another possible opportunistic behavior is, depending on the magnitude of the insurance coverage, an understatement of the resource quality and quantity to obtain short-term benefit from the reimbursement in return to neglecting the project. The potential financial liability may hinder government participation in this scheme.

Williamson (1986) suggested that an adaptive-sequential contract could attenuate opportunism behavior of the parties involved in an idiosyncratic investment project. An alternative to incorporate flexibility that also addressed the opportunity concerns is a two-phased price negotiation arrangement, where the first phase sets a boundary of acceptable prices for the project prior to any engagement and the second phase determines a specific output price based on the exploration results.

Nodes C1 and C8 at Figure 6-1 represent the negotiation series. In contrast to the previous project structure at Figure 5-1, node C1 at the present structure determines the range of acceptable prices based on the prices of electricity from other power plants supplying the base load. This step would ensure that only viable projects would survive as candidate suppliers to the base load electricity system. The first phase curbs the transaction from an excessive opportunism behavior by the private developer.

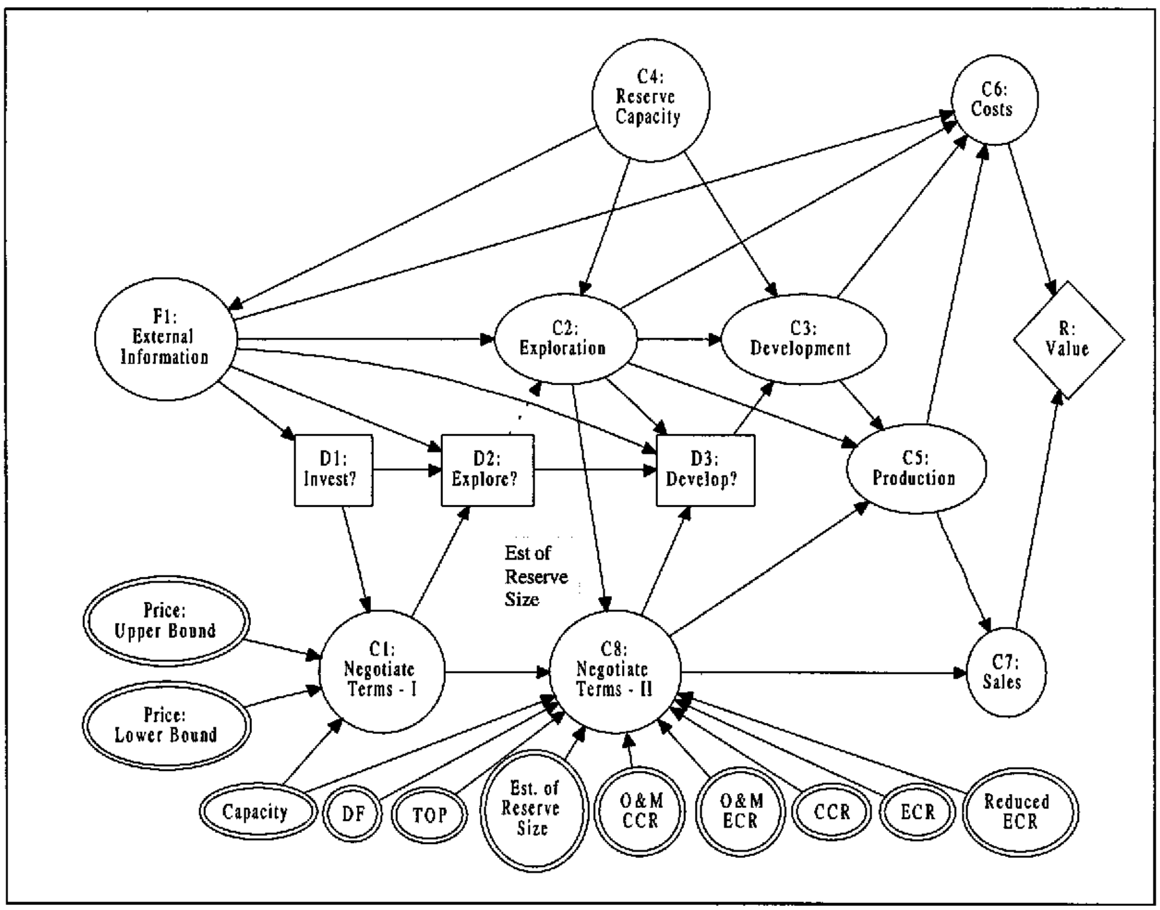


Figure 6-1. Project with Two-Phase Negotiation

The specific output price is determined at the second negotiation, which takes place after the exploration stage. At this position, exploration results provide information on a possibility to expand the capacity size. As previously illustrated by Table 5-9, the size of expansion may be significant. A negotiation table with this information is likely to draw a very different picture than that of the pre-commitment case. Some exercises for this situation indicate a considerably wide range of feasible price level, which suggest that the company would be able to lower the proposed price by significant points and still meet the capital requirements of the investment. Therefore, the second phase negotiation would facilitate a more realistic project valuation for both parties at the negotiation table.

In this case, the first phase agreement serves as pre-commitment conditions for both parties. It says that only viable projects would survive as candidate suppliers to the base load electricity system, addressing the possible opportunism behavior by the private developer. On the other hand it also says that the price range indicates acceptable charges, therefore it can be seen as a purchase guarantee from the government. Conducting the second phase negotiation after the completion of exploration activities would provide better knowledge on reserve characteristics and feasibility, and would facilitate a more realistic project valuation for both parties at the negotiation table.

6.4 CONCLUDING REMARKS

This research focuses on the influence of natural characteristics of geothermal reserves to the project value, and concluded that there are benefits from recognizing managerial flexibility into project valuation. This information can be used to facilitate the transaction process between the government and potential private developers of geothermal projects. To be able to focus on the natural characteristics of the reserve, this research incorporates several simplifying assumptions such as isolating the project from the rest of the economy and a minimal level of opportunism behavior by the market participants. Some possibilities for future research agenda that build upon the present results are to proceed in the following directions:

(i) Principal-Agent relationship:

Utilize the game theory or game theoretic approach to institutional analysis in analyzing strategic behavior of the market participants and the respective contractual ramifications. One possible area is the safeguard against opportunism behavior by both the government and the private developer with respect to the two-phased negotiation. Another area is to figure out the incentive compatibility structure of the project.

(ii) Different settings:

Analyze geothermal projects that separate field development from power generation activities. This structure involves at least two different transfer prices.

(iii) Assumption:

Testing the assumption that 'appropriate' projection of cash flow is an unbiased estimate of the asset value. Develop criterion for determining whether or not a cash flow projection is appropriate, what are the important factors that need to be considered.

APPENDIX A

MODELS FOR INVESTMENT VALUATION: STRENGTHS AND WEAKNESSES

The following evaluation is a summary of Lander (1997) and Lander and Pinches (1998) works.

A.1. Option-Based Models

Strengths:

- They are based on theory and, at least conceptually, can be used to model and value many types of business decisions,
- Flexible, can be simple yet powerful decision-making framework
- Use risk-free rate and risk-neutral probabilities, therefore avoids the issue of risky discount rates and risk preferences,
- Eliminates the need to estimate the expected rate of change in the underlying asset,
- Introduces asymmetry into the distribution of investment opportunity values,
- They model risk directly (σ), in contrast to the DCF that represent it in the risky discount rate,
- Highly appropriate when the volatility of the underlying asset is high, and there are sequential or phased projects

- Powerful and robust when traded securities are available for parameter estimation, since future values and cash flows are market determined (not based on projected or estimated cash flows) and the need for subjective probabilities are avoided.

Weaknesses:

- Assume the decision to exercise is clear-cut,
- Limited by the difficulties in determining and modeling the state variable(s),
- Theoretically require complete markets and no arbitrage opportunities assumptions to hold,
- Can quickly become complex and computationally demanding
- May provide a valuation and an initial optimal strategy, but do not necessarily provide guidelines for managing the investment opportunity,
- Severely limited if there are more than one or two fundamental sources of uncertainty

A.2. Decision Tree

Lander and Pinches (1998) note that "most of the theoretical work in real options indicates that decision trees are the least preferred decision-making frameworks" for modeling and valuing real option. However, they disagree with this view and argue that decision tree models and binomial models are equivalent when they are given the same or corresponding data. Their arguments are:

- Traditional decision trees use subjective probabilities as well as a risky discount rate that represent both time and risk preferences. However, this is similar to the discrete-time option-based models, although in the latter the probabilities are transformed into pseudo-probabilities in order to allow the use of risk-free rate as the discount rate.

- When the analysis is based on cash flow estimates (that is, if market information is not available), a decision tree model has the same data demands as an option-based model.

Nevertheless, there are major weaknesses of the traditional decision tree:

(i) The arbitrariness of the discount rate to value the tree indicates that decision trees do not properly model the volatility when an option is present (similar concern as in the traditional DCF model). The discount rate for the underlying asset alone is not the same as the discount rate for a tree as a whole (because the tree contains option). Lander and Pinches (1998) states that there is no direct way of determining the appropriate[1] discount rate for the tree.

(ii) The problem with the size and complexity of the decision tree (this is actually also present in the binomial and lattice models). It needs knowledge on joint probability distribution, and significant effort to preprocess the probabilities in a relatively complex problem. Modeling more options would result in exponentially larger size of the tree, however often not substantial in determining additional value.

(iii) Estimating the probabilities of the future uncertain values or cash flows. However, note that this is also the weakness of a traditional DCF and may be an option-based model when market price of the underlying variable is not available.

[1] This refers to the 'corresponding' discount rate that would make the analysis equivalent to that of an option-based model.

Table A-1 Decision Tree Models

Strengths	Weaknesses
• Expressive and flexible • Provide project values and optimal strategies • Address variable interdependencies • Can account for state or time dependent parameters • Useful when uncertainty is resolved at discrete points in time, or when foregone earnings and intermediate cash flows cannot be reasonably modeled using option pricing techniques	• Use arbitrary discount rate to value the tree • Size or complexity of the decision trees • Difficulty in estimating the probabilities of the future uncertain cash flows

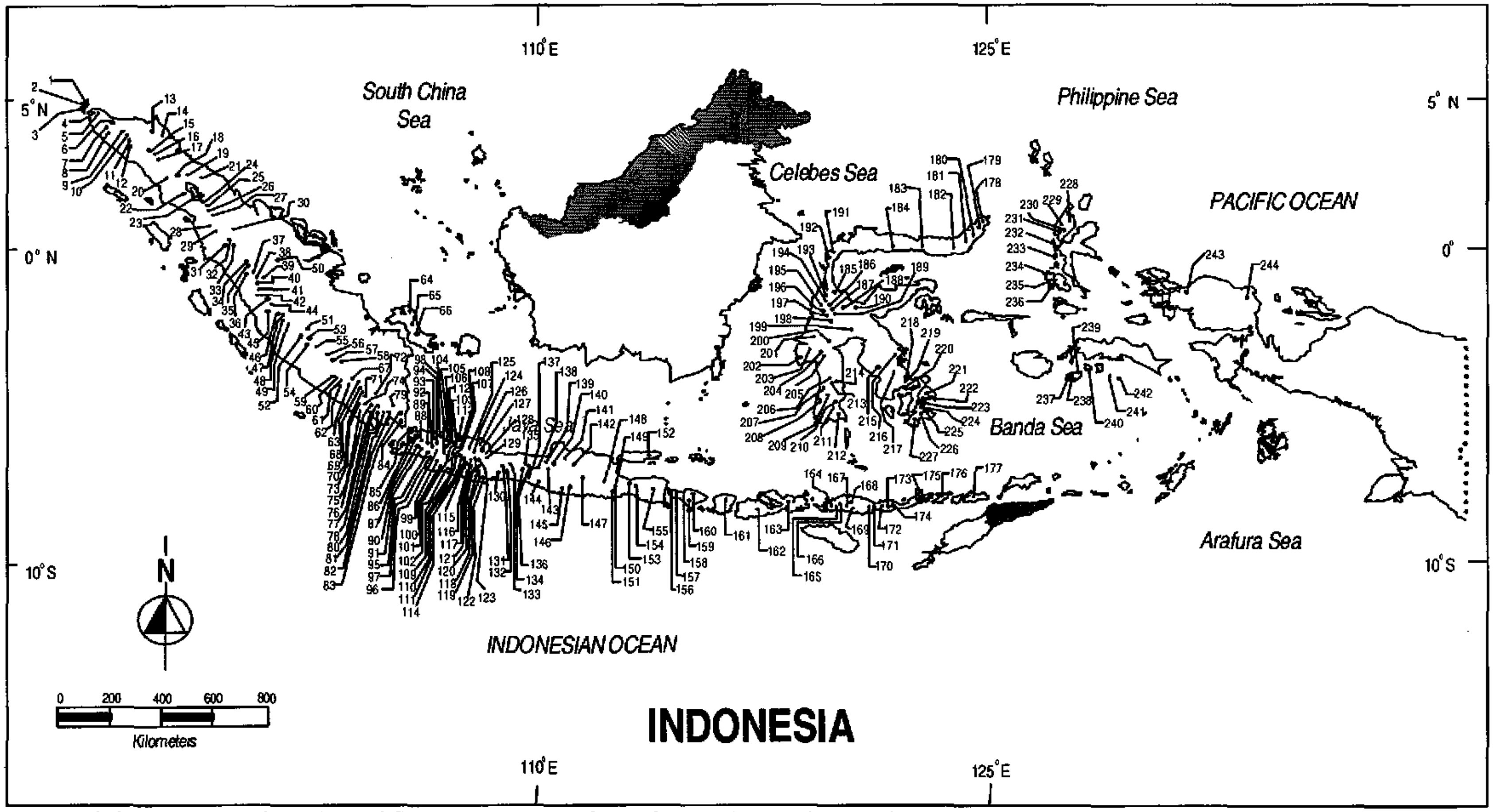
A.3. Influence Diagram

Influence Diagram shares the same strengths as decision trees, plus additional features shown in Table A-2.

Table A-2 Influence Diagrams

Strengths	Weaknesses
• Can model continuous variables • Can include both the modeling of the estimation process and the modeling of the valuation process in one diagram • Facilitate evidence propagation, where the probability distribution of one or more of the uncertainties is updated to reflect the current knowledge of the decision-maker • Although mathematically equivalent to decision trees, influence diagrams is a more compact representation of the problem that is more intuitive and easy to understand. • The graphical part grows linearly in the number of variables, not combinatorially as in decision tree as well as binomial and lattice models. Therefore, the size and complexity issues are no longer present. • Solution procedure is more efficient	• Appropriate when uncertainty can be modeled by a set of conditional probability distribution • Require dummy variables for modeling asymmetric decision problems • Can be solved exactly only if the chance and decision variables have discrete state spaces • Issue: the appropriate discount rate when an option on the underlying asset is present in the model

APPENDIX B
GEOTHERMAL DEVELOPMENT IN INDONESIA



Source: Sub Directorate of Geothermal Survey, Directorate General of Geology and Mineral Resources, Ministry of Mines and Energy of Indonesia, 1998.

Figure B-1. Geothermal Prospects in Indonesia

Notes for Figure B-1. Geothermal Prospects in Indonesia (1998)

ACEH

1. Lho Pria Laot
2. Kaneke
3. Iboih-Jaboi
4. Le Suum Krueng Raya
5. Seulawah Agam
6. Alur Canang
7. Alue Long-Bangga
8. Langsa
9. Rimba Raya
10. G. Geureudong
11. Simpang Balik
12. Silih Nara
13. Meranti
14. Brawang Buaya
15. Kafi
16. Gunung Kembar
17. Dolok Perkirapan

NORTH SUMATERA

18. Beras Tepu
19. Lau Debuk-debuk Sibayak
20. Marike
21. Dolok Marawa
22. Pusuk Bukit
23. Simbolon-Samosir
24. Pagaran
25. Helatoba
26. Sipaholon-Ria-ria
27. Sarula
28. Sibual-buali
29. Namora Ilangit
30. Sibubuhan
31. Sorik Merapi
32. Sampuraga
33. Roburan

WEST SUMATERA

34. Simisioh
35. Cubadak
36. Talu
37. Panti
38. Lubuk-Sikaping
39. Situjuh
40. Bonjol
41. Kotabaru-Marapi
42. Maninjau
43. Sumani
44. Priangan
45. Bukit Kili
46. Surian
47. Gunung Talang
48. Muaralaboh
49. Liki Pinangawan

RIAU

50. Pasir Pangarayan

JAMBI

51. Gunung Kapur
52. Gunung Kaca
53. Sungai Tutung
54. Semurup
55. Lempur
56. Air Dikit
57. Graho Nyabu
58. Sungai Tenang

BENGKULU

59. Tambang Sawah
60. Bk. Gedang-Hulu Lais
61. Suban Gergok
62. Lebong Simpang-Bukit Daun
63. Tanjung Sakti

SOUTH SUMATERA

64. Sungai Liat
65. Pangkal Pinang
66. Air Tembaga
67. Rantau-Dadap-Segamit
68. Bukit Lumut Badai
69. Ulu Danau
70. Marga Bayur
71. Wai Selabung

LAMPUNG

72. Wai Umpu
73. Danau Ranau
74. Purunan
75. Welirang Sekincau
76. Becingot
77. Suoh Antatai
78. Pajarbulan
79. Natar
80. Ulubelu
81. Lempasing
82. Wai Ratai
83. Kalianda
84. Pematang Belirang

WEST JAVA

85. Rawa Dano
86. Gunung Karang
87. Pulosari
88. Cianten – G. Endut
89. Pamancalan
90. Kawah Ratu (G. Salak)
91. Kawah Kiara Beres (G. Salak)
92. Awi Bengkok (G. Salak)
93. Ciseeng
94. Bujal – Jasinga
95. Cisukarame
96. Selabintana
97. Cisolok
98. Gunung Pancar
99. Jampang
100. Tanggeung – Cibungur
101. Saguling
102. Cilayu
103. Kawah Cibuni
104. G. Patuha
105. Kawah Ciwidey
106. Maribaya
107. G. Tangkuban Parahu
108. Sagalaherang
109. Ciarinem
110. G. Papandayan
111. G. Guntur – Masigit
112. Kamojang
113. Darajat
114. G. Tampomas
115. Cipacing
116. G. Wayang Windu
117. G. Talaga Bodas
118. G. Galunggung
119. Ciheras
120. Cigunung
121. Cibalong
122. G. Karaha
123. G. Sawal
124. Cipanas – Ciawi
125. G. Cakrabuana
126. G. Kromong
127. Sangkanurip

Notes for Figure B-1. Geothermal Prospects in Indonesia (1998) (continued)

128. Subang	166. Wai Pesi	207. Sulili
129. Cibinbin	167. Inelika	208. Malawa
CENTRAL JAVA	168. Mengaruda	209. Baru
130. Banyugaram	169. Bobo	210. Watampone
131. Bumiayu	170. Komandaru	211. Todong
132. Baturaden	171. Ndatusoko	212. Sinjai
133. Guci	172. Sokoria	213. Masepe
134. Mangunan – Wanayasa	173. Jopu	214. Danau Tempe
135. Candradimuka	174. Lesugolo	**SOUTH EAST SULAWESI**
136. Dieng	175. Oka	
137. Krakal	176. Atedai	215. Mangulo
138. Panulisan	177. Kalabahi	216. Parora
139. Gunung Ungaran	**NORTH SULAWESI**	217. Puriala
140. Candi Umbul	178. Air Madidi	218. Amohola
141. Kuwuk	179. Lahendong	219. Loanti
142. Gunung Lawu	180. Tompaso	220. Laenia
143. Klepu	181. Gunung Ambang	221. Torah
YOGYAKARTA	182. Kotamobagu	222. Kalende
144. Parangtritis	183. Gorontalo	223. Kanale
EAST JAVA	184. Petandio	224. Wonco
145. Melati	**CENTRAL SULAWESI**	225. Rongi
146. Rejosari	185. Maranda	226. Kabungka
147. Telaga Ngebel	186. Sapo	227. Sampulawa
148. G. Pandan	187. Langkapa	**MALUKU**
149. G. Arjuno Welirang	188. Napu	228. Mamuya
150. Cangar	189. Torire	229. Ibu
151. Songgoriti	190. Toare	230. Akelamo
152. Tirtosari	191. Patalogumba	231. Jailolo
153. Argopuro	192. Merawa	232. Kie Besi
154. Tiris	193. Bora	233. Akesahu – Tidore
155. Blawan Ijen	194. Pulu	234. Indari
BALI	195. Sedoa	235. Labuha
156. Banyuwedang	196. Wuasa	236. Tonga
157. Seririt	197. Watuneso	237. Larike
158. Batukao	198. Papanpulu	238. Taweri
159. Penebel	**SOUTH SULAWESI**	239. Tolehu
160. Buyan – Bratan	199. Luwuk	240. Oma-Haruku
WEST NUSA TENGGARA	200. Parara	241. Saparua
161. Sembalun	201. Pambusuan	242. Nusa Laut
162. Marongge	202. Somba	**IRIAN JAYA**
163. Huu Daha	203. Mamasa	243. Makbau-Sorong
EAST NUSA TENGGARA	204. Bituang-Rantepao	244. Ramsiki-Umsini
164. Wai Sano	205. Sangala-Makale	
165. Ulumbu	206. Sengkang	

Table B-1. ACTIVITIES IN GEOTHERMAL PROJECT DEVELOPMENT

Activities		Objective & Description of Activities	Time	Notes
1. EXPLORATION		To proof the existence of the resource & assess the resource potential	± 4 years	Cost estimate US$ 20-30 Million
1.1	**Reconnaissance Survey (Preliminary Exploration)**	• Identify surface manifestation that indicates possible existence of geothermal resources • Produce documentation on regional geology of the site • Identify possible utilization of the potential resource & preliminary market study	± 1 year	• Cost estimate: US$ 0.1-0.3 Million • Approximate degree of success that the prospect could be commercially developed: 30%-50%
	a. Literature Study	• Collect maps and data from previous survey activities in the area • Determine locations to be surveyed	1 month	Time requirement depends on data availability & accessibility
	b. Field Survey: • Geological • Hydrology • Geochemistry • Environment	• Identify global formation and types of earth's crust, rock configuration, geological structure, surface manifestations and their respective characteristics • Take fluid samples, measure the temperature, pH and flow rate • Identify environmental constraints	3 month – 1 year	Time depends on the quality of existing data; area to be covered (range varies from a few to thousands km^2), geological conditions; and team size
	c. Data Analysis & Interpretation	To obtain geological and hydrological model of the area: • To determine the prospect area (conclude the boundaries) • To estimate the type of reservoir, it's temperature, water origin and type of rock that form the reservoir		
	d. Speculate on the electricity potential	However limited, the data shall be used to estimate electricity potential of the resource. Statistical figures of the existing geothermal projects are commonly used as benchmark.		Indonesia: 20 $km^2 \cong 2.5$ MWe
	e. Preliminary market study	To verify the existence of power demand that could be fulfilled by the generation from the potential geothermal resource		
	f. Propose future activities	• Decide whether to continue the project or to abandon it. • If decided to continue, then recommend priority locations for further investigation and the respective survey type to be conducted on the next phase of the project		

Table B-1. ACTIVITIES IN GEOTHERMAL PROJECT DEVELOPMENT (continued)

Activities		Objective & Description of Activities	Time	Notes
1.2	**Pre-Feasibility Study (Advance Exploration)**	• Enhance the knowledge on the prospects by studying indirect evidence of the conditions that affects the existence of a geothermal reservoir • Delimitate the area of probable occurrence of the reservoir • Lead to a decision whether or not to continue with exploration activities	1 year	• Cost estimate: US$ 0.5-2 Million • If the investigation result is positive, there is 50% probability of eventually discover a commercial field
	a.. Field Survey: • Advance Geology • Advance Geochemistry • Hydrology • Advance Geophysics • Geography • Drilling of slim holes	• Obtain detail geology and stratigraphy information of the site • Take samples from all locations of surface manifestation and the surrounding area to examine fluids and gas at the surface as well as underneath (inspect for corrosiveness and other potential problems) • Study the groundwater circulation system • Delineate the possible position of the reservoir • Obtain information on the contour of the area, the existing infrastructure (road, clean water, electricity, telecommunication), and the surrounding population • If surface investigation leaves some doubt on the existence of an active heat source, slim exploratory wells may be drilled to test the temperature at 500-800 m depth		
	b. Data Analysis & Interpretation	To produce a preliminary geothermal model of up to 1-4 km below surface, which enable the estimation of resource potential, recoverable reserve, and electricity potential		
	c. Propose future activities	• Decide whether to continue the project or to abandon it. • If the project is considered to be likely economically feasible, then identify target and location of exploration drilling as well as the respective drilling program		

Table B-1. ACTIVITIES IN GEOTHERMAL PROJECT DEVELOPMENT (continued)

<table>
<tr><th colspan="2">Activities</th><th>Objective & Description of Activities</th><th>Time</th><th>Notes</th></tr>
<tr><td>1.3</td><td>Feasibility Study (Detail Exploration)</td><td>• To proof the existence of geothermal resource in the area
• Decide whether the prospect is technically and economically feasible, hence attractive for development.</td><td>± 2 years</td><td>• Cost estimate: US$ 10 Million
• 70% success ratio to lead to proven commercial fields</td></tr>
<tr><td></td><td>a. Reservoir & Steam Production Engineering:
• Drill exploratory wells
• Data analysis & interpretation
• Evaluate geothermal model</td><td>• To evaluate field characteristics (quality, quantity, depth) and estimate its potential (proven, probable, possible)*:
– Commonly drill 3-5 deep exploratory wells (1000-3000 m) to have 2-3 producing wells and at least 1 re-injection well
– Obtain information on the type and characteristics of reservoir (fluid; depth, type, temperature, rock)
• Decide whether there is enough information to assess the resource potential, or more exploration wells need to be drilled. If some exploration wells show enough potential, then continue with examining the feasibility for development
• Test and adjust the geothermal system model previously developed</td><td></td><td>Exploration well generally costs more than production well since it involves:
• More careful approach due to the uncertainties involved
• Drilling of deeper holes for reservoir investigation
• More measurements to better understand the underground situation and reservoir characteristics
Cost estimate (Indonesia): US$ 2.1 Million/exploratory well</td></tr>
<tr><td></td><td>b. Power Plant Engineering</td><td>Aimed at the optimization of the conversion process of the geothermal resources into electricity:
• Select conversion process, development strategy, unit size
• Select plant site and determine general design
• Identify acceptable measures to mitigate environmental impact</td><td></td><td></td></tr>
<tr><td></td><td>c. Economic Evaluation</td><td>• Pre-requisite: completion of 1.3-a and 1.3-b that yield proven reserve
• Demand assessment
• Compare the cost of implementing the project to the expected benefit from the sale of generated energy</td><td></td><td></td></tr>
<tr><td></td><td>d. Propose future activities</td><td>Decide whether the prospect is technically and economically feasible, hence attractive for development. If yes, then continue with detail planning for project implementation</td><td></td><td></td></tr>
</table>

Table B-1. ACTIVITIES IN GEOTHERMAL PROJECT DEVELOPMENT (continued)

Activities		Objective & Description of Activities	Time	Notes
2. DEVELOPMENT		Field development & power plant construction	3 years	A critical phase in a geothermal project Cost estimate: US$1200 – 2200 per kW installed (depends on power plant size, wells productivities and costs) Average development well in Indonesia • Success ratio: 80% • Cost: US$ 1.5 Million/well • Productivity: 7 Mwe/well (World average: 5 MWe)
2.1	**Planning**	To determine necessary systems and facilities to be in place, which includes detail engineering design and other aspects of field development as well as power plant construction:		
2.2	**Project Implementation**			
	a. Drill Production & Injection Wells	• Drill sufficient production wells to ensure enough steam • Drill injection wells, that are used to return the waste water into the ground • Update reservoir assessment		
	b. Power Plant Construction	• Develop the power plant and the respective infrastructure (critical activity: the supply & erection of the turbine and generator)	24-30 months	
3. OPERATION & MAINTENANCE			25-30 years	
3.1	**Production**	• Produce steam from production wells • Generate electricity at the power plant		
3.2	**Maintenance**	Drill make-up wells to compensate the depletion of the production wells due to the draw-down of the reservoir		
3.3	**Monitoring**	Obtain necessary information to decide whether to plan the drilling of replacement wells or an expansion of production capacity through: • Constantly monitor reservoir performance to detect significant variation that may indicate the decline of production • Constantly calibrate the mathematical model of the reservoir		

Notes: *Proven reserve: the highest degree of resource potential estimation that is based on information from at least one exploratory well and two delineated wells; Probable: less certain than 'Proven', based on information from an exploratory well; Possible: the least certain estimation, information is based on geological, geochemistry and geophysics surveys.

Source: Directorate General of Electricity and Energy Development of Indonesia, 1995, "Private Power Development: Geothermal and Combined Cycle Projects, Geothermal Total Projects, Volume III", Study Report by Electroconsult, Fichtner and Redecon.

Table B-2. COSTS OF A GEOTHERMAL PROJECT

Project stages	# of well [a]	Cost/well* US$	Well Cost US$	Other Cost US$	Total Cost US$	Total Cost %	Cost/kW US$/kW
Exploration			**10,350,000**	**1,850,000**	**12,200,000**	**6.1**	**221.82**
Reconnaisance				100,000			
Pre-Feasibility				1,000,000			
Feasibility	5	2,070,000	10,350,000	750,000			
Development			**25,660,000**	**52,766,000**	**78,426,000**	**39.1**	**1,425.93**
Field development	13	1,500,000	19,500,000				
Separation & gathering system**	8	770,000	6,160,000				
Power Plant (55 MW)***				50,000,000			
Other costs:							
Access Roads & Land Rights				200,000			
Engineering & Administration[b]				2,566,000			
Operation & Maintenance			**46,130,000**	**63,935,800**	**110,065,800**	**54.8**	**2,001.20**
System O&M [c]			27,380,000				
Make-up wells	1 every 2 yrs	1,500,000	18,750,000				
Engineering & administration [d]				1,435,800			
Power plant operation				62,500,000			
Total Cost for a 55 MW Installed Capacity (US$):			**82,140,000**	**118,551,800**	**200,691,800**		
Total Cost for a 55 MW Installed Capacity (US$/kW):			**1,493.45**	**2,155.49**	**3,648.94**		

Notes:

* Average Indonesian data from the existing commercial fields

** Geothermal field in Indonesia is commonly water dominated.
Hence, the stated cost estimate is for the 8 water-dominated producing wells (refer to the table below)

*** Statistics: average productivity of Indonesian wells is around 7 MWe/well

Assumptions:

(a) Wells for a 55 MW geothermal power plant are assumed as follows

	Producers	Reinjectors	Failed	Total
Exploration	2	1	2	5
Development	8	1	1	10
Reinjection (add'l)	-	2	1	3

(b) Lifetime of the project is 25 years
Engineering & administration cost is estimated at 10% of total investment costs

(c) System O&M per year is estimated at 2% of the total well investment costs

(d) About 10% of the yearly expenditures

Sources: Electroconsult Report for DGEED, 1996; PT Bayu Enerindomurni Report for DGOG, 1999

APPENDIX C

INFLUENCE DIAGRAMS

Influence Diagrams (ID) are commonly grouped as one of the methodologies in Decision Analysis. However, some similar features of other methodologies may lead to inconsistent classification in the literature. Section C.1 briefly reviews the relationship between ID and other graphical modeling that uses Bayesian approach.

Section C.2 sketches the intentions underlying ID conception and summarizes the framework. Section C.3 introduces a formal representation of basic features of ID. Section C.4 elaborates some issues related to the elements and structure in an ID representation. Section C.5 describes appropriate structure of an ID, the two evaluation procedures and their respective algorithms. Section C.6 briefly looks at a few commercially available computer software to model and analyze ID. Section C.7 describes the components of the Base Case model of this research stated in Chapter 5. Section C.8 provides additional notes for the proposed arrangement to improve some problems in the Base Case model.

C.1 The Family of Decision Analysis

Howard and Matheson (1989) describe Decision Analysis (DA) as a "discipline comprising the philosophy, theory, methodology, and professional practice necessary to formalizes the analysis of important decision". Decision Trees, Influence Diagram, and

Valuation Network are among the methodologies in DA that can be used to formally represent a decision problem.

DA deals with issues of knowledge acquisition, knowledge representation, and inference[1]. However, these issues are also shared by another strand of discipline called Artificial Intelligence (AI). Abramson (1993) observes that the two disciplines can be distinguished by their psychological motivations. DA is a sophisticated outgrowth of task analyses of inference, evaluations and decisions; while AI is rooted in descriptive psychology or observation about the way people behave. Consequently, DA prescribes what decision makers *should do*, while an ideal rule-based AI would *mimic* the behavior of a human expert. He also notes that both DA and AI could be considered as members of a large family of models called *Belief Networks*, which is a graphical embodiment of hierarchical Bayesian analysis.

Bayesian approach presumes that there are certain states of the world, one of which includes the particular situation being examined (Morgan, 1968). The analyst would deal with uncertainty by assigning probabilities to the possible states of the world. Hence, such probabilities are often referred to as "personal or subjective probabilities" and it is reasonable to ask an expert for an opinion about a rare event. In Bayesian statistics probabilities are seen as *orderly opinions*, in contrast to those in Classical statistics where they are *frequencies of occurrence* that consequently requires voluminous data to obtain the information.

[1] Inference is the process of generating new conclusions from existing knowledge (Gottinger et al, 1995).

The family of Belief Networks consists of *directed-acyclic-graphical*[2] (DAG) representation of a problem that have the following characteristics:

(i) Nodes represent individual variables, items, characteristics, or knowledge-sources,

(ii) Arcs demonstrate influence among the nodes,

(iii) Functions associated with the arcs indicate the nature of that influence.

Prior to 1980, the only known member of the family of Belief Networks is Decision Tree. More recently developed methodologies are Influence Diagrams (ID) in the DA group and Bayes Network in the AI group. Over time, the advancement of these methodologies leads to many shared characteristics. Ongoing improvements in the weaknesses of each methodology have partly benefited from leading features of each other in the form of hybrid methods. This progress yields more versatile approaches and may have more efficient computational storage or time, but also lead to vague classification.

For example, Ezawa (1998) refers to ID as a generalized Bayesian Network. Sometimes it is not clear which is the general model and which is the special case. Ndilikilikesha (1993) states that an ID containing only nodes representing the random variables is called a Belief Network, while Varis (1997) states that ID is often considered as a special case of Belief Networks.

Within the works that based on ID, there are many variants that correspond to proposed modifications or advancement by various authors. Bielza and Shenoy (1999)

[2] Directed graph with no loops. Directed graph means the arcs connecting the nodes are arrows that indicate the direction of influence (either causal or relevance) among the nodes.

feel the need to put a reference for these ID variations, such as "Smith-Holtzman-Matheson's Influence Diagrams" and "Tatman-Shachter's extension of the Influence Diagram". Significant amount of works combine ID and Decision Tree (DT) in varying ways, where the ID is used to represent the uncertainty of information and the DT is used to represent the structural asymmetry information.

Some other works claim that they develop a new methodology, but later authors consolidate these leading features back into ID framework. For example, although Valuation Networks are similar to ID in many ways, they do not require conditional probability and introduce solution technique called 'fusion algorithm'. However, as stated by Shenoy (2000), further development by Ndilikilikesha (1992, 1994) has translated the fusion algorithm into the ID framework.

Another strain of work combines DA with advances in related computational mathematics of AI. For example, Gottinger and Weimann (1995) integrate artificial intelligence-based techniques, logic-based approaches of problem solving with techniques for probabilistic analysis and decision-making under uncertainty from operations research and management science. Bielza et al (2000) show the need to incorporate various techniques including those used in Bayesian Network for solving complex decision-making problems with ID.

C.2 Influence Diagrams Framework

Influence Diagrams (IDs) were originally conceived to function both as a computer-aided modeling tool and as a representation of the decision problem that is easily understood by 'people in all walks of life and degrees of technical proficiency' (Howard and Matheson, 1981). IDs would allow many of the decision analysts' tasks to be *implemented by personal computers* such that the analysts can concentrate on major issues. IDs would also allow better communication between decision makers and decision analyst experts.

An Influence Diagram (ID) is a network representation for modeling uncertain variables and decisions. The graph shows the structure of the model, which consists of a node for each variable in the model and arcs that indicate the relationships among the variables. The nodes can represent constants, uncertain quantities, decisions, or objectives. The arcs denote the probabilistic dependence of the uncertain quantities and the *information* available at the *time* of the decision. Each node contains detailed information about the respective variable (Shachter, 1986 & 1988).

An ID is not a flowchart, although it may look like one. Instead, as Clemen (1995) states, it is a snapshot of decision maker's understanding of the decision situation at a particular time. Hence, all decision elements that play a part in the immediate decision need to be taken into account. Uncertain events are modeled using probability, which indicate that the decision maker has some idea of how likely the different possible outcomes are.

There are three levels of specification in an ID, (i) *relation*, (ii) *function*, and (iii) *number*. Howard and Matheson (1981) and Smith et al (1993) explain this arrangement as follows:

- In the deterministic case, the level of relation indicates that one variable depends in a general way on others; for example, profit is a function of revenue and cost. The level of function specifies the precise function describing this dependence; such as profit equals revenue minus cost. At the level of number, numerical values of revenue and cost are specified, and consequently this determines the numerical value of profit.
- In the probabilistic case, the level of relation indicates that, given the information available, one variable is probabilistically dependent on certain variables and probabilistically independent of others. For example, we might assert that for a given person, income depends on age and education, and that education depends on age. The level of function describes the form of these dependencies, such as, if we divide age into 10-year increments, we might assign different distributions on education for each age group under 40 and the same distribution for all age groups over 40. When assessing income given age and a particular educational level, we may wish to assign distributions for each age group. At the level of number, we specify numerical probabilities for each conditional and unconditional event. Taken together, the three levels implicitly determine a joint probability distribution over all variables.

Once the decision problem is identified, the ID representation can be evaluated using either one of the following ways. The first evaluation procedures analyzes the diagram directly through a series of transformations that preserves the solution value, although the graphical structure and the detailed data within the nodes are changed. Shachter (1986) called such transformation as a *value-preserving reduction*, which may be accomplished through (i) node removal, and (ii) arc reversal. The nodes that do not influence other nodes or do not affect the objective can be automatically removed, while the removal of other nodes are governed either by conditional expectation or conditional optimality principle. Shachter (1988) notes that this is just the basic steps in evaluating a stochastic dynamic program introduced in Bellman (1957). The arc reversal is the implementation of Bayes' Theorem. Further elaboration on these solution procedures is covered in Section D.4 of this appendix.

The second approach converts the ID into a corresponding DT representation, and then solves the decision problem in DT form by following the rollback algorithm. Marshall and Oliver (1995) note that the rollback algorithm was introduced by Raiffa (1968), but it is actually based on the principle of optimality in dynamic programming by Bellman and Dreyfus (1962).

C.3 A Formal Representation

The description of influence diagram in this section is a summary of related materials in Howard and Matheson (1981), Shachter (1986), Ndilikilikesha (1994) and Fagiuoli and Zaffalon (1998).

Let $G = (N, A)$ be a directed-acyclic-graph (DAG),

where N = set of nodes

A = set of arcs, $A \subseteq N x N$

For any node $t \in N$, define:

$\pi(t) = \{s \in N | (s,t) \in A\}$ $\pi(t)$ = the set of direct predecessors of t

$\sigma(t) = \{s \in N | (t,s) \in A\}$ $\sigma(t)$ = the set of direct successors of t

A node t is called a *source* if $\pi(t) = 0$, or a *barren* if $\sigma(t) = 0$.

For any set $W \subseteq N$, let $\pi(W) = \bigcup_{t \in W} \pi(t)$ and $\underline{\pi}(W) = W \cup \pi(W)$..

The nodes are partitioned into three sets: $N = C \cup D \cup \{v\}$. The nodes in C are called *chance nodes*, the nodes in D *decision nodes*, and *v* is called *value node* or *result node*.

The arcs entering a chance or value node are called *conditioning* arcs; the arcs entering a decision node are said *informative* arcs[3]. The informative arcs represent a basic cause/effect ordering, while the conditioning arcs represent a somewhat arbitrary order that may not correspond to any cause/effect notion and that may be changed by application of the laws of probability such as Bayes' Rule.

Any node $t \in N$ is associated to a variable $X_t \in \Omega_t$, where $|\Omega_t| \langle \infty$; a generic value of X_t is denoted by x_t . If W is a generic non-empty set of nodes, X_W denotes the vector of variables indexed by the elements of W and with values in $\Omega_t = \times_{t \in W} \Omega_t$. If t is a decision node, Ω_t is the set of the decisions associated with t. If t is a chance node, the values in Ω_t are the possible states of the random variable X_t; and for any value of $X_{\pi(t)}$ it is defined the conditional probability distribution $P[X_t | X_{\pi(t)}]$.

[3] At least Howard and Matheson (1981) as well as Fagiuoli and Zaffalon (1998) use these terminologies. Howard (1990) uses 'relevance' to describe an arrow between chance nodes or between a chance node and a deterministic node, and 'influence' to describe an arrow from a decision node to a chance node.

The case of value node is slightly different. The node v must express the utility value that is the consequence of a certain state of v parents, and therefore should contain a function $u : \Omega_{\pi(v)} \rightarrow \Omega_v$. The same concept is expressed in a different way by considering X_v a random variable and realizing the function u by means of the probability:

$$P\lfloor X_t \vert X_{\pi(t)} \rfloor = \begin{cases} 1 & if \quad X_v = u(X_{\pi(v)}) \\ 0 & otherwise \end{cases} \tag{D.1}$$

In fact, $u(X_{\pi(v)}) = \sum_{X_v} X_v P\lfloor X_v \vert X_{\pi(v)} \rfloor$. Using probability (D.1) has the advantage of treating the result node as a random variable.

Definition 1. An *Influence Diagram* is a pair (G,P) such that:

1. $G = (N, A)$ is a DAG such that $N = C \cup D \cup \{v\}$ and the following conditions are satisfied:
   (i) v is barren
   (ii) there exists a directed path connecting all the decision nodes and only them (*single decision-maker property*)[4]
   (iii) the direct predecessors of any decision node are direct predecessors of all the subsequent decision nodes (*no-forgetting property*)

[4] This implies a total ordering among decision nodes (Howard and Matheson, 1981).

2. P is the family of conditional distributions associated to the nodes in $C \cup \{v\}$.

Definition 2. Let G = (G, P) be an ID and t a decision node.

A function d_t : $\Omega_{\pi(t)} \rightarrow \Omega_t$ is called a *decision function* of t.

Note that the nodes in D model the decisions by means of decision functions. As in the case of the result node, the decision function of t can be expressed in an equivalent way by means of the following probability:

$$P\lfloor X_t | X_{\pi(t)} \rfloor = \begin{cases} 1 & \text{if} \quad X_t = d_t(X_{\pi(t)}) \\ 0 & \text{otherwise} \end{cases} \tag{D.2}$$

Definition 3. A *strategy* for an influence diagram is the function s: $\Omega_{\pi(D) \setminus D} \rightarrow \Omega_D$ resulting by the application of all the decision functions. A *partial strategy* s_K is a strategy related to a subset K of decision nodes.

When a strategy is fixed, probability (D.2) makes it possible to associate a set of conditional probabilities to the decision nodes and hence to *formally* treat the decision nodes too as chance nodes[5]. In this case any node of the graph is *formally* a chance node.

Fagiuoli et al (1998) show that ID is equivalent to Bayesian Network in many ways. These features allows the *factorization theorem* to be extended to IDs,

[5] Smith et al (1993) refers to this feature as 'determining a decision node'. See also section D.3.

$$P_s[X_N] = \prod_{t \in C \cup \{v\}} P[X_t | X_{\pi(t)}] \prod_{r \in D} P_s[X_r | X_{\pi(r)}] \qquad \text{(D.3)}$$

Expression (D.3) shows that the joint distribution is the product of the conditional distributions of the nodes. The subscription s indicates that a strategy must be fixed in order to define a joint distribution, since the decision nodes are interpreted as chance nodes only in this case. Different strategies lead to different joint distributions and therefore to different expected values of the utility. The expected value is defined as

$$E[X_v] = \sum_{X_v} X_v P_s[X_v] = \sum_{X_N} X_v \cdot \prod_{t \in N} P_s[X_t | X_{\pi(t)}] \qquad \text{(D.4)}$$

Note that the subscript s is only related to decision nodes probabilities.

Definition 4. A strategy s* is said *optimal* if for any other strategy s, $E_s[X_v] \le E_{s*}[X_v]$.

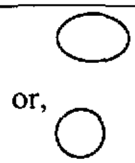
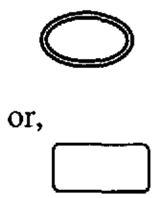
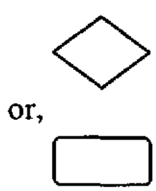
The quantity $E_{s*}[X_v]$ is said *optimal expected value.*

A procedure *solves* an ID if it computes the optimal expected value and the associated optimal strategy.

C.4 Graph Elements and Structure

Graphical representation of an influence diagram consists of nodes and directed arcs. As mentioned earlier, there are three types of nodes: (i) decision node, (ii) chance node, and (iii) value node. The nodes are connected by directed arcs, which represent possible conditional dependence among them. The arc direction relates to the perceived influence or relevance. Notations for these elements in the literature vary slightly. Table D-1 presents the symbols and a general description about the nodes.

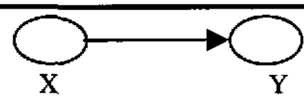
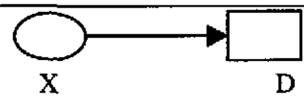
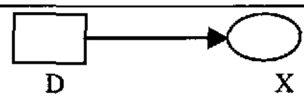
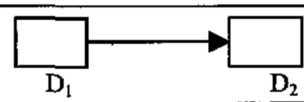
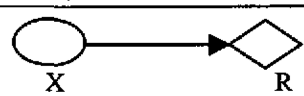
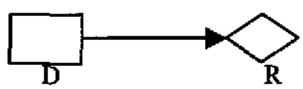
Table C-1. Elements of Influence Diagrams: the Nodes

Node Names	Notation	Remarks
Decision Node		• Indicates a decision facing the decision maker • Each decision node is associated with a *decision set* that may contain values or alternatives
Chance Node		• Represents random quantities or events, i.e. a variable (or event) whose value (or outcome) is uncertain. • Each chance node is associated with a *random outcome set*, which contains possible states of nature and the respective conditional probability distribution given the values of its predecessors
		• A *deterministic node* is a special type of chance node. Given the values of its predecessors, there is only one possible value for the deterministic node (probability=1) • No need to specify the conditional probability distribution for this node. Instead, the followings must be specified: – A mathematical *function* that defines the value of the deterministic node, as a function of the predecessor nodes' values – If any predecessor nodes are chance nodes, then the value of a deterministic node is also uncertain (when input is random, output is also random) • Other labels for this node: *Intermediate Node, Calculation Node*
Result Node		• Represent the result of the decision process, which can be measured in terms of quantity or other form of assessments such as ordering based on the preference of the decision maker. • A result node is associated with a mathematical function that may depend on the decision(s) taken and random outcome(s) that occur • Other labels: *Value Node, Outcome Node, Consequence*

Source: Marshall and Oliver (1995)

Table C-2 abridges the ideas related to the use of directed arcs. Branches emanating from a decision node represent all alternatives under consideration. Branches from a chance node must be mutually exclusive and all events included, so that the sum of probabilities is one.

Table C-2. Elements of Influence Diagrams: the Directed Arcs

Basic Arc Combinations	Description
	• X and Y may be statistically dependent, and • The outcome of the random event X will be known when the probability distribution of Y is assessed
	• The value of uncertain event X is observed and known to the decision maker before the decision D is made, and • The value of X may influence the decision D
	• The decision D is made before the random event X occurs, and • The probability distribution of X may depend on the particular decision made
	• The decision selected for D_1 is known to the decision maker before D_2 is made, and • The decision taken for D_1 may influence the decision D_2
	• The result R of the decision process depends on the outcome of the random event X
	• The result R depends o the decision alternative chosen

Source: Marshall and Oliver (1995)

The probabilistic relationship among nodes can be represented in several ways according to the 'chain rule of probabilities' of Bayes' Theorem. For example, the following expansions are both logically correct for two events or variables:

$$\{x, y|S\} = \{x|y, S\}\{y|S\}$$

$$= \{y|x, S\}\{x|S\}$$

For *n* variables there would be *n!* possible expansions, where each requires the assignment of different set of probabilities and each is logically equivalent. However, there may be considerable differences in the ease with which the decision maker can provide this information. Further, these alternative expansions provide a means for graph manipulation while preserving the objective values.

C.5 Evaluation Procedure

As previously mentioned in Section C.2, there are two ways to evaluate an ID. The first method is the *Node Reduction* technique, which involves graph transformation that preserves the objective values. The second method is the *Decision Tree based* approach, which requires a transformation of the ID into a similar DT representation.

However, there are some pre-requisites before an ID can be evaluated using any of the above evaluation procedures, even if it already represents a well-posed decision problem. In addition, there are some nodes that can be eliminated without affecting the objective to be attained in the decision problem.

Marshall and Oliver (1995) state that an ID can be evaluated directly in its graphical form if it meets certain criteria to be a *Proper Influence Diagram* (PID), while the DT-based approach needs an *Extensive Form of Influence Diagram* (EFID).

Shachter (1986) defines a PID as 'an unambiguous representation of a single decision maker's view of the world'. Further, Marshall and Oliver (1995) specify the following criteria for a PID:

(1) With a single origin node and a single value node,

(2) Without cycles,

(3) Whose origin node has no predecessors and whose value node has no successors,

(4) In which the 'no-forgetting' principle is applied to all nodes.

An *Extensive Form of Influence Diagram* (EFID), which is a PID that needs no arc reversal operations using Bayes' Rule. This means that the ordering of nodes corresponds to the real timing of actual events and decisions in the associated decision trees.

There are a couple of node positions that needs to be eliminated before the evaluation procedure, because the elimination of these nodes yields a lower complexity of the graph without compromising its information content. The first condition is the presence of *barren nodes*. As previously mentioned in Section D.3, these are chance or decision nodes that have no successors. This condition implies that the value of these nodes will not affect other nodes in the diagram and therefore, they can be removed. The second condition is the presence of *irrelevant nodes*, which can be recognized using the following definitions:

- A decision node in a PID is irrelevant if its only direct successors are decision nodes.
- A chance node in an EFID is irrelevant if its only direct successors are decision nodes.

C.5.1 Node Reduction Technique

This method evaluates the ID directly in its graphical form. The procedure is a 'one-at-a-time' deleting node, where the information constraints dictate the deletion sequence. From the node reduction procedures described by Shachter (1986) and Clemen (1995), the algorithm can be outlined as follows:

1. Look for any chance nodes that (i) directly precede the value node and (ii) do not directly precede any other node. Reduce any such chance node by calculating the

respective expected values, and the value node then inherits the predecessors of the reduced node.

2. *Look for a decision node that (i) directly precedes the* value *node, and* (ii) has a predecessors all of the other direct predecessors of the value node. If there is no such node, then continue to step 5. Otherwise, reduce this decision node by choosing the optimum value. The reduction of decision nodes does not inherit any new predecessors to the value node.

3. Return to step 2, taking into account following notes:

   - Chance nodes whose true value will not be known at the time a decision has to be made must be deleted before the decision node can be deleted.
   - Chance nodes whose true value will be known at the time a decision has to be made are deleted after the decision node is deleted
   - Decision nodes are deleted in reverse order (the last decision is deleted first)

4. If none of the remaining chance nodes satisfy the criteria for reduction, and the decision node also cannot be reduced, then one of the arrows between chance nodes must be reversed. This step requires probability manipulations through the use of Bayes' Theorem. The criteria for such nodes are (i) it directly precedes the value node, and (ii) it does not directly precede any decision node. Afterward, both nodes inherit each other's direct predecessors and keep their own predecessors. Note that the manipulation should not create any cycle in the diagram. This step may yield barren nodes, which can be directly eliminated. Afterward, return to step 2.

5. The procedure continues until only the value node remains. The value node then provides the decision-maker with the net valuation, and the optimal strategy can be constructed from the details of the deletion of the decision nodes.

C.5.2 Decision-Tree Based Approach

The second evaluation method is Decision-Tree based approach, which initially converts an ID into a DT. The evaluation is performed in the DT-format of the decision problem following the rollback algorithm. Marshall and Oliver (1995) describe the rollback algorithm as follows:

1. Start with no labels on any nodes.
2. To each result or terminal node I, assign a label that equals the payoff or loss at that node, so that $v_i = r_i,\ r_i \in R$, and *R* is the set of outcome states.
3. For any unlabeled *decision node i,* where all nodes *j* connected to *i* by a branch *(i, j)* are labeled, set

$$v_i = Max_{j \in D(i)} \{ r(i, j) + v_j \}$$

   and set d_i* equal to the decision that yields this maximum value. If the object is to minimize loss, replace Max by Min, and set d_i* equal to the decision that yields this minimum.

4. For any unlabeled chance node *i,* where all nodes *j* connected to *i* by a branch *(i, j)* are labeled, set

$$v_i = \sum_{j \in C(i)} p_{ij} \ \{ r(i, j) + v_j \}$$

5. Steps 3 and 4 are repeated until the starting node is labeled. This starting node label will give the maximum expected payoff r^* (or minimum expected loss l^*) for the tree. The d_i^*'s on each decision node identify the optimal decisions.

C.6 Commercial Software for Implementation

Some commercially available software can be used to aid the modeling of decision problems in ID and perform the evaluation procedure, provided that the above pre-requisites on structuring the decision problems are met. Table D-3 shows selected software that uses ID, either as its sole method or combined with other approaches.

This research selects DATA™ version 3.5.9 for the following reasons:

- The software accommodates both ID as well as DT, and conversion from an ID representation to a DT can be done with no trouble. This feature provides helpful corroboration during the process of model building, since these two approaches have complementary features. While ID is useful in simplifying and presenting complex decisions, ID representation shows detailed ordering of the nodes.
- The price is relatively low compared to other software with similar features.

As previously mentioned, there are slight differences in the node symbols and other notations across the ID literature. This remark is also applicable to the computer software. As a consequence of the above software selection and to provide groundwork for the ID representations in Chapter 5, it is necessary to put forward some features and conventions used by DATA™:

- Analysis and solution procedure for an ID is conducted by converting it first into a DT representation.
- Node ordering refers to the *arcs direction* and the *center of each node*.
- Time flows from left to right, therefore nodes on the left is converted before nodes on the right (this is the default setting, but users can select to change this into 'top to bottom').
- There are three types of influence that can be indicated by an arc: (i) probabilistic influence, (ii) value influence, and (iii) structural influence. Each arc may represent one or more types of influence, or none at all. The latter is used to determine timing, which corresponds to the ordering of nodes.
- The 'structural influence' feature enables DATA to incorporate asymmetry in an ID representation.

Table C-3. Selected Influence Diagram Software

Software	Approaches*			Platform				Copyright
	DT	ID	BN	Win	Mac	UNIX	WWW	
Analytica		☑			☑			Lumina, Los Altos, CA
Bayesian Network Solver		☑	☑	☑	☑	☑	☑	Nagarajan & D'Ambrosio, Corvallis, OR
DATA	☑	☑		☑	☑			TreeAge Software, Boston, MA
DAVID		☑			☑			Duke University, Durham, NC
DPL	☑	☑		☑				ADA, Menlo Park, CA
MSBN		☑	☑	☑				Microsoft Corporation, Redmond, VA

*DT = Decision Trees; ID = Influence Diagrams; BN = Belief Networks
Source: Varis (1997)

C.7 The Base Case Model

The structure of the base model in this research is shown as Figure 5-2, copied below for easier reference:

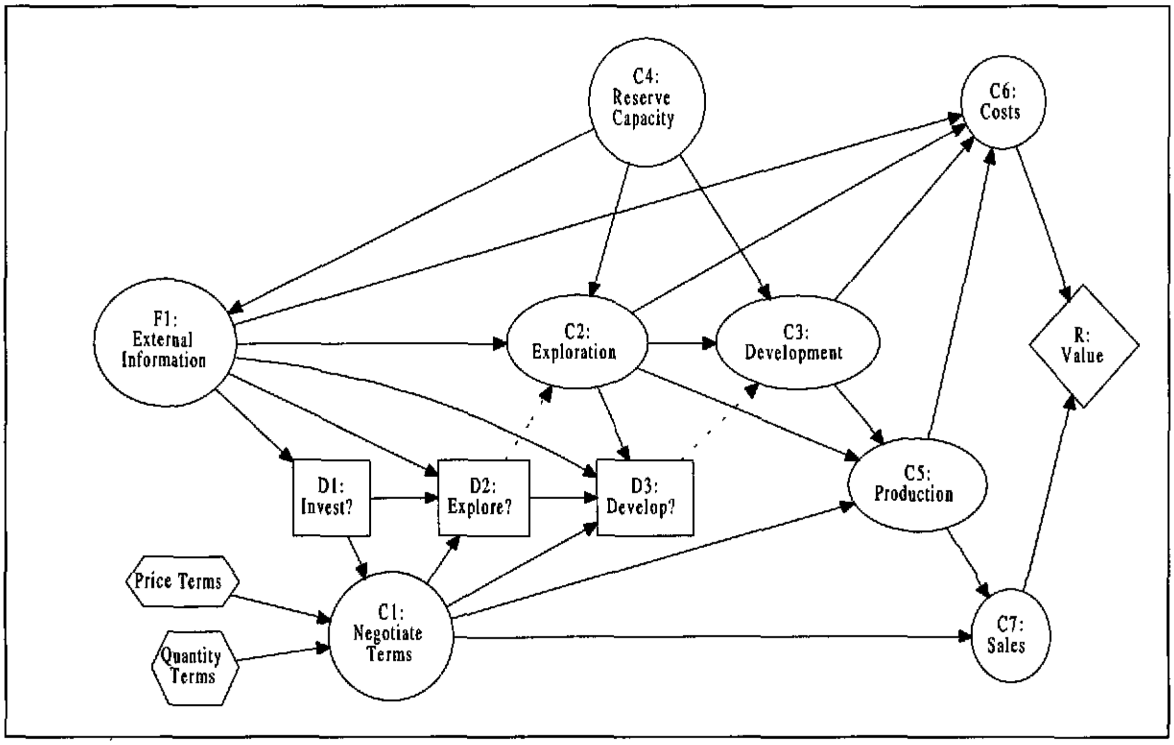


Figure 5-2. Uncertainties and Major Decisions in the Base Case Model

1. F1: A forecast or estimates on the existence of geothermal potential, provided by the government. This preliminary survey cost the least amongst test methods, but it has the worst accuracy.

2. D1: Potential investor needs to evaluate the available information, which is from the preliminary survey. Alternative decision at this point: (i) Invest if the information indicates the particular site is prospective, and (ii) Do nothing otherwise. This situation can be seen as an investment option:

spend the cost of reimbursing the government for the preliminary survey data, and acquire the right to review the information and make subsequent decisions accordingly. The payoff for this option is a right to continue and obtain another option, which is the right to explore the prospective site, provided that the potential investor and the government can reach an agreement on the price of electricity to be available when the power plant of this project is ready to operate. The price determination would involve some specification requirements as well, such as the amount of obligated purchase by the power utility company (Kahn, 1995). This obligation to purchase is commonly known as the 'take-or-pay' term. Another important terms that are embedded in the price determination are the lifetime of the project and the capacity factor for the power plant. The latter refers to the amount of energy generated from a power plant relative to the maximum possible energy generation.

3. C1: The possible outcomes are: (i) agree, and (ii) not agree. In a successful negotiation, a price and quantity of purchase are agreed upon. Otherwise, no such agreement would indicate that the option obtained at D1 is not exercised, and nothing happened or the option expires.

4. D2: The incoming arcs are from D1, C1, and F1, and these three nodes are to the left of D2. These structures indicate that the decision D1 was taken, the information known to D1 is also known to D2, and the negotiation are concluded. All may influence the decision at D2. If the prospect is

estimated as a good one, and negotiation is successful (there is a price and purchase quantity for the future electricity), the investor must make another decision from the following alternatives: (i) explore the site, or (ii) do nothing. When exploration is decided, then the investor must spend exploration expenses. Otherwise, the project is abandoned.

Node D2 contains an option, where it would cost the exploration expenses to obtain the right to a completed geothermal facility that includes a developed geothermal field and ready-to-operate power plant. Hence, the payoff is yet another option, namely the development option.

There is a possibility to have another option at this point, which is the option to wait. This option is present when there is a leeway in decision time that does not require the development decision to be exercised immediately. However, unlike the other resource extraction decision, there is no more information to be acquired at this moment. As the selling price is known and the guaranteed purchase quantity has been set, then it would be better to start the operation as soon as possible such that the recovery of the initial capital outlay can be initiated. Hence in this case, the option to wait is not appealing and therefore, would not be considered.

5. D3: The arc from F1 indicates the 'no-forgetting' property of an influence diagram, which means that this information may influence the previous decision at D1 and D2, and these relationships are 'remembered'.

6. C2: The possible outcomes of this node are: (i) good, or (ii) bad. The first one refers to the condition where the exploration activities yield proven and feasible reserves. The second one indicates uneconomical field.

   In the actual geothermal project, this node corresponds to three stages of activities. In addition to the preliminary survey, there are pre-feasibility and feasibility studies. The test sequences reflect increasingly better estimates but also significantly higher costs. There are usually reviews following each of these tests, which shall decide whether or not to continue the searching given the exploration result up to that stage. However, Model-0 regards these exploration stages as one lump of activities to simplify the model structure.

7. C3: This is the final search for figuring out the size and characteristics of the reserves and much less in significance than the exploration stage. The main activities here are to drill operation wells and construct the power plant. Hence, the arc leading out of C3 indicates that the reserves size and characteristics are considered as known for certain based on the series of search outcomes, and the facilities are ready for operation.

8. C4: This node reflects the true state of the reserves, which may never be completely revealed. The arc from C4 to C5 indicates that there are some drilling activities required to maintain the desired reserve size and characteristics.

9. C5: This is an intermediate calculation node, containing necessary formulas to yield the specified amount of electricity production. The arc from C1 determines the amount of quantity to be supplied to the utility, while the arc to C7 indicates the actual supply.

10. C6: The actual demand by the utility.

11. C7: This node is an intermediate calculation node. It contains the formulas to calculate the revenue earned from electricity sales.

12. R: This value node contains necessary formulas to calculate the ROE

Table 5-1 is copied below for easier reference. It summarizes the classifications for arc assignment on the structure of the model. The use of DATA™ 3.5 allows some of the arcs to be removed, such as those assigned for the 'no-forgetting property', because the software has an internal mechanism to automatically recognize an appropriate structure. However, Figure 5-2 presents the whole sets of these arcs for the general readers.

Figure 5-2 captures the present condition in the geothermal project in Indonesia. Some problems pertaining to this setting are as follows:

- The price is set at C1 for the life of the project, whereas at that time the estimation of reserve size and characteristics is very poor. High uncertainty on the resource presence and quality, coupled with the associated risk of losing large amount of capital that is required to search and proof the estimates, have caused investors to demand a high electricity price that range from 150% to 200% or more than the other base load supplier.

Table 5-1. Notes for The Arcs[a]

Reason for arc assignment	Relevant nodes
Single decision-maker property[b]	D1 → D2 → D3
No-forgetting property[c]	F1 → D2 F1 → D3
Imperfect information (in the form of forecasts, estimates, or tests) that will be used to represent the true state, since they are observed earlier	F1 → C4 C2 → C4 C3 → C4 F2 → C1 F2 → C6
Input for a decision	F1 → D1 C1 → D2 C1 → D3 C2 → D3
Cost components of ROI calculation	F1 → R C2 → R C3 → R C5 → R
Revenue component of ROI calculation	C7 → R

[a] Specific description, in addition to the generic remarks stated on Table D.2. Pairs of nodes and arc that are not listed only have the applicable generic remarks.
[b] Definition1-(ii), Section D.2, Appendix D
[c] Definition 1-(iii), Section D.2, Appendix D

- External adverse situation that cause electricity demand to drop have put pressure to geothermal electricity. The obligated purchase had caused tension, since the utility are obligated to take the amount but cannot afford to pay. After a long stalled condition, some of the parties agreed to renegotiate their terms of supply. An early result of this renegotiation showed a much lower price (US Embassy Jakarta, 2002).

This fact has stirred debates as to how best to accommodate the interest of both parties in the future arrangements, considering the following arguments:

- If exploration efforts can be done in a more effective and efficient manner (best available technology, experienced engineers, etc) such that investor can obtain better reserves at a much lower cost, then the 'savings' from the original estimates of exploration costs should be regarded as a positive achievement. Therefore, this shall be seen as a reward to the investor, and they have the right to keep it because they earned it. A price reduction after the exploration is seen as a punishment, since this affect the cash flow projection that would distress project performance to the lender.
- On the other hand, the government sees that the high price previously agreed because of the high uncertainty was no longer appropriate. After the exploration, the uncertainty regarding the presence and quality of the reserves are largely resolved.

C.8 Model with Two-Phase Negotiation

Figure 6-1 is copied here for an easier reference. A model with two-phase negotiation is the proposed arrangement to overcome the existing difficulties. The main difference between the structures of this model to the previous model is the presence of node C8, which allows the investor and the utility to renegotiate after the exploration stage is concluded. The new setting is as follows:

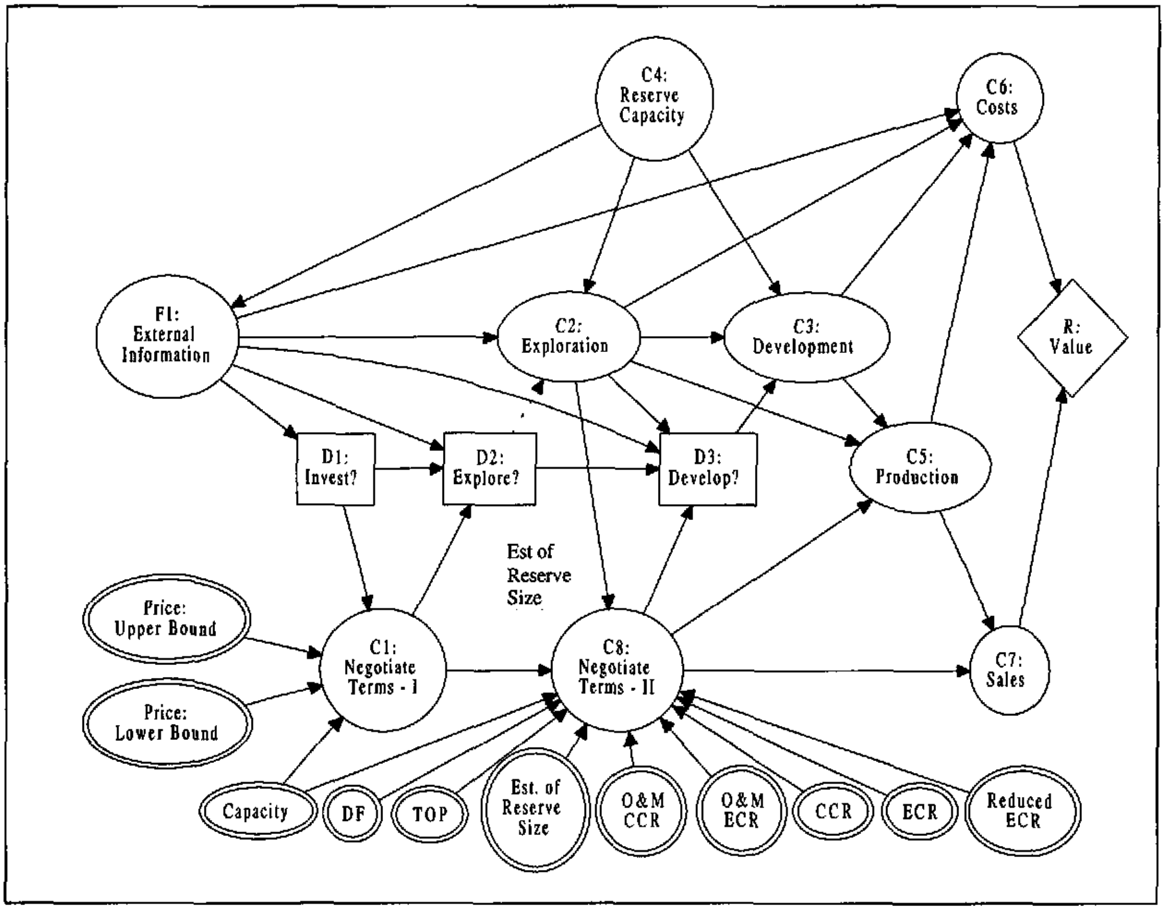


Figure 6-1. The Structure of Model with Two-Phase Negotiation

C1: Knowing that there will be a chance to renegotiate the terms of the project, the price determination at this moment will be to set an upper limit. This capped figure may be tied to the avoided cost for the base load supply. Using a benchmark such as an avoided cost or a least cost reference in the base load would assure that geothermal electricity enters the system at a competitive price.

C8: There are three possible outcomes at this node:

a. If exploration outcome shows better reserves than or equal to that previously estimated at the reconnaissance stage, then investor can select to either:

   - Stick with the previous terms: price aligned to the capped figure, and the quantity as determined before
   - Offer a lower price but demand a higher electricity sale (can be by higher capacity factor if possible, or a guaranteed capacity expansion) in the project. This alternative maybe of interest, since the investor do not need to spend a new exploration expenses but can earn more because of higher amounts of supply.

b. If reserves turn out to be worse than previously estimated, then investor abandons the project.

There are opportunities to improve the project value by exercising the options that possibly interact with the information from these nodes. Note that there is an additional option in this setting, which is the option to expand as one of the possible outcome of node C8.

APPENDIX D
SIMULATION INPUT-OUTPUT

Contents of Appendix D

D.1 Inputs for Geothermal Electricity Model (GEM): Base Case

D.1.1 Basic Project Data

Full Gross Capacity	110	MW
Project Duration	40	years
Exploration Duration	2	years
Development Duration	3	years
Total Operating Duration	35	years
of which: partial capacity period	0	years
full capacity period	30	years
declining capacity period	5	years
Capacity decline after full capacity period	50%	per year

D.1.2 Data related to Well Performance

Number of exploration wells	5	
Number of exploration wells usable as Productive wells	3	
Drilling performance during Exploration	4	Maximum number of exploratory wells per year
Average of Initial Well Production	7	MW
Required Reserve Capacity	5%	percent of full capacity
Ratio of Productive/Unproductive wells	4	
Average yearly decline of production wells	2%	per year
Ratio of Productive/Re-injection wells	3	
Drilling performance during Development	6	Maximum number of development wells per year

D.1.3 Field Fixed Costs

		Surface Exploration And Studies	Access and Land Rights
Total Costs (Million $)		3	5
Year	Project Stage		
1	Exploration	50%	20%
2	Exploration	50%	20%
3	Development		20%
4	Development		20%
5	Development		20%

D.1.4 Field Variable Costs

Drilling cost per well		
Exploratory well	2.3	Million $
Development well	1.5	Million $
Make-up well	1.5	Million $

Administrative & Engineering costs	
During Exploration & Development	10%
During Operation, as a % of Total Investment	-
During Operation, as a % of Yearly Cost	10%

Operation & Maintenance costs	
During Operation, as a % of Total Investment	2%

Generating System costs*		
Per productive well	0.72	Million $
Per make-up well	0.38	Million $

*Specific cost to connect with each productive well

D.1.5 Gathering System Costs

Total Gathering System Cost:		12.24	Million $
Yearly Disbursement:			
	Year 3	Development stage	20%
	Year 4	Development stage	30%
	Year 5	Development stage	50%

D.1.6 Power Plant Main Data

	Generation Plant	Transmission Lines by PLN	
Total costs	95	0	Million $
Administration & Engineering during Construction	10%	0%	% of yearly investment
Administration & Engineering during Operation	2%	0%	% of total investment
Operation & Maintenance	2%	0%	% of total investment
Internal Consumption	5%	-	
Scheduled Maintenance	7%	-	of gross capacity
Unscheduled Maintenance	3%	-	of gross capacity
Transmission Losses	-	0%	

Yearly Distribution of Costs				
Year	Project Stage	MW Installed	Generation Plant	Transmission Lines by PLN
3	Development	0	20%	
4	Development	0	30%	25%
5	Development	0	50%	75%
6	Full Capacity	110		

D.1.7 Financial Parameters

Discount Rates	PLN	9%
	Company (field)	20%
	Company (power plant)	20%
	Government	5%
Inflation		3%

D.1.8 Project Financial Data

	Interest		Duration (Years)	Share
	Constant Money	Current Money		
Soft Loan Terms:				1%
Field Loan	3%	6%	15	
Power Plant Loan	3%	6%	15	
Commercial Loan Terms:				99%
Field Loan	8%	11%	10	
Power Plant Loan	8%	11%	10	

* For example, Export-Import loans

Debt/Equity Shares	
Field investment covered by Equities or Internal Cash Generation, other than for Surface Exploration & Studies, Access & Land Rights, Exploratory Drilling and Administration & Engineering	11.05%
Field investment covered by Equities only (up to Unit 1 commercial operation)	42.56%
Power Plant investment covered by Equities or cash flow, other than for Administrative and Engineering	11.05%
Power Plant investment covered by Equities only (up to Unit 1 commercial operation)	19.14%
Total investment covered by Equities	27.81%

D.1.9 Royalty and Taxes

Royalty	4%
Taxes	30%

D.1.10 Depreciation and Amortization Parameters

	Operating Expenses	Constant Balance				Declining Balance				Total
		Group 1	Group 2	Group 3	Group 4	Group 1	Group 2	Group 3	Group 4	
		Depreciation Rate				Depreciation Rate				
		25%	12.5%	6.25%	5%	50%	25%	12.5%	10%	
		Service Period (years)				Service Period (years)				
		4	8	16	20	4	8	16	20	
Surface Exploration & Studies	100%	0%								100%
Access & Land Rights	100%	0%								100%
Exploration Wells	70%							30%		100%
Development Wells	70%							30%		100%
Make up Wells	70%							30%		100%
Gathering Systems	0%						20%	80%		100%
Gathering System Extension	0%						20%	80%		100%
Power Plant	0%				10%	10%	30%	50%		100%
Transmission Line	*0%*	*100%*								*100%*

D.1.11 Payment Formula

Generation Component		
Capacity Charge Rate*	20	$/kW/month
O&M Capacity Charge Rate	2	$/kW/month
Duration of Capacity Charge Rate	30	years

*CCRs are inflated up to start up of power plant, and fixed after that

Resource Component		
Energy Charge Rate*	0.0331	$/kWh
O&M Energy Charge Rate	0.007	$/kWh
Duration of Energy Charge Rate	30	years

*ECRs are inflated up to start up of power plant, and fixed after that

Other parameters:		
	Plant Factor on Gross Rated Capacity:	85%
	Take-or-Pay Plant Factor:	80%
	Reduction of ECR for energy above Take-or-Pay level:	50%
	Years from start to transfer of the plant:	30

Table D.2-1. Financial Projection for the Base Case

Capacity 110 MW; targeting minimum ROE 30%

INPUT FROM DATA3.5 USER:

Generating Capacity (MW)	110
Discretionary Plant Factor	85%
Take-Or-Pay Portion	80%
Reduced ECR	50%

Capacity Charge Rate	*($/kW/month)*	20
O&M Cap Charge Rate	($/kW/month)	2
Energy Charge Rate	($/kWh	0.0331
O&M Energy Charge Rate	($/kWh)	0.0071

Inflation	3%
Co. Discount Rate	20%
Taxes	30%
Royalty	4%

Well data	
Average initial production (MW)	7
Ratio of Productive/Unproductive wells	4

OUTPUT SUMMARY:

Summary of Expenditures:	US$ million
PV of Reimbursement or Signature Bonus	0.40
PV of Exploration Cost	11.06
PV of Development Cost	21.61

Summary of Free Cash Flow:	US$ million
PV of Exploration Period (yr 1-2)	-11.06
PV of Development Period (yr 3-5)	-21.61
PV of Production Period (yr 6-40)	74.74
Total Value of a complete project	41.67

Return on Equity	30.01%
	cents$/kWh
Levelized Price	6.19
	0
FCF No Sale	0

EXPORTED TO DATA3.5:
Project Value

US$ million		Sale All	No Sale
		74.74	0
PreProdCost	33.06	41.67	-33.06
PreDevCost	11.46		-11.46
PreExplCost	0.40		-0.40

GEM CALCULATION RESULTS, rearranged:

PROJECTED INCOME STATEMENT (US$ MILLION)

	0	1	2	3	4	5	6	7	8	9	...	35	36	37	38	39	40
1. Capacity Charges	-	-	-	-	-	-	29.7	29.7	29.7	29.7		29.7	-	-	-	-	-
2. O&M Capacity Charges	-	-	-	-	-	-	3.0	3.1	3.1	3.2		7.0	-	-	-	-	-
3. Resource Charge	-	-	-	-	-	-	26.1	26.1	26.1	26.1		26.1	-	-	-	-	-
4. O&M Resource Charge	-	-	-	-	-	-	5.8	5.9	6.1	6.3		13.6	13.3	13.0	12.7	12.5	12.2
5. Total Revenues	-	-	-	-	-	-	64.5	64.8	65.0	65.3	...	76.3	13.3	13.0	12.7	12.5	12.2
6. Reimbursement or Signature Bonus	0.4																
7. *Operating Expenses*	-	4.6	10.4	16.2	12.6	15.4	8.1	6.9	8.7	9.0		17.9	6.7	6.9	7.1	7.3	7.5
8. Depreciation and Amortization	-	-	-	-	-	-	24.1	18.1	14.2	12.2		1.2	0.9	0.9	0.8	0.7	0.5
9. Total Cost of Field Prep & Electricity Generation	0.4	4.6	10.4	16.2	12.6	15.4	32.2	25.0	22.9	21.2	...	19.1	7.5	7.8	7.9	8.0	8.0
10. Operating Profit [5-9]	(0.4)	(4.6)	(10.4)	(16.2)	(12.6)	(15.4)	32.3	39.7	42.1	44.1		57.3	5.7	5.2	4.9	4.5	4.2
11. Interest (Expenses) [-15]	-	-	-	-	-	-	(15.5)	(14.6)	(13.6)	(12.4)		-	-	-	-	-	-
12. Interest Income	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-
13. Total Other Income (Expenses)	-	-	-	-	-	-	(15.5)	(14.6)	(13.6)	(12.4)		-	-	-	-	-	-
14. Net Profit(Losses) Before Tax (NPBT) [10+13]	(0.4)	(4.6)	(10.4)	(16.2)	(12.6)	(15.4)	16.8	25.2	28.6	31.7		57.3	5.7	5.2	4.9	4.5	4.2
15. Royalty [21*royalty rate]	-	-	-	-	-	-	-	-	0.4	1.3		2.3	0.2	0.2	0.2	0.2	0.2
16. Income Taxes [21*company tax rate]	-	-	-	-	-	-	-	-	3.3	9.5		17.2	1.7	1.6	1.5	1.3	1.3
17. Net Profit (Losses) After Tax (NPAT) [14-15-16]	(0.4)	(4.6)	(10.4)	(16.2)	(12.6)	(15.4)	16.8	25.2	24.8	20.9		37.8	3.8	3.5	3.2	3.0	2.8
18. Net Profit(Losses) Before Tax (NPBT) [14]	(0.4)	(4.6)	(10.4)	(16.2)	(12.6)	(15.4)	16.8	25.2	28.6	31.7		57.3	5.7	5.2	4.9	4.5	4.2
19. Losses Carried Forward	0.4	5.0	15.4	31.6	44.2	59.5	42.8	17.6	-	-		-	-	-	-	-	-
20. Recovered Losses	-	-	-	-	-	-	16.8	25.2	17.6	-		-	-	-	-	-	-
21. Net Effect of Losses Carried Forward	-	-	-	-	-	-	-	-	11.0	31.7		57.3	5.7	5.2	4.9	4.5	4.2
22. EBIT = Earning Before Interest and Tax [10]	(0.4)	(4.6)	(10.4)	(16.2)	(12.6)	(15.4)	32.3	39.7	42.1	44.1		57.3	5.7	5.2	4.9	4.5	4.2
23. EBITDA = Earn. Bef. Int, Tax and Deprec [10]+[8	(0.4)	(4.6)	(10.4)	(16.2)	(12.6)	(15.4)	56.4	57.9	56.4	56.3		58.5	6.6	6.1	5.6	5.2	4.7

Table D.2-1. Financial Projection for the Base Case (continued)

PROJECTED CASH FLOW (US$ MILLION)	0	1	2	3	4	5	6	7	8	9	...	35	36	37	38	39	40
Cash From Operation																	
Cash In:																	
24. Cash from Collection of Revenues {24}	-	-	-	-	-	-	64.5	64.8	65.0	65.3		76.3	13.3	13.0	12.7	12.5	12.2
Cash Out:																	
25. Operating Expenses {02}	-	4.6	10.4	16.2	12.6	15.4	8.1	6.9	8.7	9.0		17.9	6.7	6.9	7.1	7.3	7.5
26. Interest Payment {15}	-	-	-	-	-	-	15.5	14.6	13.6	12.4		-	-	-	-	-	-
27. Income Taxes [16]	-	-	-	-	-	-	-	-	3.3	9.5		17.2	1.7	1.6	1.5	1.3	1.3
28. Insurance	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-
29. Royalty [15]	-	-	-	-	-	-	-	-	0.4	1.3		2.3	0.2	0.2	0.2	0.2	0.2
30. Total Cash Out [25+ ..+30]	-	4.6	10.4	16.2	12.6	15.4	23.6	21.5	26.0	32.2		37.4	8.6	8.7	8.7	8.8	8.9
31. Net Cash From Operation [24-30]	-	(4.6)	(10.4)	(16.2)	(12.6)	(15.4)	40.9	43.3	39.1	33.1		39.0	4.7	4.4	4.0	3.6	3.2
Cash From Investing																	
Cash In:	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-
Cash Out:																	
32. Reimbursement or Signature Bonus {01}	0.4																
33. Development & Construction Costs {03}	-	0.7	2.8	27.5	38.1	63.4											
34. Capital Expenditures {03}	-	-	-	-	-	-	0.8	-	0.8	0.9		-	-	-	-	-	-
35. Total Cash Out [33+34]	0.4	0.7	2.8	27.5	38.1	63.4	0.8	-	0.8	0.9		-	-	-	-	-	-
36. Net Cash From Investing [cash in - 35]	(0.4)	(0.7)	(2.8)	(27.5)	(38.1)	(63.4)	(0.8)	-	(0.8)	(0.9)		-	-	-	-	-	-
Cash From Financing																	
Cash In:																	
37. Equity Payment {09}	5.3	13.3	9.3	10.7	16.1	-	-	-	-	-		-	-	-	-	-	
38. Loan Drawing (Soft & Comm Loan) {11+12}	-	-	-	34.4	40.2	67.1	-	-	-	-		-	-	-	-	-	-
39. Total Cash In [37+38]	5.3	13.3	9.3	45.1	56.3	67.1	-	-	-	-		-	-	-	-	-	-
Cash Out:																	
40. Loan Principal Repayment {14-15}	-	-	-	-	-	-	8.4	9.4	10.4	11.5		-	-	-	-	-	-
41. Total Cash Out [40]	-	-	-	-	-	-	8.4	9.4	10.4	11.5		-	-	-	-	-	-
42. Net Cash From Financing [39-41]	5.3	13.3	9.3	45.1	56.3	67.1	(8.4)	(9.4)	(10.4)	(11.5)		-	-	-	-	-	-
43. Net Cash Changes [31+36+42]	4.9	8.0	(3.9)	1.4	5.6	(11.7)	31.6	33.9	27.8	20.7	...	39.0	4.7	4.4	4.0	3.6	3.2
44. Beginning Cash Balance	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-
45. Net Cash Changes [43]	4.9	8.0	(3.9)	1.4	5.6	(11.7)	31.6	33.9	27.8	20.7		39.0	4.7	4.4	4.0	3.6	3.2
46. Ending Cash Balance [44+45]	4.9	8.0	(3.9)	1.4	5.6	(11.7)	31.6	33.9	27.8	20.7		39.0	4.7	4.4	4.0	3.6	3.2

Table D.2-1. Financial Projection for the Base Case (continued)

		FCF1	FCF2	FCF3	FCF4	FCF5	FCF6	FCF7	FCF8	FCF9	. . .	FCF35	FCF36	FCF37	FCF38	FCF39	FCF40
47. Free Cash Flow [31-34]	-	(4.6)	(10.4)	(16.2)	(12.6)	(15.4)	40.1	43.3	38.2	32.3		39.0	4.7	4.4	4.0	3.6	3.2
48. Discount rate = adjusted WACC (+country risk)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2		0.2	0.2	0.2	0.2	0.2	0.2
49. Discount Factor for PV calculated at end Y0		0.8	0.7	0.6	0.5	0.4	0.3	0.3	0.2	0.2		0.0	0.0	0.0	0.0	0.0	0.0
50. PV of FCF at end Y0	-	(3.8)	(7.2)	(9.4)	(6.1)	(6.2)	13.4	12.1	8.9	6.3		0.1	0.0	0.0	0.0	0.0	0.0
51. PV0 (i.e. Total PV of FCF, calculated at end Y(	42.1																
52. Initial investment	(0.4)																
53. NPV of project	41.7																
54. Discount Factor for PV calculated at end Y1			0.8	0.7	0.6	0.5	0.4	0.3	0.3	0.2		0.0	0.0	0.0	0.0	0.0	0.0
55. PV of FCF at end Y0			(8.7)	(11.2)	(7.3)	(7.4)	16.1	14.5	10.7	7.5		0.1	0.0	0.0	0.0	0.0	0.0
56. PV1 (i.e. Total PV of FCF, calculated at end Y1)	**55.1**																
57. Forecase Variable (z) for this case	0.18																
58. PV0 for the Base Case (110 MW)	**42.1**																
59. Forecast Variable (z) comparing 56 & 58:	**0.18**																
z = % change of project value = ROR on the project																	
z = ln ((PV1+FCF1)/PV0)																	
60. Unit Costs (cents/kWh, nominal)	-	-	-	-	-	-	9.2	9.2	9.3	9.3		10.9	2.0	2.1	2.1	2.2	2.2
61. Unit Costs (cents/kWh, real)	-	-	-	-	-	-	7.7	7.5	7.3	7.1		3.9	0.7	0.7	0.7	0.7	0.7
62. Levelized Costs (cents/kWh, real)	6.2																

(Note: not include PLN-specific costs such as transmission costs and operational costs after the plants are transfered to PLN)

Table D.2-2. Financial Projection for Case 1

Capacity 165 MW; targeting minimum ROE 30%

INPUT FROM DATA3.5 USER:

Generating Capacity (MW)	165
Discretionary Plant Factor	0.85
Take-Or-Pay Portion	80%
Reduced ECR	50%

Capacity Charge Rate	($/kW/month)	16
O&M Cap Charge Rate	($/kW/month)	1.75
Energy Charge Rate	($/kWh	0.025
O&M Energy Charge Rate	($/kWh)	0.00334

Inflation	3%
Co. Discount Rate	20%
Taxes	0.3
Royalty	4%

Well data:	
Average initial production (MW)	7
Ratio of Productive/Unproductive wells	4

OUTPUT SUMMARY:

Summary of Expenditures:	US$ million
PV of Reimbursement or Signature Bonus	0.40
PV of Exploration Cost	11.06
PV of Development Cost	31.48

Summary of Free Cash Flow:	US$ million
PV of Exploration Period (yr 1-2)	-11.06
PV of Development Period (yr 3-5)	-31.48
PV of Production Period (yr 6-40)	83.54
Total Value of a complete project	40.60

Return on Equity	30.01%
	cents$/kWh
Levelized Price	4.64
	0
FCF No Sale	0

EXPORTED TO DATA3.5:
Project Value

US$ million		Sale All	No Sale
		83.54	0
PreProdCost	42.93	40.60	-42.93
PreDevCost	11.46		-11.46
PreExplCost	0.40		-0.40

GEM CALCULATION RESULTS, rearranged:

		FCF1	FCF2	FCF3	FCF4	FCF5	FCF6	FCF7	FCF8	FCF9	...	FCF35	FCF36	FCF37	FCF38	FCF39	FCF40
47. Free Cash Flow [31-34]	-	(4.59)	(10.41)	(32.85)	(12.77)	(15.70)	45.31	46.30	46.16	36.35	...	42.34	(0.20)	(0.69)	(1.18)	(1.68)	(2.18)
48. Discount rate = adjusted WACC (+country risk)	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20		0.2	0.2	0.2	0.2	0.2	0.2
49. Discount Factor for PV calculated at end Y0		0.83	0.69	0.58	0.48	0.40	0.33	0.28	0.23	0.19		0.00	0.00	0.00	0.00	0.00	0.00
50. PV of FCF at end Y0	-	(3.83)	(7.23)	(19.01)	(6.16)	(6.31)	15.17	12.92	10.74	7.04		0.07	0.00	0.00	0.00	0.00	0.00
51. PV0 (i.e. Total PV of FCF, calculated at end Y(	**41.00**																
52. Initial investment	(0.40)																
53. NPV of project	40.60																
54. Discount Factor for PV calculated at end Y1			0.83	0.69	0.58	0.48	0.40	0.33	0.28	0.23		0.00	0.00	0.00	0.00	0.00	0.00
55. PV of FCF at end Y0			(8.68)	(22.81)	(7.39)	(7.57)	18.21	15.51	12.88	8.45		0.09	0.00	0.00	0.00	0.00	0.00
56. PV1 (i.e. Total PV of FCF, calculated at end Y1)	**53.79**																
57. Forecase Variable (z) for this case	0.18																
58. PV0 for the Base Case (110 MW)	**42.07**																
59. Forecast Variable (z) comparing 56 & 58:	**0.16**																
z = % change of project value = ROR on the project																	
z = ln ((PV1+FCF1)/PV0)																	

	0	1	2	3	4	5	6	7	8	9	...	35	36	37	38	39	40
60. Unit Costs (cents/kWh, nominal)	0	0	0	0	0	0	6.96	6.99	7.01	7.03		7.99	0.94	0.97	1.00	1.03	1.06
61. Unit Costs (cents/kWh, real)	0	0	0	0	0	0	5.83	5.68	5.53	5.39		2.84	0.32	0.32	0.32	0.32	0.32
62. *Levelized Costs (cents/kWh, real)*	4.64																

(Note: not include PLN-specific costs such as transmission costs and operational costs after the plants are transferred to PLN)

Table D.2-3. Financial Projection for Case 2

Capacity 220 MW, targeting minimum ROE 30%

INPUT FROM DATA3.5 USER:

Generating Capacity (MW)	220
Discretionary Plant Factor	0.85
Take-Or-Pay Portion	80%
Reduced ECR	50%

Capacity Charge Rate	($/kW/month)	14
O&M Cap Charge Rate	($/kW/month)	1.25
Energy Charge Rate	($/kWh	0.01977
O&M Energy Charge Rate	($/kWh)	0.00325

Inflation	3%
Co. Discount Rate	20%
Taxes	0.3
Royalty	4%

Well data:	
Average initial production (MW)	7
Ratio of Productive/Unproductive wells	4

OUTPUT SUMMARY:

Summary of Expenditures:	*US$ million*
PV of Reimbursement or Signature Bonus	0.40
PV of Exploration Cost	11.06
PV of Development Cost	42.08

Summary of Free Cash Flow:	US$ million
PV of Exploration Period (yr 1-2)	-11.06
PV of Development Period (yr 3-5)	-42.08
PV of Production Period (yr 6-40)	92.98
Total Value of a complete project	39.44

Return on Equity	30.01%
	cents$/kWh
Levelized Price	3.89
	0
FCF No Sale	0

EXPORTED TO DATA3.5:
Project Value

US$ million		Sale All	No Sale
		92.98	0
PreProdCost	53.54	39.44	-53.54
PreDevCost	11.46		-11.46
PreExplCost	0.40		-0.40

GEM CALCULATION RESULTS, rearranged:

		FCF1	FCF2	FCF3	FCF4	FCF5	FCF6	FCF7	FCF8	FCF9	...	FCF35	FCF36	FCF37	FCF38	FCF39	FCF40
47. Free Cash Flow [31-34]	-	(4.59)	(10.41)	(50.79)	(12.96)	(16.02)	50.29	51.46	52.76	41.74	...	47.26	(0.20)	(0.83)	(1.47)	(2.11)	(2.76)
48. Discount rate = adjusted WACC (+country risk)	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20		0.2	0.2	0.2	0.2	0.2	0.2
49. Discount Factor for PV calculated at end Y0		*0.83*	*0.69*	*0.58*	*0.48*	*0.40*	*0.33*	*0.28*	*0.23*	*0.19*		*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
50. PV of FCF at end Y0	-	(3.83)	(7.23)	(29.39)	(6.25)	(6.44)	16.84	14.36	12.27	8.09		0.08	0.00	0.00	0.00	0.00	0.00
51. PV0 (i.e. Total PV of FCF, calculated at end Y(	39.84																
52. Initial investment	(0.40)																
53. NPV of project	39.44																
54. Discount Factor for PV calculated at end Y1			0.83	0.69	0.58	0.48	0.40	0.33	0.28	0.23		0.00	0.00	0.00	0.00	0.00	0.00
55. PV of FCF at end Y0			(8.68)	(35.27)	(7.50)	(7.73)	20.21	17.23	14.72	9.71		0.10	0.00	0.00	0.00	0.00	0.00
56. PV1 (i.e. Total PV of FCF, calculated at end Y1)	**52.40**																
57. Forecase Variable (z) for this case	0.18																
58. PV0 for the Base Case (110 MW)	**42.07**																
59. Forecast Variable (z) comparing 56 & 58:	**0.13**																

z = % change of project value = ROR on the project
z = ln ((PV1+FCF1)/PV0)

	0	1	2	3	4	5	6	7	8	9	...	35	36	37	38	39	40
60. Unit Costs (cents/kWh, nominal)	0	0	0	0	0	0	5.83	5.85	5.87	5.89		6.70	0.91	0.94	0.97	1.00	1.03
61. Unit Costs (cents/kWh, real)	0	0	0	0	0	0	4.89	4.76	4.64	4.52		2.38	0.32	0.32	0.32	0.32	0.32
62. Levelized Costs (cents/kWh, real)	3.89																

(Note: not include PLN-specific costs such as transmission costs and operational costs after the plants are transferred to PLN)

Table D.2-4. Financial Projection for Case 3

Capacity 220 MW; targeting the average production cost of the other base load suppliers

INPUT FROM DATA3.5 USER:

Generating Capacity (MW)	220
Discretionary Plant Factor	0.85
Take-Or-Pay Portion	80%
Reduced ECR	50%

Capacity Charge Rate ($/kW/month)	14
O&M Cap Charge Rate ($/kW/month)	1.25
Energy Charge Rate ($/kWh)	0.0215
O&M Energy Charge Rate ($/kWh)	0.00342

Inflation	3%
Co. Discount Rate	20%
Taxes	0.3
Royalty	4%

Well data:	
Average initial production (MW)	7
Ratio of Productive/Unproductive wells	4

OUTPUT SUMMARY:

Summary of Expenditures:	US$ million
PV of Reimbursement or Signature Bonus	0.40
PV of Exploration Cost	11.06
PV of Development Cost	42.08

Summary of Free Cash Flow:	US$ million
PV of Exploration Period (yr 1-2)	-11.06
PV of Development Period (yr 3-5)	-42.08
PV of Production Period (yr 6-40)	97.22
Total Value of a complete project	43.68

Return on Equity	31.41%
	cents$/kWh
Levelized Price	4.03
	0
FCF No Sale	0

EXPORTED TO DATA3.5:
Project Value

US$ million		Sale All	No Sale
		97.22	0
PreProdCost	53.54	43.68	-53.54
PreDevCost	11.46		-11.46
PreExplCost	0.40		-0.40

GEM CALCULATION RESULTS, rearranged:

		FCF1	FCF2	FCF3	FCF4	FCF5	FCF6	FCF7	FCF8	FCF9	...	FCF35	FCF36	FCF37	FCF38	FCF39	FCF40
47. Free Cash Flow [31-34]	-	(4.59)	(10.41)	(50.79)	(12.96)	(16.02)	53.29	54.47	54.04	42.40	...	49.49	0.44	(0.21)	(0.86)	(1.52)	(2.18)
48. Discount rate = adjusted WACC (+country risk)	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20		0.2	0.2	0.2	0.2	0.2	0.2
49. Discount Factor for PV calculated at end Y0		0.83	0.69	0.58	0.48	0.40	0.33	0.28	0.23	0.19		0.002	0.001	0.001	0.001	0.001	0.001
50. PV of FCF at end Y0	-	(3.83)	(7.23)	(29.39)	(6.25)	(6.44)	17.85	15.20	12.57	8.22		0.084	0.001	0.000	-0.001	-0.001	-0.001
51. PV0 (i.e. Total PV of FCF, calculated at end Y(	44.08																
52. Initial investment	(0.40)																
53. NPV of project	43.68																
54. Discount Factor for PV calculated at end Y1			0.83	0.69	0.58	0.48	0.40	0.33	0.28	0.23		0.002	0.002	0.001	0.001	0.001	0.001
55. PV of FCF at end Y0			(8.68)	(35.27)	(7.50)	(7.73)	21.42	18.24	15.08	9.86		0.101	0.001	0.000	-0.001	-0.001	-0.002
56. PV1 (i.e. Total PV of FCF, calculated at end Y1)	**57.48**																
57. Forecase Variable (z) for this case	0.18																
58. PV0 for the Base Case (110 MW)	**42.07**																
59. Forecast Variable (z) comparing 56 & 58:	**0.23**																
z = % change of project value = ROR on the project																	
z = ln ((PV1+FCF1)/PV0)																	

	0	1	2	3	4	5	6	7	8	9	...	35	36	37	38	39	40
60. Unit Costs (cents/kWh, nominal)	-	-	-	-	-	-	6.05	6.07	6.09	6.11		6.95	0.96	0.99	1.02	1.05	1.08
61. Unit Costs (cents/kWh, real)	-	-	-	-	-	-	5.07	4.93	4.81	4.68		2.47	0.33	0.33	0.33	0.33	0.33
62. Levelized Costs (cents/kWh, real)	4.03																

(Note: not include PLN-specific costs such as transmission costs and operational costs after the plants are transferred to PLN)

Table D.2-5. Financial Projection for Case 4

Capacity 220 MW, targeting the price of Case 1

INPUT FROM DATA3.5 USER:

Generating Capacity (MW)	220
Discretionary Plant Factor	0.85
Take-Or-Pay Portion	80%
Reduced ECR	50%

Capacity Charge Rate ($/kW/month)	15
O&M Cap Charge Rate ($/kW/month)	1.25
Energy Charge Rate ($/kWh	0.0256
O&M Energy Charge Rate ($/kWh)	0.0052

Inflation	3%
Co. Discount Rate	20%
Taxes	0.3
Royalty	4%

Well data:	
Average initial production (MW)	7
Ratio of Productive/Unproductive wells	4

OUTPUT SUMMARY:

Summary of Expenditures:	US$ million
PV of Reimbursement or Signature Bonus	0.40
PV of Exploration Cost	11.06
PV of Development Cost	42.08

Summary of Free Cash Flow:	US$ million
PV of Exploration Period (yr 1-2)	-11.06
PV of Development Period (yr 3-5)	-42.08
PV of Production Period (yr 6-40)	114.78
Total Value of a complete project	61.24

Return on Equity	36.62%
	cents$/kWh
Levelized Price	4.64
	0
FCF No Sale	0

EXPORTED TO DATA3.5:
Project Value

US$ million		Sale All	No Sale
		114.78	0
PreProdCost	53.54	61.24	-53.54
PreDevCost	11.46		-11.46
PreExplCost	0.40		-0.40

GEM CALCULATION RESULTS, rearranged:

		FCF1	FCF2	FCF3	FCF4	FCF5	FCF6	FCF7	FCF8	FCF9	...	FCF35	FCF36	FCF37	FCF38	FCF39	FCF40
47. Free Cash Flow [31.34]	-	(4.59)	(10.41)	(50.79)	(12.96)	(16.02)	65.61	66.87	53.88	50.71	...	60.21	5.35	4.79	4.14	3.60	3.02
48. Discount rate = adjusted WACC (+country risk)	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20		0.2	0.2	0.2	0.2	0.2	0.2
49. *Discount Factor for PV calculated at end Y0*		0.83	0.69	0.58	0.48	0.40	0.33	0.28	0.23	0.19		0.00	0.00	0.00	0.00	0.00	0.00
50. PV of FCF at end Y0	-	(3.83)	(7.23)	(29.39)	(6.25)	(6.44)	21.97	18.66	12.53	9.83		0.10	0.01	0.01	0.00	0.00	0.00
51. PV0 (i.e. Total PV of FCF, calculated at end Y(	61.64																
52. Initial investment	(0.40)																
53. NPV of project	61.24																
54. Discount Factor for PV calculated at end Y1			0.83	0.69	0.58	0.48	0.40	0.33	0.28	0.23		0.00	0.00	0.00	0.00	0.00	0.00
55. PV of FCF at end Y0			(8.68)	(35.27)	(7.50)	(7.73)	26.37	22.40	15.04	11.79		0.12	0.01	0.01	0.00	0.00	0.00
56. PV1 (i.e. Total PV of FCF, calculated at end Y1)	**78.56**																
57. Forecase Variable (z) for this case	0.18																
58. PV0 for the Base Case (110 MW)	**42.07**																
***59. Forecast Variable (z)** comparing 56 & 58:*	**0.56**																
z = % change of project value = ROR on the project																	
z = ln ((PV1+FCF1)/PV0)																	

	0	1	2	3	4	5	6	7	8	9	...	35	36	37	38	39	40
60. Unit Costs (cents/kWh, nominal)	-	-	-	-	-	-	6.93	6.95	6.98	7.01		8.10	1.46	1.51	1.55	1.60	1.65
61. Unit Costs (cents/kWh, real)	-	-	-	-	-	-	5.80	5.65	5.51	5.37		2.88	0.50	0.50	0.50	0.50	0.50
62. Levelized Costs (cents/kWh, real)	4.64																

(Note: not include PLN-specific costs such as transmission costs and operational costs after the plants are transferred to PLN)

Table D.2-6. Financial Projection for Case 5

Capacity 220 MW; targeting the Base Case price

INPUT FROM DATA3.5 USER:

Generating Capacity (MW)	220
Discretionary Plant Factor	0.85
Take-Or-Pay Portion	80%
Reduced ECR	50%

Capacity Charge Rate	($/kW/month)	20
O&M Cap Charge Rate	($/kW/month)	2
Energy Charge Rate	($/kWh	0.0331
O&M Energy Charge Rate	($/kWh)	0.0071

Inflation	3%
Co. Discount Rate	20%
Taxes	0.3
Royalty	4%

Well data:	
Average initial production (MW)	7
Ratio of Productive/Unproductive wells	4

OUTPUT SUMMARY:

Summary of Expenditures:	US$ million
PV of Reimbursement or Signature Bonus	0.40
PV of Exploration Cost	11.06
PV of Development Cost	42.08

Summary of Free Cash Flow:	US$ million
PV of Exploration Period (yr 1-2)	-11.06
PV of Development Period (yr 3-5)	-42.08
PV of Production Period (yr 6-40)	158.98
Total Value of a complete project	105.44

Return on Equity	47.39%
	cents$/kWh
Levelized Price	6.19
	0
FCF No Sale	0

EXPORTED TO DATA3.5:
Project Value

US$ million		Sale All	No Sale
		158.98	0
PreProdCost	53.54	105.44	-53.54
PreDevCost	11.46		-11.46
PreExplCost	0.40		-0.40

GEM CALCULATION RESULTS, rearranged:

		FCF1	FCF2	FCF3	FCF4	FCF5	FCF6	FCF7	FCF8	FCF9	...	FCF35	FCF36	FCF37	FCF38	FCF39	FCF40
47. Free Cash Flow [31-34]	-	(4.59)	(10.41)	(50.79)	(12.96)	(16.02)	97.69	80.57	71.83	72.14	...	86.07	10.04	9.38	8.63	7.99	7.32
48. Discount rate = adjusted WACC (+country risk)	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20		0.2	0.2	0.2	0.2	0.2	0.2
49. Discount Factor for PV calculated at end Y0		0.83	0.69	0.58	0.48	0.40	0.33	0.28	0.23	0.19		0.00	0.00	0.00	0.00	0.00	0.00
50. PV of FCF at end Y0	-	(3.83)	(7.23)	(29.39)	(6.25)	(6.44)	32.68	22.49	16.71	13.98		0.15	0.01	0.01	0.01	0.01	0.00
51. PV0 (i.e. Total PV of FCF, calculated at end Y(	105.84																
52. Initial investment	(0.40)																
53. NPV of project	105.44																
54. Discount Factor for PV calculated at end Y1			0.83	0.69	0.58	0.48	0.40	0.33	0.28	0.23		0.00	0.00	0.00	0.00	0.00	0.00
55. PV of FCF at end Y0			(8.68)	(35.27)	(7.50)	(7.73)	39.22	26.98	20.05	16.78		0.17	0.02	0.01	0.01	0.01	0.01
56. PV1 (i.e. Total PV of FCF, calculated at end Y1)	**131.60**																
57. Forecase Variable (z) for this case	0.18																
58. PV0 for the Base Case (110 MW)	**42.07**																
59. Forecast Variable (z) comparing 56 & 58:	**1.10**																
z = % change of project value = ROR on the project																	
z = ln ((PV1+FCF1)/PV0)																	

	0	1	2	3	4	5	6	7	8	9	...	35	36	37	38	39	40
56. Unit Costs (cents/kWh, nominal)	-	-	-	-	-	-	9.21	9.25	9.29	9.33		10.90	2.00	2.06	2.12	2.18	2.25
57. Unit Costs (cents/kWh, real)	-	-	-	-	-	-	7.71	7.52	7.33	7.15		3.87	0.69	0.69	0.69	0.69	0.69
58. Levelized Costs (cents/kWh, real)	6.19																

(Note: not include PLN-specific costs such as transmission costs and operational costs after the plants are transferred to PLN)

Table D-3. Real Option Valuation for a Smaller Variation in Field Data

Base Case PV

Variation in parameter values: 10% on charges, 3MW on well productivity, 3-5 good/bad well ratio

Input Parameters		Calculated Parameters	
1. Annual risk-free rate	10%	1. Up movement per step, u	1.150
2. Current value of underlying, V	**42.07**	2. Down movement per step, d	0.869
3. Life of project in years	40	3. Risk free rate p.a	0.1
4. Annual standard deviation	14.00%		
5. Number of steps per year	1		

A. Event Tree for Project Value (V, the underlying risky asset)

	0	1	2	3	4	5
0		42.07	48.39	55.67	64.03	73.66
1			36.58	42.07	48.39	55.67
2				31.80	36.58	42.07
3					27.64	31.80
4						24.03
5						

1. Annual risk-free rate	10%	1. Up movement per step	1.150
2. Current value of underlying, V	42.07	2. Down movement per step	0.869
3. Exercise Price of Option 1	11.06	3. One plus nominal rate/step	1.1
4. Exercise Price of Option 2	21.61		
5. Life of option in years	5		
6. Annual standard deviation	14.00%		
7. Number of steps per year	1		

B. Value of Sequential Compound Options*

	0	1	2	3	4	5
0						
1		17.26	21.10	37.81	44.39	52.05
2			9.29	24.21	28.75	34.06
3				13.94	16.93	20.46
4					8.00	10.19
5						2.42

*Steps: contents of year 5,4,3 are copied to Table C; calc Table D; combine results of D into Table B

Add'l value from flex = 41.0%

Node		End-of-Period Payoff		Replicating Portfolio Parameters		Option Value
Row	Column	Up State	Down State	m	B	
1	4	52.05	34.06	1	-19.64389	44.38892
2	4	34.06	20.46	1	-19.64389	28.75107
3	4	20.46	10.19	1	-19.64389	16.93223
4	4	10.19	2.42	1	-19.64389	7.99975
1	3	44.39	28.75	1	-17.85808	37.80937
2	3	28.75	16.93	1	-17.85808	24.21447
3	3	16.93	8.00	1	-17.85808	13.93967

At the end of year 2, the First Option expires. Therefore, either it must be exercised at a cost of $12.1 Million, or left unexercised (no cost). If exercised, its payout is the value of the Second Option.
For this purpose, we examine the value of the Second Option for the whole tree (Table C).
Year 3-5 of Table C are copied from Table B.
Information in year 0-2 are needed to examine the Value Tree for Option 1 (Table D).

Table D-3. Real Option Valuation for a Smaller Variation in Field Data (continued)

C. Value Tree for the Second Option

	0	1	2	3	4	5
0						
1		27.31	32.16	37.81	44.39	52.05
2			20.34	24.21	28.75	34.06
3				13.94	16.93	20.46
4					8.00	10.19
5						2.42

Node		End-of-Period Payoff		Replicating Portfolio Parameters		Option Value
Row	Column	Up State	Down State	m	B	
1	2	37.81	24.21	1	-16.2346	32.1603
2	2	24.21	13.94	1	-16.2346	20.3415
1	1	32.16	20.34	1	-14.7587	27.3138

D. Value Tree for the First Option

	0	1	2
0			
1		17.26	21.10
2			9.29

Node		End-of-Period Payoff		Replicating Portfolio Parameters		Option Value
Row	Column	Up State	Down State	m	B	
0	0	21.10	9.29	1	-24.81007	17.26248

ROA:

Total PV of project with flexibility = flexibility value + PV without flexibility

=	17.26	+	42.07
=	59.34		

Table D-4. Real Option Valuation for a Larger Variation in Field Data

Base Case PV

Variation in parameter values: 10% on charges, 4MW on well productivity, 2-5 good/bad well ratio

Input Parameters		Calculated Parameters	
1. Annual risk-free rate	10%	1. Up movement per step, u	1.284
2. Current value of underlying, V	**42.07**	2. Down movement per step, d	0.779
3. Life of project in years	40	3. Risk free rate p.a	0.1
4. Annual standard deviation	25.00%		
5. Number of steps per year	1		

A. Event Tree for Project Value (V, the underlying risky asset)

	0	1	2	3	4	5
0		42.07	54.02	69.37	89.07	114.37
1			32.77	42.07	54.02	69.37
2				25.52	32.77	42.07
3					19.87	25.52
4						15.48
5						

1. Annual risk-free rate	10%	1. Up movement per step	1.284
2. Current value of underlying, V	42.07	2. Down movement per step	0.779
3. Exercise Price of Option 1	11.06	3. One plus nominal rate/step	1.1
4. Exercise Price of Option 2	21.61		
5. Life of option in years	5		
6. Annual standard deviation	25.00%		
7. Number of steps per year	1		

B. Value of Sequential Compound Options*

	0	1	2	3	4	5
0						
1		17.34	26.73	51.51	69.42	92.76
2			5.70	24.21	34.38	47.76
3				8.33	13.12	20.46
4					2.26	3.91
5						0.00

*Steps: contents of year 5,4,3 are copied to Table C; calc Table D; combine results of D into Table B

Add'l value from flex = 41.2%

Node		End-of-Period Payoff		Replicating Portfolio Parameters		Option Value
Row	Column	Up State	Down State	m	B	
1	4	92.76	47.76	1	-19.64389	69.42371
2	4	47.76	20.46	1	-19.64389	34.37834
3	4	20.46	3.91	1	-19.64389	13.12225
4	4	3.91	0.00	0.38941811	-5.479335	2.259831
1	3	69.42	34.38	1	-17.85808	51.50784
2	3	34.38	13.12	1	-17.85808	24.21447
3	3	13.12	2.26	0.84253976	-13.16775	8.332428

At the end of year 2, the First Option expires. Therefore, either it must be exercised at a cost of $12.1 Million, or left unexercised (no cost). If exercised, its payout is the value of the Second Option. For this purpose, we examine the value of the Second Option for the whole tree (Table C).
Year 3-5 of Table C are copied from Table B.
Information in year 0-2 are needed to examine the Value Tree for Option 1 (Table D).

Table D-4. Real Option Valuation for a Larger Variation in Field Data (continued)

C. Value Tree for the Second Option

	0	1	2	3	4	5
0						
1		27.39	37.79	51.51	69.42	92.76
2			16.75	24.21	34.38	47.76
3				8.33	13.12	20.46
4					2.26	3.91
5						0.00

Node		End-of-Period Payoff		Replicating Portfolio Parameters		Option Value
Row	Column	Up State	Down State	m	B	
1	2	51.51	24.21	1	-16.2346	37.7876
2	2	24.21	8.33	0.95939328	-14.6815	16.7541
1	1	37.79	16.75	0.98952811	-14.2445	27.3875

D. Value Tree for the First Option

	0	1	2
0			
1		17.34	26.73
2			5.70

Node		End-of-Period Payoff		Replicating Portfolio Parameters		Option Value
Row	Column	Up State	Down State	m	B	
0	0	26.73	5.70	0.98952811	-24.29578	17.33619

ROA:

Total PV of project with flexibility = flexibility value + PV without flexibility

=	17.34	+	42.07
=	59.41		

REFERENCES

Abel, Andrew B. 1983. "Optimal Investment Under Uncertainty". *The American Economic Review* 73 (March): 228-233.

Abel, Andrew B and Janice C. Eberly. 1994. "A Unified Model of Investment Under Uncertainty". *The American Economic Review* 84 (December): 1369-1384.

Abel, Andrew B, Avinash K. Dixit, Janice C. Eberly and Robert S. Pindyck. 1996. "Options, The Value of Capital, and Investment". *Quarterly Journal of Economics* (August): 753-777.

Abramson, B. 1993. "On the Design of Belief Networks for Knowledge-Based Systems" in Hand, D. J. (ed), *Artificial Intelligence Frontiers in Statistics.* Chapman and Hall, London.

Akerlof, George A. 1970. "The Market for Lemons: Qualitative Uncertainty and the Market Mechanism". *Quarterly Journal of Economics* 84 (November): 488-500.

Akmal, Firdaus and Herman Darnel and Puguh Sugiharto. 2000. "Geothermal Power Business in Java-Bali: Trading Mechanism, Competitiveness with Fossil Fuel, and Challenges to Its Development" 2nd draft for *World Geothermal Congress,* 2000.

Amram, Martha and Kulatilaka, Nalin. 1999. *Real Options: Managing Strategic Investment in an Uncertain World.* Harvard Business School Press.

Aoki, Masahiko. 2001. *Toward a Comparative Institutional Analysis.* The MIT Press.

Ariani, Ratna. 2001. *Member Presentations: Summary of APEC Member Economies in A Survey of Renewable-Energy Priority Needs and Issues Relating to Sustainable Development.* APEC Expert Group Meeting on NRET, Portland, Oregon, 27-28 March 2001. (http://www.apecnetwork.org/forum/egnet/18/indonesia.htm)

Armstead, H. Christopher. 1983. *Geothermal Energy.* 2nd ed. E & F.N. Spon.

Arrow, Kenneth J. 1968. "Optimal Capital Policy with Irreversible Investment," in J. N. Wolfe, ed., *Value, Capital and Growth. Papers in honour of Sir John Hicks.* Edinburg University Press.

Asian Development Bank, 2002. "Country Economic Review – Indonesia". (http://www.adb.org/Documents/CERs/INO/2002)

Bailey, Warren. 1991. "Valuing Agricultural Firms". *Journal of Economics Dynamics and Control* 15: 771-791.

Bellman, Richard E. 1957. *Dynamic Programming.* Princeton University Press, Princeton, NJ.

Bellman, Richard E and Stuart E. Dreyfus. 1962. *Applied Dynamic Programming.* Princeton University Press, Princeton, NJ.

Bhattacharya, Kankar and Math H. J. Bollen and Jaap E. Daalder. 2001. *Operation of Restructured Power Systems*. Kluwer's Power Electronics and Power System Series. Kluwer Academic Publishers.

Bielza, Concha and Prakash P. Shenoy. 1999. *A Comparison of Graphical Techniques for Asymmetric Decision Problems*. Draft dated 4/12/1999 of Working Paper No. 271, School of Business, University of Kansas, Lawrence KS. <ftp.bschool.ukans.edu/home/pshenoy/wp271.pdf>

Bielza, C, M. Gomez, S. Rios-Insua, and J. A. Fernandez del Pozo. 2000. "Structural, Elicitation and Computational Issues Faced When Solving Complex Decision Making Problems With Influence Diagram". *Computers & Operations Research* 27: 725-740.

Bodie, Zvi and Robert Merton. 2000. *Finance*. Prentice Hall.

Bonini, Charles P, and Hausman, Warren H, and Bierman, Harold, Jr. 1997. *Quantitative Analysis for Management*. Irwin.

Black, Fischer and Myron Scholes. 1973. "The Pricing of Options and Corporate Liabilities". *Journal of Political Economy* 81: 637-659.

Blair, Peter D, and Thomas A.V. Cassel and Robert H. Eldstein. 1982. *Geothermal Energy: Investment Decisions and Commercial Development*. John Wiley and Sons

Bowman, Edward H and Gary T. Moskowitz. 2001. "Real Options Analysis and Strategic Decision Making". *Organization Science* 12(6): 772-777.

Brennan M. J and Schwartz, E. S. 1985. "A New approach to Evaluating Natural Resource Investments". *Midland Corporate Finance Journal* 3 (Spring): 37-47.

Brennan, Michael J and Trigeorgis, Lenos. 2000. "Real Options – Development and New Contributions" in Brennan, Michael J and Trigeorgis, Lenos (eds). *Project Flexibility, Agency, and Competition*. Oxford University Press.

Broadman, Harry G. 1985. "Incentives and Constraints on Exploratory Drilling for Petroleum in Developing Countries". *Annual Reviews of Energy* 10: 217 - 249

Chairath, Arjun and Michael J. Seiler, 1997. "Capital Budgeting and the Stochastic Cost of Capital". *Managerial Finance* 23 (9): 16-23.

Clemen, Robert T. 1996. *Making Hard Decisions*. Duxbury Press, Pacific Grove, CA.

Coff, Russell W and Kevin J. Laverty. 2001. "Real Options on Knowledge Assets: Panacea or Pandora's Box?". *Business Horizons* (November-December): 73-79.

Copeland, Tom and Antikarov, Vladimir. 2001. *Real Options - A Practitioner's Guide*. Texere.

Copeland, Tom and Antikarov, Vladimir. 2001. *Solutions Manual for Real Options - A Practitioner's Guide*. Monitor Group.

Copeland, Tom and Koller, Tim and Murrin, Jack. 2000. *Valuation – Measuring and Managing the Value of Companies*. John Wiley and Sons, Inc.

Copeland, Tom and Keith M. Howe. 2002. "Real Options and Strategic Decisions". *Strategic Finance* 83 (10): 8-11.

Cortazar, Gonzalo and Eduardo S. Schwartz and Jaime Casassus. 2001. Optimal Exploration Investments Under Price and Geological-Technical Uncertainty: A Real Options Model". *R & D Management* 31 (2): 181-189.

Cox, John C, Stephen A. Ross and Mark Rubinstein. 1979. "Option Pricing: A Simplified Approach". *Journal of Financial Economics* 7: 229-263.

Deng, Shi-Jie, and Blake Johnson, and Aram Sogomonian. 2001. Exotic Electricity Options and the Valuation of Electricity Generation and Transmission Assets. *Decision Support Systems* 30: 383-392.

Dickson, Mary H and Mario Fanelli. 1995. *Geothermal Energy.* John Wiley and Sons Ltd.

DiPippo, R. 1991. "Geothermal Energy: Electricity Generation and Environmental Impact". *Energy Policy.* October 1991: 798 - 807

Directorate General of Oil and Gas. 1996. *Geothermal Resource Potentials in Indonesia.* Ministry of Mines and Energy of Indonesia

Dixit, Avinash K and Robert S. Pindyck. 1994. *Investment Under Uncertainty.* Princeton University Press.

Dixit, Avinash K and Robert S. Pindyck. 1995. "The Options Approach to Capital Investment". *Harvard Business Review* (May-June): 105 – 115.

Dow, Sheila C. 1985. *Macroeconomic Thought A Methodological Approach.* Basil Blackwell.

Electroconsult, Fichtner, and Redecon. 1996. "Geothermal Total Projects, Volume III, Evaluation Technique". *Final Report of Private Power Development: Geothermal and Combined Cycle Project,* for the Directorate General of Electricity and Energy Development of Indonesia.

Electroconsult, Fichtner, and Redecon. 1996. "Geothermal Total Projects, Volume IV, Technical-Financial Model User Guide". *Final Report of Private Power Development: Geothermal and Combined Cycle Project,* for the Directorate General of Electricity and Energy Development of Indonesia.

Energy Information Administration, US-DOE. 2002. *Country Analysis Briefs Indonesia.* (http://www.eia.doe.gov/emeu/cabs/indonesia.html)

Enerindomurni, Bayu. 1999. "Studi Pengurangan Resiko Eksplorasi dan Optimasi Pembiayaan Pengembangan Panasbumi". Laporan Akhir Proyek Peningkatan Pengusahaan Panas Bumi, Direktorat Jenderal Minyak dan Gas Bumi.

Erb, Claude B and Campbell R. Harvey and Tadas E. Viskanta. 2002. *Expected Returns and Volatility in 135 Countries.* An updated version of the article published in Journal of Portfolio Management, Spring 1996, page 46-58. (http://www.duke.edu/~charvey/Country_risk/ccr/ccr1.htm)

Ezawa, Kazuo J. 1998. "Evidence Propagation and Value of Evidence on Influence Diagrams". *Operations Research* 46 (1, January-February): 73-83.

Fagiuoli, Enrico and Marco Zaffalon. 1998. "A Note About Redundancy in Influence Diagrams". *International Journal of Approximate Reasoning* 19: 351-365.

Frayer, Julia and Nazli Z. Uludere. 2001. What Is It Worth? Application of Real Options Theory to the Valuation of Generation Assets. *The Electricity Journal* (October): 40-51.

Geske, Robert. 1979. "The Valuation of Compound Options". *Journal of Financial Economics* 7: 63-81.

Glantz, Morton. 2000. *Scientific Financial Management.* AMACOM, American Management Association, New York.

Goodman, L J and R. N Love, eds. 1980. *Geothermal Energy Projects, Planning and Management.* Pergamon Press.

Gottinger, H. W and H. P Weimann. 1995. "Intelligent Inference Systems Based on Influence Diagrams". *Decision Support Systems* 15: 27-43.

Harahap, Rudy M. 1999. *Strategies for Preventing Corruption in Indonesia.* Asia Pacific School of Economic and Management Working Papers. Asia Pacific Press at the Austalian National University. (http://ncdsnet.anu.edu.au/pdf/wp99/gov99-3.pdf)

Hartman, Richard. 1972. "The Effects of Price and Cost Uncertainty on Investment". *Journal of Economic Theory* 5: 258-266.

Haugen, Robert A. 1997. *Modern Investment Theory* 4th ed. Prentice Hall, New Jersey.

Howard, John. 1999. "Deceit and Deception – US Dealings in Indonesia". Friday, 24 September 1999 Scoop Headlines. (http://www.scoop.co.nz/mason/stories/HL9909/S00200.htm)

Howard, Ronald A and James E. Matheson. 1981. "Influence Diagrams" in *Readings on The Principles and Applications of Decision Analysis*, Vol. II, 1989. Strategic Decisions Group.

Hubalek, F and W. Schachermayer. 2001. "The Limitations of No-Arbitrage Arguments for Real Options". *International Journal of Theoretical and Applied Finance* 4 (2): 361-373.

Hull, John C. 1997. *Options, Futures, and Other Derivatives.* Prentice Hall.

Institute for Policy Studies and The Transnational Institute. 2001. *Corruption, Collusion and Nepotism: Ex-Im's Support for the Paiton Power Project, Indonesia.* A Case Study, Sustainable Energy & Economy Network. (http://www.seen.org/pages/ifis/exim/paiton.shtml)

Jessop, A. M. 1990. *Thermal Geophysics.* Elsevier

Jorgenson, Dale. 1963. "Capital Theory and Investment Behavior". *American Economic Review* 53 (May): 247-259.

Kahn, Edward. 1995. "Regulation by Simulation: The Role of Production Cost Models in Electricity Planning and Pricing". *Operations Research* 43 (3, May-June): 388-398.

Kaplan, Steven N and Richard S. Ruback. 1995. "The Valuation of Cash Flow Forecasts: An Empirical Analysis". *The Journal of Finance* L(4): 1059-1093.

Kensinger, John W. 1987. "Adding the Value of Active Management Into the Capital Budgeting Equation". *Midland Corporate Finance Journal* (Spring): 31-42.

Laffont, Jean-Jaques and David Martimort. 2002. *The Theory of Incentives The Principal-Agent Model.* Princeton University Press.

Lander, Diane M. 1997. *Modeling and Valuing Real Options: An Influence Diagram Approach.* PhD Dissertation University of Kansas.

Lander, Diane M and George E. Pinches. 1998. "Challenges to the Practical Implementation of Modeling and Valuing Real Options". *The Quarterly Review of Economics and Finance* 38 (Special Issue):537-567.

Lensink, Robert and Hong Bo and Elmer Sterken. 2001. *Investment, Capital Market Imperfections, and Uncertainty.* Edward Elgar.

Luehrman, Timothy A. 1997. "What's It Worth? A General Manager's Guide to Valuation". *Harvard Business Review* (May-June): 132-142.

Luenberger, David G. 1998. *Investment Science.* Oxford University Press.

Majd, S and Pindyck, R. S. 1987. "Time to Build, Option Value, and Investment Decisions". *Journal of Financial Economics* 18 (March): 7-27.

Marshall, Kneale T and Robert M. Oliver. 1995. *Decision Making and Forecasting.* McGraw-Hill, Inc.

Mas-Collel, Andreu and Michael D. Whinston and Jerry R. Green. 1995. *Microeconomic Theory.* Oxford University Press.

McDonald, Robert L. 2000. "Real Options and Rules of Thumb in Capital Budgeting", in Michael J. Brennan and Lenos Trigeorgis, eds., *Project Flexibility, Agency, and Competition, New Developments in the Theory and Application of Real Option.* Oxford University Press.

McDonald, R.L. and Siegel, D. R. 1986. "The Value of Waiting to Invest". *Quarterly Journal of Economics* 101 (Novermber): 707-727.

McKinsey & Company, Inc. 2000. *Valuation: Measuring and Managing the Value of Companies.* John Wiley & Sons Inc.

Merton, Robert C. 1973. "Theory of Rational Option Pricing". *Bell Journal of Management Science* 4 (Spring).

Michaelowa, A. 2001. "Potential and Obstacles for Using the CDM to Promote Geothermal Energy". *Proceeding of the 5th INAGA Annual Scientific Conference and Exhibition.* March 7-10, 2001.

Moel, Alberto and Tufano, Peter. 2000. "Bidding for the Antamine Mine" in Brennan, Michael J and Trigeorgis, Lenos (eds). *Project Flexibility, Agency, and Competition, New Developments in the Theory and Application of Real Option.* Oxford University Press.

Moore, William T. 2001. *Real Options and Option-Embedded Securities.* John Wiley & Sons, Inc.

Morgan, Bruce W. 1968. *An Introduction to Bayesian Statistical Decision Processes.* Prentice-Hall Inc, Englewood Cliffs, NJ.

Motoyama, Hisako and Nurina Widagdo. 1999. *Power Sector Restructuring in Indonesia A preliminary Study for Advocacy Purposes.* Friends of the Earth – Japan and Bank Information Center – USA. (http://www.bicusa.org/asia/powersect.pdf)

Myers, S.C and Majd, S. 1990. "Abandonment Value and Project Life". Advances in Futures and Options Research 4: 1-21.

Ndilikilikesha, Pierre C. 1993. "Potential Influence Diagrams". *International Journal of Approximate Reasoning* 10: 251-285.

Nickell, S. J. 1978. *The Investment Decisions of Firms.* James Nisbet & Co. Ltd and Cambridge University Press.

Oliver, R. M and J. Q. Smith, ed. 1990. *Influence Diagrams, Belief Nets and Decision Analysis.* John Wiley & Sons Ltd, Chichester, UK.

O'Reilly, Philip F. 1995. *Optimal Ground Water Use Amidst Uncertainty: Applications of Option Theory in the Absence of Market Prices.* PhD Dissertation, University of Colorado.

Paddock, James L, Daniel R. Siegel and James L. Smith. 1988. "Option Valuation of Claims on Real Assets: the Case of Offshore Petroleum Leases". *Quarterly Journal of Economics* 103 (August): 479-508.

Partnership for Governance Reform in Indonesia. 2002. *A Diagnostic Study of Corruption in Indonesia.* Final Report February 2002. (http://www.partnership.or.id/data/pdf/DiagnosticStudy-eng.pdf)

Partowidagdo, Widjajono. 2000. "Exploration Insurance for Geothermal Energy Development in Indonesia". Proceedings, *World Geothermal Congress 2000,* Kysuhu – Tohoku, Japan. May 28-June 10, 2000.

Perlez, Jane. 2002. "World Bank Assails Indonesia Corruption". The New York Times, Wednesday, August 28, 2002. (online at The Salt Lake Tribune, http://www.sltrib.com/2002/aug/08282002/nation_w/765921.htm)

Petrick, Alfred . Jr. 1986. *Energy Resource Assessment.* Westview Press. Boulder and London.

Pickles, Eric and James L. Smith. 1993. "Petroleum Property Valuation: A Binomial Lattice Implementation of Option Pricing Theory". *The Energy Journal* 14 (2): 1-26.

Pinches, George E. 1998. "Real Options: Developments and Applications". *The Quarterly Review of Economics and Finance* 38 (Special Issue): 533-535.

Pindyck, Robert S. 1982. "Adjustment Costs, Uncertainty, and the Behavior of the Firm". *The American Economic Review* 72 (June); 415-427.

Pindyck, Robert S. 1991. "Irreversibility, Uncertainty and Investment". *Journal of Economic Literature* 26 (September): 1110-1148.

Pindyck, Robert S. 1993. "Investment of Uncertain Cost". *Journal of Financial Economics* 34: 53-76.

Samuelson, Paul. 1965. "Proof that Properly Anticipated Prices Fluctuate Randomly. *Industrial Management Review* (Spring): 41-49.

Sangster, Alan. 1993. "Capital Investment Appraisal Techniques: A Survey of Current Usage". *Journal of Business Finance and Accounting* 20 (3): 307-332.

Schoemaker, Paul J.H and Russo, J. Edward. 1994. "A Pyramid of Decision Approaches" in Rios, Sixto (ed). *Decision Theory and Decision Analysis; Trends and Challenges*. Kluwer Academic Publishers.

Seymour, Frances and Agus P. Sari. 2002. Indonesia Electricity Reform Under Economic Crisis. In Power Politics: Equity and Environment in Electricity Reform. World Resources Institute. (http://pdf.wri.org/powerpolitics_chap5.pdf; http://pubs.wri.org/pubs_pdf.cfm?PubID=3159)

Shachter, Ross D. 1986. "Evaluating Influence Diagrams". *Operations Research* 34 (6, November-December): 871-882.

Shachter, Ross D. 1988. "Probabilistic Inference and Influence Diagrams". *Operations Research* 36 (4, July-August): 589-604.

Shenoy, Prakash P. 2000. "Valuation Network Representation and Solution of Asymmetric Decision Problems". *European Journal of Operational Research* 121: 579-608.

Smit, Han T.J. 1997. "Investment Analysis of Offshore Concessions in the Netherlands". *Financial Management* 26 (2, Summer): 5-17.

Smith, Charles R. 2002. "National Security Crimes". Thusrsday, October 2002. Newsmax.com. (http://www.newsmax.com/archives/articles/2002/10/16/173247.shtml)

Smith, James E and Kevin F. McCardle. 1999. "Options in the Real World: Lessons Learned in Evaluating Oil and Gas Investments". *Operations Research* 47 (1, January – February): 1-15.

Smith, James E and Kevin F. McCardle. 1998. "Valuing Oil Properties: Integrating Option Pricing and Decision Analysis Approaches". *Operations Research* 46 (2, March-April): 198-217.

Smith, James E and Robert F. Nau. 1995. "Valuing Risky Projects: Option Pricing Theory and Decision Analysis". *Management Science* 31 (5, May): 795-816.

Smith, James E, Samuel Holtzman and James E. Matheson. 1993. "Structuring Conditional Relationships in Influence Diagrams". *Operations Research* 41 (2, March-April): 280-297.

Smith, J. Q. 1989. "Influence Diagrams for Bayesian Decision Analysis". *European Journal of Operational Research* 40: 36-376.

Smith, J. Q. 1994. "Decision Influence Diagrams and Their Uses" in Rios, Sixto (ed). *Decision Theory and Decision Analysis; Trends and Challenges.* Kluwer Academic Publishers.

Soejachmoen, Kuki. 2002. *Energy and Sustainable Development in Indonesia.* Sustainable Energy Watch 2002 Report. Helio International. (http://www.helio-international.org/Helio/Reports/2002/English/Indonesia/ INDSummary.html)

Stoll, Harry G. 1989. *Least-Cost Electric Utility Planning.* John Wiley & Sons.

Sub Directorate of Geothermal Survey. 1998. *Distribution Map of Geothermal Areas in Indonesia.* Directorate General of Geology and Mineral Resources. Ministry of Mines and Energy of Indonesia.

Summer, Charles E. 1980. *Strategic Behavior in Business and Government.* Little, Brown and Company.

Teisberg, Elizabeth O. 1994. "An Option Valuation Analysis of Investment Choices by a Regulated Firm". *Management Science* 40 (4, April): 535-548.

Teisberg, Elizabeth O. 1995. "Methods for Evaluating Capital Investment Decisions Under Uncertainty". In Trigeorgis, Lenos, ed. *Real Options in Capital Investment.* Praeger.

Trigeorgis, Lenos. 1993. "The Nature of Option Interactions and the Valuation of Investments with Multiple Real Options". *Journal of Financial and Quantitative Analysis* 28 (1, March): 1-19.

Trigeorgis, Lenos (ed). 1995. *Real Options in Capital Investment Models, Strategies, and Applications.* Praeger.

Tobin, James. 1969. "A General Equilibrium Approach to Monetary Policy". *Journal of Money, Credit and Banking* 1 (February): 15-29.

US Embassy Jakarta. 2002. *Indonesia's Geothermal Development.* Date of Report: February 15, 2002. <http://www.usembassyjakarta.org/econ/geothermal.html>

Varis, Olli. 1997. "Bayesian Decision Analysis for Environmental and Resource Management". *Environmental Modelling & Software 12* (2-3): 177-185.

Williamson, Oliver E. 1985. *The Economic Institutions of Capitalism.* The Free Press.

Williamson, Oliver E. 1986. *Economic Organization: Firms, Markets and Policy Control.* New York University Press.

Willner, Ram. 1995. "Valuing Start-Up Venture Growth Options". In Trigeorgis, Lenos, ed. *Real Options in Capital Investment.* Praeger.

World Energy Council. 2001. *Electricity Market Design and Creation in Asia Pacific.* World Energy Council. (http://www.worldenergy.org/wec-geis/global/downloads/emd/emd.pdf)

Wright, Phillip Michael. 1998. "Geothermal Energy –Harnessing Heat from the Centre of the Earth". *Chemistry and Industry.* 16 March 1998: 208-212

Wright, P.M, and J.E Mock and J.W. Tester. 1997. "Geothermal Energy From the Earth: Its Potential Impacts as an Environmentally Sustainable Resource". *Annual Review of Energy Environment* 1997, 22: 305-56.